THE EFFECTS OF GENERATIVE LEARNING STRATEGY PROMPTS AND METACOGNITIVE FEEDBACK ON LEARNERS’ SELF-REGULATION, GENERATION PROCESS, AND ACHIEVEMENT

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ABSTRACT

Instructional designers need to understand the internal processes of learning, identify learners’ cognitive difficulties with those processes, and create strategies to help learners overcome those difficulties. Generative learning theory, one conception of human learning about cognitive functioning and process, emphasizes that meaningful learning occurs from the learner’s creation of understanding about the information (Wittrock, 1992). The essence of this generative learning theory is that learners need to selectively attend to events and to actually create relationships and meaning from the events.

However, this learning process is not always easy nor is it unconscious for learners, specifically in computer-based learning environments. Computer-based learning environments, such as hypermedia and web-based instruction, require learners to increase control, both cognitively and metacognitively, over what and how they learn. Accordingly learners may need more support and guidance, to help them use cognitive learning strategies, monitor their understanding, and refine their learning process.

Prompting learners to use generative learning strategies may increase the frequency of their using appropriate learning strategies which may improve learning when learners use those strategies. Also, providing feedback about their metacognitive processes can guide learners to assess the suitability of cognitive strategies employed and to refine the learning strategies they use. As a result, learning should be enhanced.
Therefore, this study examined the effects of generative learning strategy prompts and metacognitive feedback and the mediation effects of learners’ self-regulation and use of generative learning strategies on their learning.

In the spring of 2008, 223 undergraduate students, enrolled in general education courses in a large land grant university in the northeastern United States, participated in this study. The participants were randomly assigned to three treatment groups: static visualized instruction with generative learning strategy tools as control group (T1), static visualized instruction with generative learning strategy tools and prompts (T2), and static visualized instruction with generative learning strategy tools and prompts with metacognitive feedback (T3).

The study included a prior knowledge pre test and a post self-regulation survey measuring cognitive and metacognitive control. Two criterion tests measuring recall and comprehension served as post-tests. The study also measured the quality of learners’ overt use of generative learning strategies. The primary statistical analysis method was Structural Equation Modeling (SEM) to analyze the treatments and their mediation effects.

The study found that the participants who were given generative learning strategy prompts with metacognitive feedback scored significantly higher in self-regulation, the quality of generative learning strategy use, and recall and comprehension after controlling for their prior domain knowledge than the participants who were given only generative learning strategy tools. Furthermore, generative learning strategy prompts with metacognitive feedback had indirect effects on learners’ recall and comprehension.
through learners’ use of generative learning strategies, and on learners’ use of generative learning strategies through learners’ self-regulation. This result supported the mediation processes of self-regulation and the use of generative learning strategies.

This study found positive effects from the use of metacognitive feedback in generative learning. This suggests that instructional designers or teachers should provide cognitive and metacognitive prompts while learners study. This study also answers the questions regarding what should be supported to improve students’ learning and how to provide appropriate supports. Finally, this study contributes to educational research practice by demonstrating how to gather and analyze overt evidence of learners’ actual interactions with the instructional interventions and by illustrating an application of Structural Equation Modeling for experimental research to understanding intervening processes of learning. This approach may stimulate future research in instructional design and development for more complex, technology-enriched learning environments.
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Chapter 1

INTRODUCTION

Background

Designing a learning environment requires one to understand the internal processes of learning, identify cognitive difficulties that learners may encounter with those processes, and create strategies to help learners overcome those difficulties. Developing conceptions of human learning based on empirical and theoretical evidence about cognitive functioning and process has been a prime concern in the field of educational technology because these concepts guide the design of the environment for learning. Generative learning theory is one such conception that explains how students learn meaningfully and provides a framework, from which to draw implications for designing instruction (Grabowski, 2004).

Generative Learning Theory

According to generative learning theory, to comprehend a complex topic, learners need to “…selectively attend to events and generate meaning for events by constructing relations between new or incoming information and previously acquired information, conceptions, and background knowledge” (Wittrock, 1992, p. 532). In this theory, comprehension and understanding result from the generation of relations both among concepts and between experience or prior learning and information. In other words,
learners need to make their own meaning by integrating new information with current existing knowledge, rather than just transferring the presented information into memory (Grabowski, 2004).

Considering the essence of this theory of generative learning, learning strategies should involve the actual creation of relationships and meaning (Wittrock, 1990, 1991). Through these learning strategies, learners meaningfully combine ideas from what they read with what they already know, thereby creating personally meaningful understanding. The learning strategies employed in the name of generative learning are simple coding strategies such as underlining, note taking, and adjunct questions; complex coding strategies such as creating hierarchies and headings, summarizing and concept mapping; and elaborative integration strategies such as imaging and creating examples, interpretation, or analogies (Doctorow, Wittrock, & Marks, 1978; Rickards, 1979; Rickards & August, 1975; Wittrock, 1990; Wittrock & Carter, 1975). Many studies have supported the effectiveness of those generative learning strategies (Barnett, DiVesta, & Rogonzenski, 1981; Davis & Hult, 1997; King, 1992; Rickards & August, 1975; Shrager & Mayer, 1989). Even though theoretically potential learning benefits should arise from generative learning strategies, the effects are not always consistent in every learning environment.

Problems with Computer-Based Learning Environments

Computer-Based Learning Environments, such as hypermedia and web-based instruction, have recently been widely used as an expected means of enhancing students’
understanding of complex and challenging topics. Despite the educational potential of CBLEs, research has shown that learners are not always successful controlling their own learning in CBLEs. Consequently, the expected prediction that the use of hypermedia would lead to significant learning gains has inconsistent support (Azevedo, Cromley, & Seibert, 2004; Dabbach & Kitsantas, 2005). In other words, the characteristics of CBLEs, such as freedom of navigation or sequencing of instruction, can interfere with the learners’ learning processes. Therefore, learners may need more support while learning in CBLEs (Hmelo-Silver & Azevedo, 2006; Winne et al., 2006).

In order to design instructional supports in computer-based learning environments, two key aspects of generative learning theory should be addressed. First, learners’ control over their learning process is necessary. Thus, learners’ self-regulation is a critical aspect of the theory and should be considered when designing instructional supports (Barab, Young, & Wang, 1999; Wittrock, 1991). Second, when learners generate their own knowledge, they need to create relationships between new information and their prior knowledge. Therefore, prior knowledge is another key aspect of the theory that should be considered.

**Self-regulation in Generative Learning**

Current theoretical and empirical advances about self-regulation can further inform the mechanism of generative learning theory, because learners’ cognitive and metacognitive regulation is a critical process in knowledge generation (Barab, Young, & Wang, 1999; Wittrock, 1991). In other words, by its very nature, learners must be
accountable and responsible for their knowledge generation processes. Accordingly, the central aspects of self-regulation for knowledge generation are learner’s cognitive and metacognitive control. Cognitive control regulates the use of cognitive strategies to accomplish learning goals and metacognitive control monitors and modifies their cognitive strategies in order to make any adaptive changes while they are learning (Schunk, 1996; Zimmerman, 2000).

However, several studies have shown that learners do not regulate their own learning or they often make inappropriate metacognitive decisions, especially in a computer-based learning environment (Azevedo & Cromley, 2004; Roll et al., 2005). As a result, providing support and guidance may be necessary to help learners regulate their learning more appropriately.

Two questions arise regarding support and guidance: What to support? And, how to support learners? First, considering the generative learning processes, support and guidance should help learners selectively attend to events, meaningfully generate their own knowledge, and monitor the knowledge they have generated. Specifically, underlining or highlighting is a strategy that learners use to select relevant information and integrate the information with their own preconceptions (e.g., Rickards & August, 1975). Learners, also, can create headings, organizations, or summaries with note-taking tools (e.g., Peper & Mayer, 1986). Adjunct questions can provide learners with an opportunity to review their learning and create personally meaningful learning (e.g., R. C. Anderson & Biddle, 1975). Therefore, providing those types of learning tools help learners selectively attend to events and create meaningful understanding from the events.
Second, prompting learners to use generative learning strategy tools may increase the frequency of using those strategies and may improve the quality of using those strategies. Asking learners to highlight important sentences, summarize their understandings, and interact with given adjunct questions may facilitate and increase learners’ use of given generative learning strategies. Simple prompting may be enough to get learners to use the generative learning strategy, but may not be enough to help them monitor, be aware of, or adjust their learning processes according to how well they are learning (Azevedo & Cromley, 2004; Kramarski & Mevarech, 2003). Thus, one hypothesized strategy would be to provide feedback about their metacognitive processes such as decisions about which cognitive strategies to use and how to use them (Butler & Winne, 1995; Winne, 1997; Wittrock, 1992). Metacognitive feedback can remind learners to assess the suitability of cognitive strategies employed and correcting strategy use (Jacobs & Dempsey, 1993; Narciss, 2008). In sum, support for learners’ knowledge generation processes should be present in computer-based learning environments, and this support should help the learners’ cognitive and metacognitive control.

Prior Knowledge in Generative Learning and Self-regulation

Learners’ prior domain knowledge also plays a critical role in their knowledge generation and self-regulation. According to existing research, prior domain knowledge is a significant predictor of learning outcomes (Alexander, 2003; Alexander, Jetton, & Kulikowich, 1995; Shapiro, 2004). It represents the basic building blocks of human information processing, key units of comprehension, and a determining factor in learning
(Ausubel, Novak, & Hanesian, 1978). Furthermore, prior domain knowledge can influence cognitive processes during learning. “…[N]ovice learners are not typically familiar with the procedures associated with constructive self-regulative learning” (Tergan, 1997, p. 227-228). Some research indicates that low-prior domain knowledge students are not successful in regulating their learning by using key self-regulatory processes, such as planning their learning, activating their prior domain knowledge, monitoring their emerging understanding of the topic, or deploying effective strategies (Azevedo, Cuthrie, & Seibert, 2004; Shapiro, 2004). Thus, learners’ prior domain knowledge should be considered as an individual factor impacting self-regulation, generative learning strategy use, and learning.

**Purpose of the Study**

The purpose of this study was to investigate whether using generative learning strategy prompts and metacognitive feedback in a computer-based learning environment facilitates learners’ recall and comprehension and whether learners’ self-regulation and the quality of their use of generative learning strategies mediate that facilitation. Specifically, the study, first, conceptualized a path model to explain how generative learning strategy prompts and metacognitive feedback affect learning. Second, the study investigated the direct effects of generative learning strategy prompts and metacognitive feedback on learners’ self-regulation, generative learning strategy use, and learning after controlling for learners’ prior domain knowledge. Finally, the study examined the
indirect effects of generative learning strategy prompts and metacognitive feedback on learning through learners’ self-regulation and generative learning strategy use.

The proposed generative learning conceptual framework on which the path model was conceptualized appears in Figure 1-1. This framework explains the essence of generative learning theory and describes the predicted cognitive mechanism of related psychological constructs.

![Diagram of generative learning conceptual framework]

Based on a theoretical understanding and empirical research, generative activities enhance learners’ knowledge generation among or between new information with existing knowledge. This process results in the acquisition of new knowledge which becomes prior knowledge which is necessary for subsequent knowledge generation. Also,
learner self-regulation controls those generative activities (Lee, Lim, & Grabowski, 2008; Wittrock, 1974b, 1990, 1991, 1992). In addition to the mechanism as represented by solid lines in Figure 1-1, dotted lines indicate two proposed, hypothesized mechanisms. First, this study hypothesized that generative learning strategy prompts and metacognitive feedback would enhance learners’ regulation over their learning, and accordingly, improve their generative activities such as use of strategies. Second, as learners’ generative activity improves, in turn, the study predicted that these learners’ knowledge generation would improve due to their active meaning making while learning.

Based on the conceptual understanding provided in Figure 1-1, the study proposed a preliminary path model (see Figure 1-2).

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Figure 1-2. Preliminary path model of the current study
In the preliminary path model proposed, hypothesized relationships are predicted between and among treatments—generative learning strategy prompts and metacognitive feedback—prior knowledge, and learning performance for which the generative learning strategy use and self-regulation are mediators. In other words, the learners, given generative learning strategy prompts or generative learning strategy prompts with metacognitive feedback, would report higher levels of self-regulation and generative learning strategy use, and learning performance after controlling for their prior domain knowledge.

Additional hypotheses concerned the indirect effects of the treatments on learning performance through learners’ self-regulation and generative learning strategy use.

**Research Questions**

The purpose of this study was to examine the direct effects of generative learning strategy prompts and metacognitive feedback and the mediation effects of learners’ self-regulation and use of generative learning strategies on their learning.

This study investigated the following two research questions:

Question 1: Do generative learning strategy prompts or generative learning strategy prompts with metacognitive feedback positively affect learners’ self-regulation (cognitive control and metacognitive control), the quality of overt use of generative learning strategies, or learning performance in recall and comprehension after controlling for learners’ prior domain knowledge over the control condition without generative learning strategy prompts or metacognitive feedback?
Question 2: Do generative learning strategy prompts or generative learning strategy prompts with metacognitive feedback indirectly affect learners’ learning performance in recall and comprehension through learners’ self-regulation (cognitive control and metacognitive control) and the quality of overt use of generative learning strategies?

Definitions, Rationale, and Hypotheses

Research Question 1: Main Effects of Generative Learning Strategy Prompts and Generative Learning Strategy Prompts with Metacognitive Feedback

Do generative learning strategy prompts or generative learning strategy prompts with metacognitive feedback positively affect learners’ self-regulation (cognitive control and metacognitive control), the quality of overt use of generative learning strategies, or learning performance in recall and comprehension after controlling for learners’ prior domain knowledge over the control condition without generative learning strategy prompts or metacognitive feedback?

Definitions

Generative learning strategy means cognitive activities such as selecting, organizing, and relating, directed by learners who actually create relationships and meaning between or among information to be learned and learners’ existing knowledge (Wittrock, 1990, 1991). Generative learning strategy prompts mean written statements directing learners to use generative learning strategies when they study instructional materials. Directing learners to underline important sentences, summarize their
understandings, and interact with adjunct questions are examples of generative learning strategy prompts.

*Metacognitive feedback* refers to any information given to learners about their decisions regarding which cognitive strategies use and how to use them (Butler & Winne, 1995). It functions as a reminder for assessing the suitability of cognitive strategies employed and correcting strategy use (Jacobs & Dempsey, 1993; Narciss, 2008). In this study, metacognitive feedback is feedback given to students’ responses to adjunct questions. It takes the form of reminding learners to evaluate the adequacy of their cognitive strategy use and correct the execution of the strategies (L. W. Anderson & Krathwohl, 2001; Jacobs & Dempsey, 1993; McCormick, 2003).

*Self-regulation* refers to “self-generated thought, feelings, and actions that are planned and cyclically adopted to the attainment of goals” (Zimmerman, 2000, p.14). The key components of self-regulation in learning are cognitive control and metacognitive control (Brown et al., 1983; Winne et al., 2006; Zimmerman, 1986). *Cognitive control* means regulating the use of various cognitive strategies for memory, learning, reasoning, problem solving, and thinking. *Metacognitive control* means the awareness and control of one’s thought processes. In other words, metacognitive control refers to learners’ activities for planning, monitoring, and modifying their cognitions to make any adaptive changes in their learning (Pintrich, 2000).

*Learner’s overt use of generative learning strategies* is operationally defined as the learner’s underlined sentences and notes taken on the instructional material provided. *The quality of learner’s overt use of generative learning strategies* refers to how well a learner attends to important information by selectively highlighting sentences having the
main idea and how well a learner creates relationships and meaning by taking notes with his/her own words.

Prior knowledge refers “…the knowledge, skills or ability that students bring to the learning process” (Jonassen & Grabowski, 1993, p. 417). More specifically, prior domain knowledge is operationally defined as a learner’s accurate and well-formed knowledge about the field in general that integrates with the instructional material (Alexander, Jetton, & Kulikowich, 1995).

Recall refers to learners’ retrieving previously learned information from long-term memory when asked to do so. In other words, a learner searches relevant knowledge from long-term memory and brings that to working-memory for processing. Remembering the meanings of words, facts, terminologies, and definitions is evidence of recall. This is an essential process for meaningful learning and more complex tasks (L. W. Anderson & Krathwohl, 2001).

Comprehension means making meaning from the given information. Comprehension refers to understanding of concepts, procedures and functions of a complex system and occurs through integration of newly learned knowledge with existing schemas and cognitive frameworks (Mandl & Levin, 1989).

Rationale

The primary interest of this study was to investigate whether using generative learning strategy prompts and metacognitive feedback in a computer-based learning environment facilitates learner’s recall and comprehension of the given instructional
materials. A body of literature on testing the effectiveness of generative learning strategies, such as generative underlining (Rickards & August, 1975), summarizing (Doctorow, Wittrock, & Marks, 1978), using note fields (Barab, Young, & Wang, 1999), provides evidence that learner’s recall and comprehension can be improved through generative activities, but that evidence is inconsistent.

Just providing generative learning strategy tools might not be enough to improve learners’ learning, since learners need to take control over their thinking and learning. Thus, prompting learners to use generative learning strategies would be a strategy encouraging learners to use the given generative learning strategies more than just providing tools for them to use those strategies. Also, metacognitive feedback may enhance learners’ use of generative learning strategies, because this recursive communication reminds the learners to evaluate the adequacy of the cognitive strategies they used and change the execution of the strategies, if they perceive themselves not to be learning. Accordingly, the quality of overt use of generative learning strategy should improve from the metacognitive feedback. Therefore, using generative learning strategy prompts and metacognitive feedback should result in expected improvement of learner’s self-regulation (cognitive control and metacognitive control), the quality of overt use of generative learning strategies, and performance in recall and comprehension.

In addition, decades of educational research on prior knowledge indicated that learner’s prior domain knowledge provides an important foundation for the development of integrated and generative knowledge (Shapiro, 2004). Research on the effects of prior domain knowledge on knowledge acquisition (Alexander, Kulikowich, & Schulze, 1994) and the relationship between prior domain knowledge and self-regulatory process
(Azevedo, Cuthrie, & Seibert, 2004; Garner & Alexander, 1989) provides evidence that learner’s recall and comprehension performance and its regulatory process closely relate to the learner’s prior domain knowledge. Therefore, learner’s prior domain knowledge should be controlled, when examining the effects of the treatments on learner’s self-regulation (cognitive control and metacognitive control), the quality of overt use of generative learning strategies, and performance in recall and comprehension.

Predicted Results

Hypothesis 1.1.1: Learners receiving generative learning strategy prompts will demonstrate significantly higher scores on a post-survey for self-regulation (cognitive control and metacognitive control) than learners who do not receive the prompts after controlling for learners’ prior knowledge.

Hypothesis 1.1.2: Learners receiving generative learning strategy prompts with metacognitive feedback will show significantly higher scores on a post-survey for self-regulation (cognitive control and metacognitive control) than learners who do not receive the prompts and feedback after controlling for learners’ prior knowledge.

Hypothesis 1.2.1: Learners receiving generative learning strategy prompts will demonstrate significantly higher scores on the quality of overt use of generative learning strategies than learners who do not receive the prompts after controlling for learners’ prior knowledge.

Hypothesis 1.2.2: Learners receiving generative learning strategy prompts with metacognitive feedback will demonstrate significantly higher scores on the quality of
overt use of generative learning strategies than learners who do not receive the prompts and feedback after controlling for learners’ prior knowledge.

Hypothesis 1.3.1: Learners receiving generative learning strategy prompts will perform significantly better on a post-test for recall than learners who do not receive the prompts after controlling for learners’ prior knowledge.

Hypothesis 1.3.2: Learners receiving generative learning strategy prompts with metacognitive feedback will perform significantly better on a post-test for recall than learners who do not receive the prompts and feedback after controlling for learners’ prior knowledge.

Hypothesis 1.4.1: Learners receiving generative learning strategy prompts will perform significantly better on a post-test for comprehension than learners who do not receive the prompts after controlling for learners’ prior knowledge.

Hypothesis 1.4.2: Students receiving generative learning strategy prompts with metacognitive feedback will perform significantly better on a post-test for comprehension than learners who do not receive the prompts and feedback after controlling for learners’ prior knowledge.

Research Question 2: Indirect Effects of Generative Learning Strategy Prompts or Generative Learning Strategy Prompts with Metacognitive Feedback through Learners’ Self-regulation (Cognitive Control and Metacognitive Control) and the Quality of Overt Use of Generative Learning Strategies.

Do generative learning strategy prompts or generative learning strategy prompts with metacognitive feedback indirectly affect learners’ learning performance in recall and comprehension through learners’ self-regulation (cognitive control and metacognitive control) and the quality of overt use of generative learning strategies?
Rationale

This study attempted to discover mediation effects of learners’ self-regulation and generative learning strategy use while they are learning. Therefore, identifying the indirect effects of the treatments on learners’ learning was another important inquiry of the study.

Generative learning strategy prompts and metacognitive feedback should help learners take more control over their learning and thinking. The expectation was that learners who used more cognitive and metacognitive control would use more generative learning strategies, and accordingly would perform better in recall and comprehension. Although previous research did not attempt to identify direct and indirect effects, those studies’ findings that learners’ self-regulating skill related to their academic achievement support this expectation (Azevedo & Cromley, 2004; Kramarski & Gutman, 2006; Pintrich & De Groot, 1990; Zimmerman, 1998b; Zimmerman & Schunk, 2001).

Predicted Results

Hypothesis 2.1: Generative learning strategy prompts will have significant, indirect, positive effects on performance in recall and comprehension through the quality of overt use of generative learning strategies.

Hypothesis 2.2: Generative learning strategy prompts with metacognitive feedback will have significant, indirect, positive effects on performance in recall and comprehension through the quality of overt use of generative learning strategies.
Hypothesis 2.3: Learners’ self-regulation (cognitive control and metacognitive control) will have significant, indirect, positive effects on performance in recall and comprehension through the quality of overt use of generative learning strategies.

**Significance of the Study**

The findings of this study contribute to the existing body of literature in four significant ways. First, this study investigated the use of metacognitive feedback in generative learning. The results provide instructional designers or teachers with guidance regarding the inclusion of cognitive and metacognitive support while learners generate their own knowledge.

Second, this study investigated the mediation effects of learners’ self-regulation and use of generative learning strategies on recall and comprehension. The findings answer the questions regarding what should be supported to improve students’ learning and how to provide appropriate supports.

Third, this study gathered and analyzed overt evidence of generative learning from learners’ highlighting and note-taking products instead of log files. Also, this study developed a rubric for assessing the quality of learner’s overt use of generative learning strategies and applied generalizability theory in order to verify the reliability of performance-based assessment.

Finally, this study applied a comprehensive approach for analyzing data arising from experimental studies using Structural Equation Modeling (SEM) procedures which
can test theories regarding how interventions affect observed outcomes (Bollen, 1989; Kline, 2005; Russell, Kahn, & Altmaier, 1998). Conventionally, experimental research studies have used statistical techniques testing mean differences between groups such as t-test, analysis of variance (ANOVA) and analysis of covariance (ANCOVA) to determine the effects of interventions. However, cognitive functioning and processes related to learning are intricate and human learning involves various psychological constructs. Theoretical advances for understanding human cognition and learning processes require considering intervening psychological constructs that may affect how an intervention is used when designing learning environments. In addition, with technological advances, educators infuse more assistive technologies into learning environments. Accordingly, the effectiveness of these innovations are not simply demonstrated by mean differences, since these interventions could relate to underlying mediating processes that may be responsible for the desired outcomes. Thus, as current technology-enriched learning environments and theoretical constructs involved in instructional design and development become more sophisticated and more complex, a need arises for equally sophisticated analytical methods to research these environments, theories, and models. The comprehensive methods used in this research can serve as a model for other instructional design researchers interested in understanding how intervening psychological constructs affect how an intervention is used.
Chapter 2

LITERATURE REVIEW

Introduction

The purpose of this study was to investigate whether using generative learning strategy prompts and metacognitive feedback in a computer-based learning environment facilitates learners’ recall and comprehension and whether learners’ self-regulation and the quality of their use of generative learning strategies mediate that facilitation. Specifically, the study, first, conceptualized a path model to explain how generative learning strategy prompts and metacognitive feedback affect learning. Second, the study investigated the direct effects of generative learning strategy prompts and metacognitive feedback on learners’ self-regulation, generative learning strategy use, and learning after controlling for learners’ prior knowledge. The study, also, examined the indirect effects of generative learning strategy prompts and metacognitive feedback on learning through learners’ self-regulation and generative learning strategy use.

This chapter presents Generative Learning Theory as a theoretical justification for the predictions made in the current study. As two major phenomena of interest, self-regulated learning and prior knowledge are described in terms of their relationship with Generative Learning Theory. The synthesis of related literature allowed proposing a preliminary path model for the current study.
Generative Learning

Human Information Processing

Over the past decade, understanding internal processes of human learning has evolved from extensive theoretical perceptions and empirical evidence about cognitive functioning and the processes and structure of human memory. One important concept which explains this human learning mechanism is information processing theory. Information processing theory is not the name of a single theory; it is a generic name applied to theoretical perspectives dealing with the sequence and execution of cognitive events. “Humans are processors of information. The mind is an information-processing system. Cognition is a series of mental processes. Learning is the acquisition of mental representations” (Mayer, 1996, p.154).

Internal processes that intervene between stimuli and responses are the main concern of this theory rather than external conditions. Learners are active seekers and processors of information. Learners selectively attend to features of the environment, transform and rehearse information, relate new information to previously acquired knowledge, and organize knowledge to make it meaningful (Schunk, 2004).

Information processing begins with a stimulus input which impinges on one or more senses. The appropriate sensory register receives the input and holds it briefly in sensory form. The sensory register transfers information to short-term memory (STM) which has limited duration. Information units in STM must be rehearsed to be retained. Without rehearsal, information is lost after a few seconds. While new information is in
STM, related knowledge which is activated and placed in STM from long-term memory (LTM), is integrated with the new information (Atkinson & Shiffrin, 1968).

Generative Learning Theory

The prime interest of instructional designers is a mechanism for stimulating internal processes. Generative learning theory, whose main focus is providing appropriate and learner-centric instructional activities, is one such concept. Wittrock’s generative learning theory provides a concept of learning processes and guides the design of learning environments.

At the essence of this functional model are the generative learning processes that people use actively and dynamically to (a) selectively attend to events and (b) generate meaning for events by constructing relations between new or incoming information and previously acquired information, conceptions, and background knowledge (Wittrock, 1992, p. 532).

In this model, comprehension and understanding result from the formulation of connections both among concepts and between experiences or prior learning and information. In other words, comprehension occurs from the learner’s creation of new understanding of the information, rather than transforming the presented information (Grabowski, 2004). Generative learning theory places more emphasis on the generation of new conceptual understandings by the learner, while information processing theory explains transforming information.

The conceptualization of the ideas presented in Wittrock’s writings (Wittrock, 1974a, 1974b, 1985, 1990, 1991, 1992) and Grabowski’s (2004) concept map regarding the progression of generative learning appears in Figure 2-1.
As shown inside the dotted rectangle in the figure, the learner’s self-generation of relationships is key to the meaning making process. In this process, learners should be mentally active in creating relationships between what they are learning with what they already know using various learning strategies from simple coding to integration strategies depending on their prior learning in the domain or their strategy, or their preference (Wittrock, 1990). Motivation shown inside the dotted rectangle is another essential component of meaning making, since persistence and sustained interest promote...
the intention to learn and make meaning (Wittrock, 1991). Finally, Wittrock (1991) emphasized that learners should regulate their cognitive activities in generative processes and therefore, metacognition controls those generative learning processes.

The outcome of this meaning making process was originally investigated in reading comprehension (e.g., Doctorow, Wittrock, & Marks, 1978; McGuire, 1999), and many research studies extended this theory to investigate a variety of generative learning strategies that were expected to promote different levels of learning in various domains (e.g., Carnine & Kinder, 1985; Linden & Wittrock, 1981; Smith & Dwyer, 1995). Recent interests include higher order thinking skill and self-regulated learning skill as outcomes of generative learning (e.g., Barab, Young, & Wang, 1999; Chularut & DeBacker, 2004; Friend, 1999).

**Generative Learning Strategy**

The key value of Generative Learning Theory is that it provides instructional implications about selecting appropriate learner-centric instructional activities for the learner (Grabowski, 2004; Wittrock, 1985, 1991). Considering the essence of this model of generative learning—knowledge generation—only those activities that make learners actually create relationships and meaning would be classified as examples of generative learning strategies (Wittrock, 1990, 1991).

Grabowski (2004) analyzed the studies investigating the viability of the generative learning theory and classified the strategies tested in the name of generative learning. Simple coding strategies include underlining (e.g., Rickards & August, 1975),
note taking (e.g., Peper & Mayer, 1986), and adjunct or inserted questions (e.g., R. C. Anderson & Biddle, 1975). More complex coding strategies include creation of hierarchies (e.g., Wittrock & Carter, 1975), headings and summaries (e.g., Doctorow, Wittrock, & Marks, 1978), and concept maps (e.g., Smith & Dwyer, 1995) or manipulation of objects (e.g., Haag & Grabowski, 1994). Also, elaborative integration strategies include imaging (e.g., Kourilsky & Wittrock, 1987) and creation of examples (e.g., DiVesta & Peverley, 1984), interpretations (e.g., Johnsey, Morrison, & Ross, 1992), or analogies (e.g., Linden & Wittrock, 1981); and finally metacognitive training (e.g., Friend, 1999).

Among various generative learning strategies, this study selectively reviewed several related studies that employed underlining and summarizing strategies. First, for underlining strategies, which is a controversial but plausible generative learning strategy, Rickards and August (1975) found that college students, allowed to underline text they considered most relevant, performed better on posttests. This result explained that a mental interaction between sentences that learners underlined and their own preconceptions occurred when they underlined the sentences that they considered more relevant. Second, for note taking or summarizing which sometimes is considered as either a simple coding strategy or an organizational strategy, Davis and Hult (1997) studied immediate and delayed free recall in note taking and writing summaries in introductory psychology classes. Their results supported the findings of Barnett, DiVesta, and Rogozenski (1981): writing summaries during pauses in the lecture note-taking activity significantly improved free recall and delayed retention. Third, regarding to the questioning strategy combined with other strategies, King (1992) examined the effect of
self-questioning, summarizing, and note taking on immediate and delayed recall of under-prepared college students. On immediate recall, summarizers performed better than self-questioners, who were better than note takers, indicating a progressive, generative effect. Self-questioners performed best on the delayed tests, indicating that deeper processing may occur in more generative tasks like self-questioning. This result supported the notion that providing questions stimulates learners to more actively process ideas from passages together, and consequently promotes creating personally meaningful understanding (Wittrock, 1990). Finally, regarding aptitude-generative learning strategy interaction, Shrager and Mayer (1989) reported interesting results regarding prior knowledge and note taking strategy interaction. Note-takers recalled more than non-note-takers among students with low levels of prior knowledge, but not for those with high levels of prior knowledge.

Previous research has shown the effectiveness of generative learning strategies when the learner is active in the learning process and when instruction includes activities that relate new information together and new information to preconception. Although, learner-generated activities have shown significant gains in learning, the results are not consistent and issues of developmental appropriateness and preconception require investigation regarding differences in effect (Grabowski, 2004).

**Implications for the Current Study**

Based on an understanding of the Generative Learning Theory, the following implications apply to the current study:
- Designing a learning environment should be based on understanding cognitive functioning and processing and structure of memory.

- Comprehension occurs from selective attention to events and generation of meaning for events by constructing relationships between what learners learn with what they already knew.

- Instructional strategies should encourage learners to engage themselves in the generation processes.

- Overall, previous research supports the effectiveness of generative learning strategies, but further research on encouraging learners to use them more effectively is necessary.

Self-Regulated Learning in Generative Learning

Self-Regulated Learning

Current theoretical and empirical advances about self-regulation can further inform how generative learning theory works, because learners’ cognitive and metacognitive regulation is a critical process in knowledge generation (Barab, Young, & Wang, 1999; Wittrock, 1991). In other words, by its very nature, learners must be accountable and responsible for their learning, thus self-regulation should be activated to accomplish learners’ learning goal (Schunk, 1996; Zimmerman, 2000).

According to Zimmerman (2000), self-regulation refers to “self-generated thoughts, feelings, and actions that are planned and cyclically adopted to the attainment
of personal goals” (p. 14). Hence, self-regulated learning is an active and constructive process whereby learners attempt to plan, monitor, control and reflect on their cognition, motivation, and behavior in their learning to achieve their goals (Pintrich, 2000). Self-regulated learners are behaviorally, motivationally, and metacognitively active participants in their own learning process (Zimmerman, 2000).

A variety of models of self-regulated learning propose different mechanisms, but all the models share basic assumptions. The first assumption is that learners are active participants in the learning process constructing their own meaning, goals, and strategies using the internal and external information available. The second assumption is that learners have the potential to monitor, control, and regulate their own cognition, motivation, and behavior. This assumption means some monitoring, control, and regulation is possible, but does not mean learners will or can implement this regulatory process in all contexts or at all times. The third assumption is that learners can set their own goals in their learning, monitor their progress toward their goals, and then select and adapt their cognition, motivation, and behavior in order to accomplish their goals. Finally, the accepted view is that self-regulatory activities are mediators between internal or external events and actual achievement or performance (Pintrich, 2000).

**Regulation of Psychological Functions**

According to Pintrich (2000), a learner can attempt to monitor, control, and regulate three different areas of psychological functioning: cognition, motivation, and behavior. First, regulation of cognition concerns the different cognitive strategies used to
learn and perform a task as well as metacognitive strategies used to control cognition (Bransford, Brown, & Cocking, 1999; Pintrich, 2000). Second, regulation of motivation concerns the different beliefs that learners may have about their ability or the task, such as self-efficacy or values for the task (Boekaerts, 1993; Corno & Mandinach, 1983). Finally, regulation of behavior concerns activities that individuals attempt to control their own overt activity such as time and effort management (McKeachie, Pintrich, & Lin, 1985) and help-seeking (Karabenick & Sharma, 1994). Regulation of cognition, which is the main interest of this study, is further discussed in the next section.

**Regulation of Cognition**

Regulation of cognition is a central aspect of self-regulated learning for academic performance (Brown et al., 1983; Pintrich & De Groot, 1990). It refers to the activities and strategies in which learners engage to plan, monitor, and regulate their cognition. To illustrate, for a learning task (e.g., reading a textbook), learners set specific cognitive goals for learning (Schunk, 1989; Zimmerman, 1989) (e.g., comprehension), and activate automatically or consciously their prior knowledge (e.g., related domain knowledge) and metacognitive knowledge (e.g., selection of cognitive strategies) the learners might have (Alexander, Schallert, & Hare, 1991; Flavell, 1979). Learners monitor their progress toward the goals (Flavell, 1979) (e.g., monitor reading comprehension), and they make any adaptive changes (e.g., changing cognitive strategies) based on monitoring results which provide information about the relative gap between current progress and their own goals (Zimmerman, 1989, 1994). Finally, learners make cognitive judgments about their
achievements and make attributions for their performance (Zimmerman, 1998a) (e.g.,
evaluation of comprehension).

Regulation of cognition consists of two components: cognitive control and
metacognitive control. First, cognitive control is regulating the use of cognitive strategies
to accomplish learning goals. In other words, self-regulated learners are able to control
the process of selecting and using various cognitive strategies for remembering, learning,
reasoning, problem solving, and thinking (Pintrich, 2000). The variety of cognitive
strategies such as rehearsal, elaboration, and organizational strategies that learners can
use to help them understand and learn the material has been investigated and their
positive influence on learning and performance has been demonstrated (Pintrich & De
control means the awareness and control of one’s thought processes. In other words, self-
regulated learners are able to plan, monitor, and modify their cognition to make any
adaptive changes in their learning (Pintrich, 2000). Pintrich and De Groot (1990) also
reported that significant relationships exist between metacognitive control and classroom
academic performance among 173 seventh graders. The learners who set goals,
monitored their progress towards their goals, and adapted their strategy use showed better
performance. As illustrated before, self-regulated learners use cognitive and
metacognitive control repeatedly to accomplish the learning goal justifying these two
control processes as significant predictors of learners’ learning performance (Pintrich,
2000; Zimmerman, 2000).
**Metacognitive Feedback**

Metacognitive control is the series of activities that learners use to help themselves plan their learning, monitor their learning process, and regulate or change their learning strategies. This metacognitive control is a critical aspect of effective self-regulated learning, because it provides learners with self-generated information about their learning processes and performance (Butler & Winne, 1995; Pintrich, Wolters, & Baxter, 2000).

Therefore, in order to facilitate learners’ self-regulatory processes and improve their learning performance, supporting and guiding learners’ metacognitive control is necessary. One effective method facilitating learners’ self-regulation and learning may be to provide feedback on their metacognitive processes, such as decisions about which and how to use cognitive strategies (Butler & Winne, 1995; Winne, 1997; Wittrock, 1992). Metacognitive feedback is the communication that makes a learner conscious of the learning strategies and styles being used and the degree of success. Feedback is an accepted strategy for increasing the learner’s awareness of what is unknown, what knowledge is needed, and what learning strategies work (Jacobs & Dempsey, 1993).

Several studies investigated the effect of metacognitive feedback which used self-questioning or prompting. Mevarech and Fridkin (2006) examined the effects of self questions on students’ mathematical knowledge, mathematical reasoning, and metacognition. The study included four types of self questions: comprehension questions (e.g., What is the problem all about?), connection questions (e.g., What are the similarities and differences between the given problem and problems you have solved in
the past, and why?), strategic questions (e.g., What strategies are appropriate for solving the problem, and why?), and reflection questions (e.g., What am I doing here?). Learners using self questions significantly outperformed the students who were not using them on mathematical knowledge and reasoning tests and metacognition. Kramarski and Gutman (2006) supported the previous study by testing the effectiveness of self questioning on metacognition in their study. Students supported with self questioning on metacognition in e-learning environments significantly outperformed the students who were not supported with self questioning on metacognition in achievement and use of self-monitoring strategies.

Other studies tested the effect of metacognitive prompts: Veenman and his colleagues (1994) examined the effect of metacognitive prompts on use of learning strategy and learning performance and an interaction effect between metacognitive prompts and learners’ intelligence. The researchers used think-aloud protocols and found the metacognitive prompts, which requested paraphrasing the question, generating a hypothesis, or evaluating outcomes, increased the occurrence and improved the quality of orientation activities, systematic orderliness, and evaluation activities. Accordingly, this improvement enhanced learning performance. Also an aptitude-treatment-interaction suggested low intelligence students profited relatively more from the metacognitive prompts. Kauffman (2004) tested the effects of self-monitoring prompts in his investigation of students' use of self-regulated learning strategies in a web-based setting. The students who received self-monitoring prompts, which requested a confidence judgment about the completeness of their learning, had higher achievement than the control group.
Implications for the Current Study

Based on an understanding of self-regulated learning theory, the following implications apply to the current study:

- Learners’ cognitive and metacognitive regulation is a critical process in knowledge generation, so self-regulated learning theory can provide further understanding for the mechanism of a generative learning model.

- Learners are assumed to be active participants in the learning process and they have the potential to monitor, control, and regulate their own cognition. However, this does not mean learners will or can accomplish this regulatory process in all contexts or at all times.

- Moreover, metacognitive control is a critical aspect of effective self-regulated learning, since it provides learners with self-generated information about their own learning processes and performance.

- Therefore, supporting and guiding learners’ metacognitive control, in order to facilitate their self-regulatory processes and improve their performance on learning tasks, is necessary. This supporting procedure should be a cyclical and recursive process, which utilizes feedback mechanisms for students to monitor, to be aware, and to adjust their learning processes accordingly.

- Empirically, it is supported that metacognitive feedback could increase the occurrence and improve the quality of learning strategy use, and accordingly, improve learning performance.
**Prior Knowledge in Generative Learning**

**Prior Knowledge and Learning**

Over the past decade, research has demonstrated that learners with more background knowledge about a particular domain generally understand and remember better in that domain than those with only limited domain knowledge (Alexander & Judy, 1988). In other words, prior knowledge that learners have in a domain is a crucial variable that contributes to learning outcomes (Alexander, 2003; Alexander, Jetton, & Kulikowich, 1995; Shapiro, 2004). Prior knowledge represents the basic building blocks of the human information processing system, key units of the comprehension process, and consequently a determinant factor in learning (Ausubel, Novak, & Hanesian, 1978).

The quality of prior knowledge is another variable that several studies consider. Correct prior knowledge can facilitate learning but incorrect or inaccurate prior knowledge can hinder learning from texts more than having no prior knowledge at all. In other words, changing the existing knowledge is more difficult than understanding new unfamiliar concepts (Alexander & Judy, 1988; Lipson, 1982). In addition to the quality of prior knowledge, its breadth is another important consideration in prior knowledge research. Topic knowledge and domain knowledge are distinctly different. The former refers to particular knowledge that is more specific to a given learning task (e.g., the human heart); whereas, the latter refers to the general knowledge of a formal field of study (e.g., physiology) (Alexander, Kulikowich, & Schulze, 1994). Even though the predicted tendency is for individuals with more topic knowledge in a field to have more domain knowledge, the contribution of each type of knowledge on learning is unclear.
Alexander and her colleagues (1994) investigated the effect of these two types of knowledge on learning outcome and found domain knowledge was a better predictor of learning outcome than topic knowledge.

**Relationship between Prior Knowledge and Self-regulation**

Another research issue involving prior knowledge is the relationship between prior knowledge and regulation of learning processes (Alexander & Judy, 1988). A significant amount of research supports domain knowledge as necessary for the efficient and effective utilization of learning strategies. In other words, prior knowledge can influence cognitive processes during learning. “…[N]ovice learners are not typically familiar with the procedures associated with constructive self-regulative learning” (Tergan, 1997, pp.227-228).

Support exists for the prediction that low-prior knowledge students are not successful in regulating their learning by using key, self-regulatory processes, such as planning their learning, activating their prior knowledge, monitoring their emerging understanding of the topic, or deploying effective strategies (Alexander *et al.*, 1989; Azevedo, Cuthrie, & Seibert, 2004; Shapiro, 2004). Alexander and her colleagues found that sixth graders who had low levels of prior knowledge in human biology benefited little from general strategy instruction of analogical reasoning.
Implications for the Current Study

Based on the understanding of prior knowledge, the following implications apply to the current study:

- Prior knowledge that learners have in a domain is a crucial variable that contributes to learning outcomes.
- Domain knowledge is a better predictor of learning outcome than topic knowledge.
- A certain amount of domain knowledge is necessary for the efficient and effective utilization of learning strategies and the regulation of cognition.

The Proposed Model of the Study

Information processing theory provides a very fundamental understanding of human learning. Individuals are processors of information in a learning environment, and their learning is the acquisition of mental representations through a series of mental processes (Mayer, 1996). Even though this fundamental psychological premise has wide agreement, learner’s active meaning making is more important than transforming information. In other words, comprehension occurs from the learner’s creation of new understanding of the information, rather than transforming the presented information (Grabowski, 2004). Although, learner-generated activities have shown significant gains in learning, providing some support and guidance to help learners better perform in knowledge generation processes is necessary.
Current theoretical and empirical advances about self-regulation and prior knowledge can improve an understanding of a generative learning theory. Learners’ cognitive and metacognitive regulations are critical processes in knowledge generation (Barab, Young, & Wang, 1999; Wittrock, 1991), because learners are active participants, rather than passive recipients, throughout their learning processes. The basic assumption of self-regulated learning is that self-regulated learners actively monitor, control, and regulate their own cognition, motivation, and behavior. The learners can set their own goals for their learning, monitor their progress toward their goals, and then select and adapt their cognition in order to accomplish their goals. Also, these self-regulatory activities are mediators between internal or external events and actual achievement or performance (Pintrich, 2000). Thus, to support learners’ self-regulatory process and meaningful generation of learning, one effective method may be to provide feedback about their use of metacognitive processes such as decisions about which cognitive strategies to use and how to use them (Butler & Winne, 1995; Winne, 1997; Wittrock, 1992).

In addition, learners with more background knowledge about a particular domain generally understand and remember better in that domain than those with only limited domain knowledge (Alexander & Judy, 1988). A large amount of research supported the notion that a certain amount of domain knowledge is necessary for the efficient and effective utilization of learning strategies. The synthesis from the literature review proposed the preliminary path model of the study which appears in Figure 2-2.
Figure 2-2. Preliminary path model
Chapter 3

METHODS

The purpose of this study was to investigate whether using generative learning strategy prompts and metacognitive feedback in a computer-based learning environment facilitates learners’ recall and comprehension and whether learners’ self-regulation and the quality of their use of generative learning strategies mediate that facilitation. This chapter describes this study’s methodologies, including pilot study, participants, treatments, measurement instruments, procedures, and data analysis.

Pilot Study

A pilot study was conducted in the fall of 2006 to test and improve treatment materials, experiment logistics, and methodology of the study by gathering preliminary information prior to the main study. The pilot study investigated three research questions: (1) Do generative learning strategy prompts or generative learning strategy prompts with metacognitive feedback improve learners’ comprehension and self-regulation? (2) Does an interaction exist between generative strategy prompts or generative strategy prompts with metacognitive feedback and the level of prior knowledge on learners’ comprehension and self-regulation? (3) Does a relationship exist between learners’ self-regulation and comprehension?
The pilot study used a 2 x 3 factorial design with two levels of prior knowledge—high versus low—and three treatment groups—static visualized instruction, generative learning strategy prompts, and generative learning strategy prompts with metacognitive feedback. Forty-one college students, from an undergraduate general science course of a northeastern university, volunteered to participate in the pilot study. Thirty-six participants completed the study. Participants included four freshmen, ten sophomores, thirteen juniors, and nine seniors. Eleven participants were female and twenty-five participants were male. The means and standard deviations for the comprehension test and the self-regulation survey by treatment group and prior knowledge level are shown in Table 3-1.

<table>
<thead>
<tr>
<th>Group</th>
<th>Prior Knowledge</th>
<th>n</th>
<th>Comprehension (a)</th>
<th>Self-Regulation (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Control</td>
<td>Low</td>
<td>4</td>
<td>11.50 (60.5%)</td>
<td>2.082 3.55 .723</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>6</td>
<td>12.50 (63.2%)</td>
<td>2.588 3.64 .317</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>10</td>
<td>12.10 (63.7%)</td>
<td>2.331 3.60 .482</td>
</tr>
<tr>
<td>Generative strategy</td>
<td>Low</td>
<td>5</td>
<td>14.80 (77.9%)</td>
<td>2.280 3.86 .237</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>9</td>
<td>14.33 (75.4%)</td>
<td>1.500 3.99 .877</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>14</td>
<td>14.50 (76.3%)</td>
<td>1.743 3.94 .703</td>
</tr>
<tr>
<td>Metacognitive feedback</td>
<td>Low</td>
<td>5</td>
<td>15.40 (81.1%)</td>
<td>2.966 4.50 .434</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>7</td>
<td>16.86 (88.7%)</td>
<td>2.854 4.07 .600</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>12</td>
<td>16.25 (85.5%)</td>
<td>2.864 4.26 .559</td>
</tr>
<tr>
<td>Total</td>
<td>Low</td>
<td>14</td>
<td>14.07 (74.1%)</td>
<td>2.868 4.00 .603</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>22</td>
<td>14.64 (77.1%)</td>
<td>2.787 3.92 .673</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>36</td>
<td>14.42 (75.9%)</td>
<td>2.792 3.95 .639</td>
</tr>
</tbody>
</table>

Note. (a) The comprehension test contains 19 items and each item was worth 1 point. Thus the scores could range from a low of 0 to a high of 19 (b) Likert scale: 7="very true of me", 1="not at all true of me".
A two-way ANOVA provided answers to Research Questions 1 and 2. The results of the two-way ANOVA for the post-test score on comprehension appear in Table 3-2. Analysis of variance revealed a significant main effect for treatment with large differences ($F(2,30)=8.015; p=.002; \text{partial Eta squared}=.348$). However, the main effect for prior knowledge was not significant ($F(1,30)=.656; p=.425; \text{partial Eta squared}=.021$), nor was the interaction of treatment and prior knowledge significant ($F(2,30)=.548; p=.584; \text{partial Eta squared}=.035$).

<table>
<thead>
<tr>
<th>Source</th>
<th>$df$</th>
<th>Type III SS</th>
<th>Mean Square</th>
<th>$F$</th>
<th>$P$</th>
<th>partial Eta-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>2</td>
<td>90.497</td>
<td>45.249</td>
<td>8.015</td>
<td>.002</td>
<td>.348</td>
</tr>
<tr>
<td>Prior Knowledge</td>
<td>1</td>
<td>3.701</td>
<td>3.701</td>
<td>.656</td>
<td>.425</td>
<td>.021</td>
</tr>
<tr>
<td>Interaction</td>
<td>2</td>
<td>6.184</td>
<td>3.092</td>
<td>.548</td>
<td>.584</td>
<td>.035</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>169.357</td>
<td>5.645</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The pair-wise comparisons among the three treatment groups demonstrated that the comprehension mean score for the generative strategy prompts with metacognitive feedback group was significantly higher than the comprehension mean score for the control group ($p=.001$). However, no significant difference in comprehension mean scores appeared between the generative strategy prompts group and the control group ($p=.053$), or between the generative strategy group and the generative strategy with metacognitive feedback group ($p=.164$).
The results of the two-way ANOVA for the post-survey score for self-regulation appear in Table 3-3. Analysis of variance revealed a significant main effect for treatment. ANOVA revealed significant differences between the three groups ($F(2,30)=3.429; p=.046; \text{partial } \eta^2=.186$). However, the main effect for prior knowledge was not significant ($F(1,30)=.108; p=.744; \text{partial } \eta^2=.004$), nor was the interaction of treatment and prior knowledge significant ($F(2,30)=.731; p=.490; \text{partial } \eta^2=.046$).

Games and Howell’s modification of Tukey’s HSD, used for the pair-wise comparisons among three treatment groups, is appropriate for unequal variances (Toothacker, 1993). The results demonstrate that the self-regulation mean score for the generative strategy with metacognitive feedback group was significantly higher than the self-regulation mean score for the control group ($p=.021$). However, no significant difference in the self-regulation mean score appeared between the generative strategy group and the control group ($p=.387$), or between the generative strategy group and the generative strategy with metacognitive feedback group ($p=.407$).

<table>
<thead>
<tr>
<th>Source</th>
<th>$Df$</th>
<th>Type III SS</th>
<th>Mean Square</th>
<th>$F$</th>
<th>$P$</th>
<th>$\text{partial } \eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>2</td>
<td>90.497</td>
<td>1.298</td>
<td>3.429</td>
<td>.046</td>
<td>.186</td>
</tr>
<tr>
<td>Prior Knowledge</td>
<td>1</td>
<td>3.701</td>
<td>.041</td>
<td>.108</td>
<td>.744</td>
<td>.004</td>
</tr>
<tr>
<td>Interaction</td>
<td>2</td>
<td>6.184</td>
<td>.277</td>
<td>.731</td>
<td>.490</td>
<td>.046</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>169.357</td>
<td>.379</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3-3. Two-way ANOVA for the Self-regulation Scores of the Pilot Study
A correlation analysis tested the relationship between participants’ self-regulation and their comprehension test score. Calculation of Pearson’s $r$ determined the correlation between comprehension and self-regulation variables. Comprehension positively and significantly correlated with self-regulation ($r=.396; p<.05; n=36$).

The results of this study support the notion that learners who received the generative learning strategy prompts with metacognitive feedback scored significantly higher on the comprehension and self-regulation than the control group, and that a significant, positive relationship exists between learner’s comprehension and cognitive self-regulation. However, the study did not detect an interaction between prior knowledge and instructional treatment.

Based on the lessons from the pilot study results, the following changes were made in order to improve the quality of study.

(1) The prior knowledge test was not successful in differentiating learner’s prior knowledge level. The data shows low mean score and low variance ($M=4.42$ of a total of 15, $SD=1.948$), and moderate positive skewness ($Skewness=.772$). The terminology test measuring topical knowledge served as the prior knowledge test for the pilot study, and was too difficult for the participants. Moreover, the literature review supports that domain knowledge is a better predictor of learning performance than topic knowledge (Alexander, Kulikowich, & Schulze, 1994). Thus, a human physiology test, which tested domain knowledge of human physiology and showed fairly normal distribution in previous research ($M=22.23$ of a total of 36, $SD=3.88$) (Wang, 2003), replaced the terminology test as the prior knowledge test in the main study. Also, the interaction of treatment and
prior knowledge was not significant, thus prior knowledge was used as a covariate in the main study to control the levels of prior knowledge of learners.

(2) The control group was not provided the learning strategy tools for highlighting and note-taking. Consequently, the design of the pilot study was unable to detect the effect of generative learning strategy prompts itself because treatment difference from the control group included both learning strategy tools and generative learning strategy prompts. Therefore, the control group of the main study was provided access to highlighting and note-taking tools without any prompts.

(3) The pilot study detected a significant, positive, and moderate correlation between comprehension and self-regulation. Also the pilot study detected significant main effects of the treatments on both comprehension and self-regulation. In other words, self-regulation could be considered as a mediator between the treatment and comprehension. Thus, the main study employed Structural Equation Modeling (SEM) in order to identify direct and indirect effects among variables.

(4) Even though the results supported the effect of generative learning strategy prompts with metacognitive feedback on comprehension, there was no evidence collected about whether they actually used the highlighting, note-taking, or adjunct questions. Thus this data regarding the quality of their generative learning strategy use was added to the main study to better understand the effect of the treatments.

(5) The pilot study employed only comprehension post test measuring learners’ understanding of concepts and their relationships. However, the treatments may have different effects on learners’ comprehension and recall because comprehension requires
more generative learning than recall. Thus the main study added a recall test measuring remembering facts and terminologies.

Main Study

Participants

The population of interest, for this study, consists of college students. Because the primary interest of this study is the processes employed while learning complex science topics, and self-regulation is hypothesized as one factor mediating the processes, participants should have some initial level of domain knowledge and self-regulation skill. In the spring of 2008, 261 undergraduate students, who enrolled in two general education courses in a large land grant university in northeastern United States, volunteered for this study. One of the two courses was in the College of Information Sciences and Technology (IST) and the other was in the College of Education. Fifty-three of 150 students, or 35 percent of the IST course, and 208 of 360 students, or 58 percent of the College of Education course, volunteered.

Even though the students participated voluntarily, the participants received extra points: 1.5 percent of the final grade for the IST course and one percent of the final grade for the course in the College of Education. Also, the students scoring highest in each group of each course was given a $20 gift certificate.

Of the volunteers, 238 of 261 completed all tasks of the study. The participants consisted of freshmen through seniors who represented a variety of majors from
throughout the campus. Among the 238 participants, 15 participants missed one or more survey items. Little’s Missing at Completely Random (MCAR) test examined the pattern of the missing data (Cohen et al., 2003). The test indicated that the nature of the missing data was random and not systematic (chi-square = 237.855; df = 235; $p=.811$). That is, no evidence was collected to suggest that an identifiable pattern existed for the missing data. Thus, listwise deletion of missing data resulted in 15 incomplete data points being eliminated from further analysis. A total of 223 participants’ data, or 94 percent of the entire data set, formed the data base for analysis. This final data set had no missing items or cases, thus, eliminating the need for further missing data treatment. The demographic distribution of 223 participants appears in Table 3-4.
Independent (Exogenous) Variables

This study examined two independent (exogenous) variables: (1) three levels of support for generative learning strategy use and (2) learners’ prior knowledge of human physiology as a covariate.
Dependent (Endogenous) Variables

This study included four dependent (endogenous) variables: (1) learners’ self-regulation (cognitive control and metacognitive control), (2) the quality of learners’ overt use of generative learning strategies, (3) learners’ recall of terminology and facts, and (4) learners’ comprehension of concepts and relationships.

Instructional Materials

The paper-based text material, developed by Dwyer and Lamberski (1977) about the human heart, was adapted for this study. The original script for the instructional content about the human heart contained approximately 1,800 words divided into three sections: the parts of the heart, circulation of blood, and cycle of blood pressure. The original, visualized version of the content consisted of one page of introduction and 20 pages of instructions. The introduction page presents the purpose of the instruction and directs participants to pay attention to both verbal and visual information. Pages 1 through 9 introduce the parts of the heart; the circulation of blood is the subject in pages 10 to 17, and an explanation of the cycle of blood pressure appears in pages 18 to 20. On each instructional page, the instructional text appears on the left side of the page and a corresponding static graphic covers the right side of the page. These paper-based materials were adapted for use on the computer as a PDF file resulting one page of introduction and 20 pages of instructions.

The choice of this content is appropriate for this study because it deals with a complex system which has multiple interconnected components including several
chambers, layers of membranes and muscle, valves, and veins. Because these components function simultaneously interacting with each other, learners need to understand the structural, behavioral, and functional relationships among the components of the heart, and they must comprehend the heart’s overall functioning.

**Item Analysis**

In order to position instructional interventions, item analysis was conducted to identify where learners had difficulties with criterion tests from two previous research studies, which have similar population (Chen, 2002; Zhu, 2006), and the pilot study. The summary of the item analysis results appears in Table 3-5 and Table 3-6.

The average item difficulty scores of the terminology test items were calculated from the difficulty scores of two previous research studies, weighted by the number of participants. Also, the average difficulty item scores of comprehension test items were calculated from the item difficulty scores of two previous research studies and the pilot study, weighted by the number of participants. For thirty-three out of forty test items, learners’ achievement fell below 60% correct: sixteen items of the terminology test and seventeen items of the comprehension test.
Table 3-5. Item Difficulties of Recall Test

<table>
<thead>
<tr>
<th>Item</th>
<th>% Correct 1 (^a)</th>
<th>% Correct 2 (^b)</th>
<th>Weighted Average</th>
<th>Computer Screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>49</td>
<td>22</td>
<td>40.5</td>
<td>S3</td>
</tr>
<tr>
<td>#2</td>
<td>54</td>
<td>44</td>
<td>50.9</td>
<td>S19</td>
</tr>
<tr>
<td>#3</td>
<td>69</td>
<td>56</td>
<td>64.9</td>
<td>S18</td>
</tr>
<tr>
<td>#4</td>
<td>60</td>
<td>28</td>
<td>50.0</td>
<td>S7</td>
</tr>
<tr>
<td>#5</td>
<td>40</td>
<td>28</td>
<td>36.2</td>
<td>S9</td>
</tr>
<tr>
<td>#6</td>
<td>49</td>
<td>28</td>
<td>42.4</td>
<td>S8</td>
</tr>
<tr>
<td>#7</td>
<td>51</td>
<td>65</td>
<td>55.4</td>
<td>S7</td>
</tr>
<tr>
<td>#8</td>
<td>40</td>
<td>22</td>
<td>34.4</td>
<td>S9</td>
</tr>
<tr>
<td>#9</td>
<td>51</td>
<td>29</td>
<td>44.1</td>
<td>S9</td>
</tr>
<tr>
<td>#10</td>
<td>49</td>
<td>24</td>
<td>41.2</td>
<td>S4</td>
</tr>
<tr>
<td>#11</td>
<td>20</td>
<td>35</td>
<td>24.7</td>
<td>S4</td>
</tr>
<tr>
<td>#12</td>
<td>69</td>
<td>47</td>
<td>62.1</td>
<td>S4</td>
</tr>
<tr>
<td>#13</td>
<td>46</td>
<td>41</td>
<td>44.4</td>
<td>S5</td>
</tr>
<tr>
<td>#14</td>
<td>57</td>
<td>35</td>
<td>50.1</td>
<td>S4</td>
</tr>
<tr>
<td>#15</td>
<td>69</td>
<td>59</td>
<td>65.9</td>
<td>S9</td>
</tr>
<tr>
<td>#16</td>
<td>71</td>
<td>44</td>
<td>62.5</td>
<td>S6</td>
</tr>
<tr>
<td>#17</td>
<td>63</td>
<td>25</td>
<td>51.1</td>
<td>S8, 10</td>
</tr>
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<td>#18</td>
<td>57</td>
<td>19</td>
<td>45.1</td>
<td>S14</td>
</tr>
<tr>
<td>#19</td>
<td>57</td>
<td>25</td>
<td>47.0</td>
<td>S4</td>
</tr>
<tr>
<td>#20</td>
<td>69</td>
<td>38</td>
<td>59.3</td>
<td>S9</td>
</tr>
</tbody>
</table>

\(^a\) % correct 1 from 35 participants (Zhu, 2006)  
\(^b\) % correct 2 from 16 participants (Chen, 2002)
Table 3-6. Item Difficulties of Comprehension Test

<table>
<thead>
<tr>
<th>Item</th>
<th>% Correct 1</th>
<th>% Correct 2</th>
<th>% Correct 3</th>
<th>Weighted Average</th>
<th>Computer Screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>89</td>
<td>63</td>
<td>100</td>
<td>84.7</td>
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</tr>
<tr>
<td>#2</td>
<td>46</td>
<td>38</td>
<td>30</td>
<td>40.8</td>
<td>S13</td>
</tr>
<tr>
<td>#3</td>
<td>43</td>
<td>50</td>
<td>50</td>
<td>46.2</td>
<td>S15</td>
</tr>
<tr>
<td>#4</td>
<td>37</td>
<td>19</td>
<td>80</td>
<td>41.2</td>
<td>S12</td>
</tr>
<tr>
<td>#5</td>
<td>40</td>
<td>31</td>
<td>50</td>
<td>39.8</td>
<td>S18</td>
</tr>
<tr>
<td>#6</td>
<td>17</td>
<td>13</td>
<td>0</td>
<td>12.5</td>
<td>S12, S20</td>
</tr>
<tr>
<td>#7</td>
<td>57</td>
<td>44</td>
<td>70</td>
<td>56.4</td>
<td>S19</td>
</tr>
<tr>
<td>#8</td>
<td>60</td>
<td>69</td>
<td>90</td>
<td>68.3</td>
<td>S8</td>
</tr>
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<td>46</td>
<td>31</td>
<td>70</td>
<td>47.1</td>
<td>S19</td>
</tr>
<tr>
<td>#10</td>
<td>60</td>
<td>50</td>
<td>70</td>
<td>59.5</td>
<td>S5</td>
</tr>
<tr>
<td>#11</td>
<td>54</td>
<td>38</td>
<td>100</td>
<td>59.3</td>
<td>S15</td>
</tr>
<tr>
<td>#12</td>
<td>51</td>
<td>31</td>
<td>60</td>
<td>47.8</td>
<td>S13</td>
</tr>
<tr>
<td>#13</td>
<td>54</td>
<td>44</td>
<td>30</td>
<td>46.6</td>
<td>S15, S20</td>
</tr>
<tr>
<td>#14</td>
<td>69</td>
<td>63</td>
<td>80</td>
<td>69.7</td>
<td>S15</td>
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<tr>
<td>#16</td>
<td>57</td>
<td>33</td>
<td>70</td>
<td>53.6</td>
<td>S13, S15</td>
</tr>
<tr>
<td>#17</td>
<td>49</td>
<td>40</td>
<td>70</td>
<td>51.0</td>
<td>S14, S19</td>
</tr>
<tr>
<td>#18</td>
<td>40</td>
<td>60</td>
<td>50</td>
<td>47.0</td>
<td>S12, S20</td>
</tr>
<tr>
<td>#19</td>
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<td>27</td>
<td>60</td>
<td>46.8</td>
<td>S14, S19</td>
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<td>#20</td>
<td>43</td>
<td>53</td>
<td>70</td>
<td>51.0</td>
<td>S18</td>
</tr>
</tbody>
</table>

* % correct 1 from 35 participants (Zhu, 2006)
* % correct 2 from 16 participants (Chen, 2002)
* % correct 3 from 13 participants of the pilot study
Fifteen instructional computer screens were matched to these 33 test items, and the screen numbers are highlighted in Table 3-7.

<table>
<thead>
<tr>
<th>Computer Screen</th>
<th>Recall Test</th>
<th></th>
<th>Comprehension Test</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>below 60% correct</td>
<td>above 60% correct</td>
<td>below 60% correct</td>
<td>above 60% correct</td>
</tr>
<tr>
<td>S1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td>10, 11, 14, 19</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S5</td>
<td>13</td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>S6</td>
<td></td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S7</td>
<td>4, 7</td>
<td></td>
<td></td>
<td></td>
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<td>S8</td>
<td>6, 17</td>
<td></td>
<td></td>
<td>1, 8</td>
</tr>
<tr>
<td>S9</td>
<td>8, 9, 20</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S10</td>
<td>17</td>
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<tr>
<td>S11</td>
<td></td>
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<td>S12</td>
<td></td>
<td></td>
<td>4, 6, 18</td>
<td></td>
</tr>
<tr>
<td>S13</td>
<td></td>
<td></td>
<td>2, 12, 16</td>
<td></td>
</tr>
<tr>
<td>S14</td>
<td>18</td>
<td></td>
<td>17, 19</td>
<td></td>
</tr>
<tr>
<td>S15</td>
<td></td>
<td></td>
<td>3, 11, 13, 16</td>
<td>14</td>
</tr>
<tr>
<td>S16</td>
<td></td>
<td></td>
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<td>S17</td>
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<td>15</td>
<td></td>
</tr>
<tr>
<td>S18</td>
<td>3</td>
<td></td>
<td>5, 20</td>
<td></td>
</tr>
<tr>
<td>S19</td>
<td>2</td>
<td></td>
<td>7, 9, 17, 19</td>
<td></td>
</tr>
<tr>
<td>S20</td>
<td></td>
<td></td>
<td>6, 13, 18</td>
<td></td>
</tr>
</tbody>
</table>


**Instructional Treatments**

The self-paced computer-based instruction about the human heart included 20 screens for each treatment, and used interactive form fields from Adobe Acrobat Professional® software with static graphics. This software was appropriate because it: (1) provided a highlighting function not readily available in a web environment, and (2) could easily save the records of learners’ highlighted sentences and notes.

**Treatment 1: Static Visualized Instruction with Generative Learning Strategy Tools**

This treatment contained four pages of tutorial on how to use highlighting and note-taking tools in Adobe Acrobat 8.0 Professional® prior to the instruction to minimize participants’ frustration from lack of familiarity with the software (see Appendix B), one page of introduction, and 20 pages of PDF screens with instructional content on the left and corresponding graphics on the right. Three navigational buttons, “direction,” “previous,” and “next,” appeared at the bottom of each screen. A text box for note taking was provided on each those 15 pages identified. Participants were allowed to navigate at a self-paced manner. A sample screen of the static visualized treatment appears in Figure 3-1.
Treatment 2: Static Visualized Instruction with Generative Learning Strategy Prompts

The instructional scripts and graphics of this treatment were the same as the control group (T1) except 15 instructional screens (#3 to #5, #7 to #10, #12 to #15, and #17 to #20) contain embedded generative learning strategy prompts asking participants to highlight and summarize important information from the instructional text. Ten adjunct questions appeared on the respective, succeeding ten screens (#5, #8, #9, #12, #13, #14, #15, #18, #19, and #20). The item analysis results directed selection of those 15 screens (see Table 3-7) and conceptual clusters of the 15 screens directed placement of the ten adjunct questions.
This treatment prompted participants to highlight important sentences in the instructional script (e.g. “Highlight one or more sentences that you think are important in this section.”), and then prompted them to summarize or organize their understanding in the provided note taking field (e.g. “Summarize the sequence of a wave of muscular contraction of the heart in your own words.”). Following the ten instructional screens, an adjunct question appeared. Simple knowledge of correct response feedback was provided—right or wrong. The instruction proceeded regardless of the correctness of the learner’s response or if the respondent ignored the question. All of the prompts and questions embedded in the instructional material appear in Appendix H. A sample screen of the three generative learning strategy prompts appears in Figure 3-2.
The Human Heart

**Direction:**
Highlight one or more sentences that you think important in this section.

*The Circulation of Blood Through the Heart*
A wave of muscular contraction starts at the top of the heart and passes downward, simultaneously, over both sides of the heart, that is, both atricles contract at the same time and then relax as the contraction passes down to the ventricles. When the atricles are caused to contract, they become small and close and as doing so the blood in their chambers is subjected to increased pressure which forces blood to the ventricles through the opened mitral and atrial valves.

As the ventricles fill, edges of the blood float the flaps on both the mitral and atrial valves back to a partially closed position.

**Direction:**
Summarize “the sequence of a wave of muscular contraction of the heart” in the following box.

---

The Human Heart

**Direction:**
Select the answer you feel best answers the question and mark the corresponding radio button

Q: A wave of muscular contraction of the heart starts in ______
   - [ ] The Right Atricle
   - [x] Both Atricles simultaneously
   - [ ] Both Venticles simultaneously
   - [ ] The Arteries

*incorrect!*

---

Figure 3-2. Sample screens of the generative learning strategy prompts
Treatment 3: Static Visualized Instruction with Generative Learning Strategy Prompts and Metacognitive Feedback

This treatment was the same as the second treatment (T2) except for metacognitive feedback in addition to knowledge of correct response feedback for the ten adjunct questions. For instance, if a participant selects an incorrect answer, the following feedback appears: “Incorrect! Now would be a good time to ask yourself if you have learned all the important information. If you haven’t, it would be a good idea to return to the previous pages to revise your highlighting or notes.” Figure 3-3 is a sample screen.

Figure 3-3. Sample screen of the generative learning strategy prompts with metacognitive feedback
Measurement Instruments

Prior Knowledge Test

The prior knowledge test of human physiology consists of 20 multiple-choice question items. Seventeen items test general knowledge about human physiology and three items test topic specific knowledge about the human heart. The original human physiology test, developed by Dwyer (1978) consisted of 36 multiple-choice questions (see Appendix C). The Cronbach’s alpha of all 36-item test scores was .42 (n=223). In order to improve the internal consistency of the test score, sixteen items including numbers 1, 2, 9, 10, 12, 14, 16, 17, 19, 24, 27, 29, 30, 32, 34 and 36 were deleted based on a careful review of corrected-item-total-correlation and scale-if-item-deleted. The Cronbach’s alpha of the remaining 20-item test scores improved to .55 (n=223) (see Appendix D).

Self-regulation Survey

The self-regulation survey was adapted from the Motivated Strategies for Learning Questionnaire (MSLQ) developed by Pintrich and his colleagues (Pintrich et al., 1991) which is a self-report instrument measuring “college students’ motivational orientations and their use of different learning strategies” (p. 3). The original MSLQ consists of 15 different constructs. This study selected two constructs including cognitive control and metacognitive control. The former measures four facets of college students’ cognitive strategy use: rehearsing, elaborating, organizing, and critical thinking and the
latter measures two facets of college students’ metacognitive strategy use: regulating and monitoring.

The original items were slightly revised reflecting the study context. The revised questions were the same as in the original, except “material” replaced the words “class” or “course.” An example of the survey items is:

If the contents of the material were difficult to understand, I changed the way I studied the material.

The survey consists of 25 items with a seven point Likert-type scale ranging from 1 (not at all true of me) to 7 (very true of me) (see Appendix E). The higher score means learners use more cognitive or metacognitive control while they are learning. Several studies have confirmed the validity of the original form of the MSLQ (Garcia & Pintrich, 1994; Pintrich et al., 1991; Pintrich et al., 1993). Classical reliability tests examined the internal consistency of the measures using Cronbach’s alpha and the corrected-item-total-correlation. The Cronbach’s alpha of the total questionnaire scores was .88 (n=223). The Cronbach’s alpha of the scores for cognitive control and metacognitive control were .82 and .74 respectively, with most of items indicating a modest positive item-total-correlation, above .3, suggesting these items measure the same theoretical constructs (Nunnally & Bernstein, 1994) (see Table 3-8).
Table 3.8. Self-regulation Survey Item Analysis

<table>
<thead>
<tr>
<th>Constructs</th>
<th>Number of items</th>
<th>Alpha</th>
<th>Item #</th>
<th>Corrected item-total correlation</th>
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<td>.504</td>
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</table>
The Quality of Learners’ Overt Use of Generative Learning Strategy

The quality of learners’ overt use of generative learning strategies is operationally defined as how well a learner attends to information by selectively highlighting sentences having the main idea and how well a learner summarizes or paraphrases relationships and meaning. To illustrate, each highlighted sentence and note taken by a learner were indicators of the quality of this instrument. An example page of the collected material appears in Figure 3-4.

The rubric for accessing the quality of learners’ overt use of generative learning strategies for this study followed the generic guidelines of developing rubrics suggested by Nitko and Brookhart (2007), and was further reviewed by an educational psychology...
professor for validation. This rubric, shown in Table 3-9, identifies four different levels of quality in the overt use of generative learning strategies and describes evidence indicating each level.

### Table 3-9. Rubric for Assessing the Quality of Learner’s Overt Use of Generative Learning Strategies

<table>
<thead>
<tr>
<th>Screen #</th>
<th>Main Idea</th>
<th>Type of Activity</th>
<th>Not Manipulated</th>
<th>Manipulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designated instructional material page</td>
<td>Highlighting</td>
<td>No highlighted sentence on the page</td>
<td>Highlighted all of the paragraph on the page</td>
<td>Selectively highlighted sentences not including main idea</td>
</tr>
<tr>
<td>Note taking</td>
<td>No note on the note field</td>
<td>Copied and pasted instructional scripts</td>
<td>Summarized or paraphrased understanding not including main idea</td>
<td>Summarized or paraphrased understanding including main idea</td>
</tr>
</tbody>
</table>

Verifying the reliability of the assessment scores, 32 PDF files that learners uploaded after they interacted with the material, including ten materials from Group 1, ten materials from Group 2, and 12 materials from Group 3, were randomly selected and evaluated. Examination of reliability occurred by calculating a generalizability coefficient based on the generalizability theory (Cronbach & Gleser, 1965; Cronbach et al., 1972). Frequently many studies report inter-rater reliability for this type of performance-based assessments, which use parallel test forms’ reliability based on classical reliability theory (e.g. Pearson’s r) (Nynally & Bernstein, 1994). However, performance-based
assessments involve multiple sources of errors which may operate in a measurement such as raters, criteria, or tasks. Thus, generalizability theory, which accounts for more sources of variation and provides more information of potential error variances of an observed score, is more appropriate for verifying the reliability of this rubric (De Gruijter & Van der Kamp, 2003).

The universe of admissible observations of this measurement is that learner’s overt use of generative learning strategy is assessed by two raters: the researcher and a doctoral student of education, based on two performance criteria—highlighting and note-taking. The object of measurement is the overt use of learner’s generative learning strategy. Thus, rater and performance criteria were the facets of the measurement, and two facets of fully crossed design was employed to perform the G-study, as represented by the Venn diagram in Figure 3-5. Then D-study determined a specific design, which appears as bold line in Figure 3-5, that was most appropriate for this study.

Figure 3-5. Venn diagram for the two-facet crossed $p$(person) x $r$(rater) x $c$(criteria) design relative model.
Table 3-10 reports the results of the generalizability study of the quality of learner’s overt use of generative learning strategy, including the estimated variance components and estimated generalizability coefficients for the design of persons (learner) crossed with raters and criteria.

<table>
<thead>
<tr>
<th>Source</th>
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</tbody>
</table>

Note. nr=number of raters, nc=number of criteria, N=32
Result was produced by GENOVA v3.1

The effects of the raters on measures of the quality of learner’s overt use of generative learning strategy were very different from the effect of the criteria. Raters appeared to be an insignificant source of variation. The variance components for the main effect for the rater, the interaction between persons and raters, and the interaction
between raters and criteria were all zero or near zero. These results indicate that the raters gave nearly identical scores to the learners and imply that a single rater was sufficient to assess the quality of learner’s overt use of generative learning strategy. Thus, a single rater, a doctoral student in education, conducted further assessment, and the Cronbach’s alpha of the assessed scores were .94 (n=223) for highlighting tasks and .96 (n=223) for note taking performance.

Recall Test

A posttest, adopted from the terminology test developed by Dwyer (1978), measured specific facts, terminology, and definitions (see Appendix F). Participants answered 20 multiple choice questions by selecting responses that best describe different parts of the heart. Each test item scored one point and the total test scored 20 points. A higher score means higher recall performance. A test item example is:

_______ is (are) the part(s) of the heart which control(s) its contraction and relaxation.

a. MYOCARDIUM  b. ENDOCARDIUM  c. VENTRICLES

d. AURICLES        e. SEPTUM

The test measures two subtypes: terminology and facts. Cronbach’s alpha and the corrected-item-total-correlation examined the internal consistency of the measure. The reliability coefficient for all 20-item scores was .84 (n=223). The Cronbach’s alpha for
terminology subtype scores was .74, and for fact subtype scores was .73. Most of the items indicated a modest positive item-total correlation, above .3, suggesting these items measure the same theoretical constructs (Nunnally & Bernstein, 1994) (see Table 3-11).

<table>
<thead>
<tr>
<th>Constructs</th>
<th>Number of items</th>
<th>Alpha</th>
<th>Item #</th>
<th>Corrected item-total correlation</th>
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</thead>
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<tr>
<td>Recall</td>
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<td>.84</td>
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<td></td>
<td>#20</td>
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Comprehension Test

Another posttest, adopted from the criterion test developed by Dwyer (1978), measured the participants’ comprehension of the human heart. The test consists of 20 multiple choice questions. This test measures understanding of complex procedures and/or interactive functions of each component (see Appendix F). A high score indicates that participants understand the heart, its components, its internal functioning, and the simultaneous processes that occur during the systolic and diastolic phases. The test measures the higher-level cognitive task of whether or not the participant understood what was being communicated—concepts—and could use it to explain some other phenomenon—relationships (Dwyer, 1978). Each test item was scored as one point and the total possible test score was 20 points. A higher score means higher performance in comprehension. A test item example is:

When the pressure in the right ventricle is superior to that in the pulmonary artery, in what position is the tricuspid valve?

a. Closed b. Open c. Beginning to close d. Confined by pressure from the right auricle

Cronbach’s alpha and the corrected-item-total-correlation were measures of the internal consistency. The Cronbach’s alpha for all 20-item scores was .85 (n=223). The Cronbach’s alpha for concept subtype scores was .75, and for the relationship subtype scores was .72. Most of items indicated a modest positive item-total correlation above .3 except item # 15. A careful review of this test item and its corresponding instruction
indicated that the instructions in the instructional material were not clear. Thus, the reliability coefficient of the instrument was re-examined with 19-item scores, excluding item #15. The reliability and item-total correlation for the relationship subtype scores slightly improved, suggesting the relationship subtype had internal consistency (see Table 3-12).

<table>
<thead>
<tr>
<th>Constructs</th>
<th>Number of items</th>
<th>Alpha</th>
<th>Item #</th>
<th>Corrected item-total correlation</th>
<th>Number of items</th>
<th>Alpha</th>
<th>Item #</th>
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Table 3-13 summarizes all of the latent and observed variables and their measurement description and reliability coefficients.

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<tr>
<td>Relationship</td>
<td></td>
<td>11 items</td>
<td>.75</td>
</tr>
</tbody>
</table>

Procedures

Prior to the Experiment

Visits to classrooms of the two general education courses resulted in recruited participants. During the visit, students received information about the study and a webpage address, where they could register and select a computer lab session convenient for
their schedules. Fifty-three of 150 students, or 35 percent, of the students in the IST course and 208 of 360 students, or 58 percent, of the students in the College of Education course registered. All students (n=261), who registered for a computer lab session received a random assignment to one of the three generative learning strategy treatment groups by advance use of a random number generator.

**During the Experiment**

Dividing the computer lab into three sections by rows (e.g. the first two rows for Group 1, the fourth and fifth rows for Group 2, and the sixth and seventh rows for Group 3), minimized the possibility of interference among the different groups. When the participants arrived at the computer lab, they first registered and then sat in their assigned sections. They received the first directional sheet, Study Procedure I (see Appendix G), which had information about their sequential activities for the first-half of the session and included an access code to the first-half tasks. Participants provided their consent by signing an informed consent document (see Appendix A) and then they began the session individually. First, the participants logged onto the research site, administered through the course management system of the university. They gained access using their university access IDs, and then took an online pretest. Second, the participants downloaded the instructional material from the research site to the computer that they were using. They first studied the tutorial about how to use the highlighting and note-taking tools in Adobe Acrobat Professional® software. After they finished studying the tutorial, they studied, in a self-paced manner, the instructional material with a given
generative learning strategy treatment. As soon as they completed studying the material, they saved and uploaded their instructional material to the drop box on the site. Then, they checked to determine if they had completed all above the tasks by marking the check list given in the Study Procedure I, and then they raised their hands as the study procedure instructed. The administrators of the sessions confirmed each participant’s completion of all the tasks, and then distributed the second directional sheet, Study Procedure II (see Appendix G), which included information regarding their tasks for the second-half of the session along with an access code for the second-half tasks. Third, the participants deleted the saved instructional material file and then completed the post-survey about self-regulation. Fourth, the participants took a recall test and then a comprehension test. In order to prevent potential interference from the criterion tests on learners’ perception of self-regulation, the self-regulation survey was administered prior to the post-tests. The number of participants for each experimental session was limited to less then 40 participants, a number that allowed the session administrators to prevent any disruptive behavior or collaboration between participants.

Data Analysis

The primary statistical analysis method was Structural Equation Modeling (SEM) to analyze: (1) the direct effects of generative learning strategy prompts and metacognitive feedback on learners’ self-regulation, generative learning strategy use, and learning after controlling for learners’ prior knowledge and; (2) the indirect effects of generative learning strategy prompts and metacognitive feedback on learning through
learners’ self-regulation and generative learning strategy use. The model analysis used LISREL® 8.8 with maximum likelihood estimation. Descriptive statistics, such as frequency distributions, means, and standard deviations were analyzed using SPSS® 15.0.

**Rationale for Using SEM**

The research questions in the current study attempt to explain how generative learning strategy prompts and metacognitive feedback affect learning by increasing learner’s self-regulation and improving generative learning strategy use. The Structural Equation Modeling (SEM) approach allows the study to examine mediating processes (Bagozzi & Yi, 1989; Kahn & Altmaier, 1998). That is, SEM analysis permits the testing of the processes underlying treatment influences. In this study, learners’ self-regulation and use of generative learning strategies are hypothesized to mediate the effects of the treatments on the learning outcomes. Obviously, the traditional approach has been successful in finding the effectiveness of interventions, but it was not successful for understanding the intervening psychological constructs that may influence how an intervention affects on learners’ achievement. Second, the traditional MANOVA/MANCOVA analysis assumes the dependent variables have no measurement error. Ignoring measurement error of the dependent variables increases the chances of making Type II errors. On the other hand, SEM, using latent variables, allows the estimation and correction of measurement error. For example, learners’ self-regulation, one of the latent variables of the study, was measured by cognitive and metacognitive control. This latent variable includes the measurement errors of cognitive control and
metacognitive control in estimation. As a result, latent variable SEM estimates the experimental intervention effects more accurately than traditional methods (Kahn & Altmaier, 1998). More detailed discussion appears in Chapter 5.

**Data Analysis Procedure**

Kline (2005) recommends five basic steps of SEM: (1) Model Specification; (2) Model Identification; (3) Data Preparation and Screening; (4) Estimation of the Model; and (5) Model re-specification, if necessary. Based on this basic procedure, the data analysis of the current study modified the five steps in order to analyze the experimental data: (1) Model Specification; (2) Model Identification; (3) Data Preparation and Screening; (4) Estimation of the Measurement Model and Structural Model; and (5) Model re-specification for One-Way MANCOVA with a Latent Variable Structural Model.

(1) **Model Specification**

An hypothesized model, consisting of a network of direct causal links among the variables, was hypothesized based on theory, and the literature (see Figure 2-2). To examine group differences on latent variables, a Multiple Indicators and Multiple Causes (MIMIC) model was specified based on generative learning theory and the relevant empirical research on self-regulation and prior knowledge. This SEM approach, where factors are regressed on one or more dichotomous cause indicators that represent group membership (i.e., coded 0 = control and 1 = treatment), allowed testing
for multiple group differences on latent variables (Kaplan, 2000). The MIMIC approach specified a preliminary structural equation model with three exogenous variables—two dummy variables for three levels of generative learning strategy treatments and prior knowledge and four endogenous variables—self-regulation, the quality of overt use of generative learning strategy, recall, and comprehension (see Figure 3-6).

Figure 3-6. Specified structural equation model of the study
The two causal indicators in the structural model of Figure 3-6 are two dichotomies using the *group code (dummy code)* approach (Aiken, Stein, & Bentler, 1994). One dummy variable, g1, coded as 1 = generative learning strategy prompts group (T2) and 0 = control group (T1) as well as generative learning strategy prompts with metacognitive feedback group (T3). This dummy variable represents the comparison of generative learning strategy prompts group (T2) with control group (T1). Another dummy variable, g2, coded 1 = generative learning strategy prompts with metacognitive feedback group (T3) and 0 = control group (T1) as well as generative learning strategy prompts group (T2). This dummy variable represents the comparison of generative learning strategy prompts with metacognitive feedback group (T3) and control group (T1). Table 3-14 shows this dummy code system.

<table>
<thead>
<tr>
<th>Group</th>
<th>Dummy 1 (g1)</th>
<th>Dummy 2 (g2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group (T1)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Generative Learning Strategy Prompts Group (T2)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Generative Learning Strategy Prompts with Metacognitive Feedback group (T3)</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

(2) **Model Identification:**

This step examined whether or not the model can theoretically identify a unique estimate of every model parameter. Two steps are necessary for model identification: measurement model identification (see Figure 3-7) and structural model identification (see Figure 3-6).
In order to test model identification of the measurement model (see Figure 3-7), $t$-rule and two-indicator rule were employed (Kline, 2005). The measurement model has 36 data points ($8 \times (8+1)/2 = 36$) for those 8 observed variables (e.g., rectangles). The number of parameters to be estimated includes four factor loadings (e.g., self-regulation $\rightarrow$ cognitive control), eight error terms (e.g., $E$), four variances (e.g., variances of latent variables), and six covariances (e.g., dashed, curved lines) among latent variables for a total of 22 parameter estimates. Thus this model was overidentified with 14 degrees of freedom.
freedom (36-22=14). In addition, the two-indicator rule was satisfied, because all factors have more than one indicator, and the model has more than one factor. Also, every latent variable has a scale.

In order to identify the structural equation model (see Figure 3-6), t-rule and rank condition were examined (Kline, 2005). The full model has 66 data points (11*(11+1)/2=66) for those 11 observed variables (e.g., rectangles). The number of parameters to be estimated includes 12 regression coefficients (e.g., generative learning strategy prompts → self-regulation), four factor loadings (e.g., self-regulation → cognitive control), eight error terms (e.g., E), seven variances (e.g., latent variables and exogenous variables), and nine covariances (e.g., dashed, curved lines) among exogenous variables and errors of dependent latent variables for a total of 40 parameter estimates. Thus this model is overidentified with 26 degrees of freedom (66-40=26).

The structural portion of the model (see Figure 3-8), looking only at the relationships among the variables, is also identified. This structural model has seven observed variables for 28 data points (7(7+1)/2=28). The number of parameters to be estimated includes 12 regression coefficients, seven variances, and nine covariances among exogenous variables and errors of dependent latent variables for a total of 27 parameter estimates. Thus, this model is also overidentified with one degree of freedom (28-27=1).

The structural portion of the model is nonrecursive, because it has all possible disturbance correlations. Thus, the rank condition which is a sufficient condition for nonrecursive models was checked to establish model identification (Kline, 2005). The rank of each endogenous variable’s system matrix was three which is equal to the total
number of endogenous variables minus one. Therefore, the model was identified and allowed estimation of all of the model parameters in subsequent analyses.

Figure 3-8. Structural portion of the full model

(3) Data Preparation and Screening

After collecting data, a one-way analysis of variance (ANOVA) indicated that no significant difference on all four dependent variables existed between the two courses allowing for combining the data from the IST course and the data from the College of Education course. Also, missing data, normality, outliers, and multicollinearity were
tested prior to the further analysis. Detail results of data preparation and screening appear in Chapter 4.

(4) Estimation of the Measurement Model and Structural Model

The measurement model (see Figure 3-7) includes four latent variables—self-regulation, overt use of generative learning strategies, recall, and comprehension—and eight observed variables—cognitive control, metacognitive control, highlighting, note taking, terminology, facts, concepts, and relationships. A Confirmatory Factor Analysis (CFA) analyzed the hypothesized measurement model based on its covariance matrix and used robust maximum likelihood estimation as implemented in LISREL® 8.8. Fixing one factor loading per latent variable equal to 1.0 sets the scale of each latent variable (Kline, 2005).

Model fit, determining how well a model as a whole explains the data, was evaluated on two levels: overall model fit assessment and component fit assessment. For overall model fit assessment, among numerous model fit indices being used, this study reported and examined the model chi-square, the Root Mean Square Error of Approximation (RMSEA) with its 90% confidence interval, the Comparative Fit Index (CFI), and the Standardized Root Mean Square Residual (SRMR), which are recommended by Kline (2005). Table 3-15 summarizes the recommended fit indices and their criteria.

Once overall model fit was satisfied, component fit examined parameter estimates regarding their signs, magnitudes, and significances. This study reported t-statistics, and absolute t-values greater than 1.96 indicated the parameter was significant at the .05 level
If the model does not successfully fit the data, model modification is possible, based on the theory and the modification indices, and is followed by evaluation of the revised model.

The initial structural equation model (see Figure 3-6) with three exogenous variables—two dummy variables for three levels of generative learning strategy treatments and prior knowledge and four endogenous variables—self-regulation, the quality of overt use of generative learning strategy, recall, and comprehension was evaluated based on the procedure described in the previous step.

(5) Model re-specification for One-Way MANCOVA with a Latent Variable Structural Model

This study employed a latent variable structural equation modeling approach to take into account multiple measures of constructs and possible causal orderings among constructs, which can not be accomplished with traditional MANCOVA design (Bagozzi & Yi, 1989), although a traditional MANCOVA design can test simultaneously the mean differences across two or more groups on two or more dependent variables controlling
the overall alpha level (Bray & Maxwell, 1985). This design analyzes the augmented moment matrix (see Appendix J) instead of usual correlation or covariance matrices (Jöreskog & Shörbom, 1984) to examine experimental effects properly by using a mean structure.

Figure 3-9 presents a model testing the case with four latent dependent variables, three groups, and one covariate, adopting Kühnel’s (1988) one-way MANOVA design applying the LISREL notation (Jöreskog & Shörbom, 1984). As shown in Figure 3-9, a pseudovariable, “CONST,” was added to the initial structural model. This pseudovariable is a constant added to the sample moment matrix as another variable having 1 in the diagonal and the means of all other variables as off-diagonal elements. This reparameterization enables analyzing the means of the observed dependent variables as a function of the categorical independent variables (Bagozzi & Yi, 1989). That is, the first set of regression coefficients, $\gamma_{11}^\ast, \gamma_{12}^\ast, \gamma_{13}^\ast$ and $\gamma_{14}^\ast$, are the differences in the means of dependent latent variables between the generative learning strategy prompts group and the control group, and, in the same way, the second set of regression coefficients, $\gamma_{21}^\ast, \gamma_{22}^\ast, \gamma_{23}^\ast$, and $\gamma_{24}^\ast$, are the difference in the means of dependent latent variables between the generative learning strategy prompts with metacognitive feedback group and the control group.
Thus, an examination of the paths from the dummy exogenous variables to the dependent latent variables enabled testing the multivariate null hypothesis of equality in means of the dependent variables across groups, which is analogous to the omnibus test commonly used in traditional MANCOVA analyses (e.g., the Pillai’s $\Lambda$ or Wilks’ $\Lambda$).
That is, if all regression coefficients from the dummy variables equal 0, then the null hypothesis, the means of dependent latent variables are equal across groups, is retained.

In order to test the null hypothesis of equal means across groups, a chi-square difference test between a full model and the other restricted model (i.e., $\gamma_{11}^* = \gamma_{12}^* = \gamma_{13}^* = 0$ and $\gamma_{14}^* = 0$ and $\gamma_{21}^* = \gamma_{22}^* = \gamma_{23}^* = 0$ and $\gamma_{24}^* = 0$) was conducted (Kaplan, 2000).
Chapter 4

RESULTS

The purpose of this study was to investigate whether using generative learning strategy prompts and metacognitive feedback in a computer-based learning environment facilitates learners’ recall and comprehension and whether learners’ self-regulation and the quality of their use of generative learning strategies mediate that facilitation.

This study investigated the following two research questions based on the proposed generative learning conceptual framework (see Figure 1-1):

- Do generative learning strategy prompts or generative learning strategy prompts with metacognitive feedback positively affect learners’ self-regulation (cognitive control and metacognitive control), the quality of overt use of generative learning strategies, or learning performance in recall and comprehension after controlling for learners’ prior domain knowledge over the control condition without generative learning strategy prompts or metacognitive feedback?

- Do generative learning strategy prompts or generative learning strategy prompts with metacognitive feedback indirectly affect learners’ learning performance in recall and comprehension through learners’ self-regulation (cognitive control and metacognitive control) and the quality of overt use of generative learning strategies?
Data Preparation and Screening

Data Preparation

Comparisons between the two courses allowed for combining the data from the IST course and the data from the College of Education course. One-way analysis of variance (ANOVA) indicated that no significant difference exists between the two different courses regarding prior knowledge test, $F(1, 221) = 3.501, p = .063$; self-regulation survey, $F(1, 221) = 1.311, p = .218$; the quality of overt use of generative learning strategies, $F(1, 221) = 2.190, p = .140$; recall test, $F(1, 221) = .000, p = .431$; comprehension test, $F(1, 221) = .021, p = .230$ (see Table 4-1).

<table>
<thead>
<tr>
<th>Measures</th>
<th>Course</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>df</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Knowledge Test</td>
<td>IST</td>
<td>46</td>
<td>11.065</td>
<td>.394</td>
<td>1</td>
<td>3.501</td>
<td>.063</td>
</tr>
<tr>
<td></td>
<td>COE</td>
<td>177</td>
<td>11.893</td>
<td>.201</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-Regulation Survey</td>
<td>IST</td>
<td>46</td>
<td>4.186</td>
<td>.119</td>
<td>1</td>
<td>1.311</td>
<td>.218</td>
</tr>
<tr>
<td></td>
<td>COE</td>
<td>177</td>
<td>4.033</td>
<td>.061</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Quality of Use of Strategies</td>
<td>IST</td>
<td>46</td>
<td>46.848</td>
<td>3.391</td>
<td>1</td>
<td>2.190</td>
<td>.140</td>
</tr>
<tr>
<td></td>
<td>COE</td>
<td>177</td>
<td>52.480</td>
<td>1.728</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall Test</td>
<td>IST</td>
<td>46</td>
<td>10.609</td>
<td>.705</td>
<td>1</td>
<td>.000</td>
<td>.431</td>
</tr>
<tr>
<td></td>
<td>COE</td>
<td>177</td>
<td>10.616</td>
<td>.359</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comprehension Test</td>
<td>IST</td>
<td>46</td>
<td>9.696</td>
<td>.726</td>
<td>1</td>
<td>.021</td>
<td>.230</td>
</tr>
<tr>
<td></td>
<td>COE</td>
<td>177</td>
<td>9.576</td>
<td>.370</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* IST: Information Sciences and Technology

COE: College of Education
Table 4-2 shows the means and standard deviations of the measures, combining the data from the IST course and the College of Education course, by treatment levels.

<table>
<thead>
<tr>
<th>Observed Variables (Label)</th>
<th>Control (N=75)</th>
<th>Generative Learning Strategy (GLS) Prompts (N=75)</th>
<th>GLS Prompts with Metacognitive Feedback (N=73)</th>
<th>Latent Variable Label</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Prior Knowledge</td>
<td>11.773</td>
<td>0.311</td>
<td>11.827</td>
<td>0.311</td>
</tr>
<tr>
<td>Self-Regulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cognitive Control (cog)</td>
<td>4.116</td>
<td>0.100</td>
<td>4.204</td>
<td>0.100</td>
</tr>
<tr>
<td>Metacognitive Control (meta)</td>
<td>3.707</td>
<td>0.097</td>
<td>3.863</td>
<td>0.097</td>
</tr>
<tr>
<td>The Quality of Overt Use of Generative Learning Strategy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note taking (note)</td>
<td>10.480</td>
<td>0.969</td>
<td>33.333</td>
<td>0.969</td>
</tr>
<tr>
<td>Recall</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terminology (termi)</td>
<td>4.427</td>
<td>0.311</td>
<td>4.627</td>
<td>0.311</td>
</tr>
<tr>
<td>Fact (fact)</td>
<td>5.373</td>
<td>0.290</td>
<td>5.973</td>
<td>0.290</td>
</tr>
<tr>
<td>Comprehension</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept (conc)</td>
<td>3.840</td>
<td>0.272</td>
<td>4.440</td>
<td>0.272</td>
</tr>
<tr>
<td>Relationship (relat)</td>
<td>4.547</td>
<td>0.326</td>
<td>5.173</td>
<td>0.326</td>
</tr>
</tbody>
</table>

A one-way analysis of variance (ANOVA) indicated that the three treatment groups were not significantly different from each other regarding their prior knowledge scores, \( F(2, 220) = 0.199; p = 0.820 \).
Data Screening

Means, standard deviations, skewness, and kurtosis of the composite score of each observed variable appear in Table 4-3.

Table 4-3. Descriptive Statistics of the Observed Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total Score</th>
<th>Mean</th>
<th>SD</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Knowledge</td>
<td>20</td>
<td>11.722</td>
<td>2.687</td>
<td>.210</td>
<td>-.392</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Self-Regulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cognitive Control</td>
<td>7</td>
<td>4.182</td>
<td>.867</td>
<td>-.266</td>
<td>-.099</td>
<td>1.73</td>
<td>6.13</td>
</tr>
<tr>
<td>Metacognitive Control</td>
<td>7</td>
<td>3.887</td>
<td>.852</td>
<td>.100</td>
<td>-.388</td>
<td>1.90</td>
<td>5.80</td>
</tr>
<tr>
<td>The Quality of Overt Use of Generative Learning Strategy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highlighting</td>
<td>45</td>
<td>24.955</td>
<td>12.384</td>
<td>-1.011</td>
<td>-.270</td>
<td>0</td>
<td>42</td>
</tr>
<tr>
<td>Note taking</td>
<td>42</td>
<td>26.363</td>
<td>14.106</td>
<td>-.954</td>
<td>-.563</td>
<td>0</td>
<td>42</td>
</tr>
<tr>
<td>Recall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terminology</td>
<td>10</td>
<td>4.623</td>
<td>2.690</td>
<td>.467</td>
<td>-.872</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Fact</td>
<td>10</td>
<td>5.991</td>
<td>2.556</td>
<td>-.075</td>
<td>-.898</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Comprehension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept</td>
<td>8</td>
<td>4.368</td>
<td>2.378</td>
<td>.140</td>
<td>-1.269</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Relationship</td>
<td>11</td>
<td>5.233</td>
<td>2.871</td>
<td>.401</td>
<td>-.914</td>
<td>0</td>
<td>11</td>
</tr>
</tbody>
</table>

Note. P-values are in parentheses.

Data screening examined outliers, normality, and multicollinearity. All observed variables range within three standard deviations from the mean of the variable, supporting that no univariate outlier exists. Mahalanobis Distances of all observed
variables are less than 26.125, which is the critical value of chi-square (df = 8) at the .001 level, providing evidence that no multivariate outliers exist (Kline, 2005).

Z-score test indicated univariate normality of note-taking, terminology, and relationship variables; whereas univariate normality of six other observed variables were not statistically significant. Thus, absolute values of the skew indices and kurtosis indices were examined. Absolute values of skewness of all variables are less than one, and absolute values of kurtosis of all variables are less than two. Because skew indices greater than 3.0 and kurtosis indices greater than 10 are considered problematic (Kline, 2005), this data does not severely violate the assumption of normality. Therefore, an alternative estimation method, robust maximum likelihood was used in the SEM analysis (Kline, 2005).

Third, the Pearson correlations among nine observed variables indicated that .742 is the highest bivariate correlation coefficient among pairs of the observed variables (See Appendix I). This result indicated that multicollinearity was not a concern in this study (Bivariate correlations among all observed variables < .85).

The data collected from 223 participants satisfied all three key examinations, thus, further analyses were conducted with this data.
Analysis of the Measurement Model

A Confirmatory Factor Analysis (CFA) analyzed the hypothesized measurement model based on its covariance matrix (see Appendix I) and used robust maximum likelihood estimation as implemented in LISREL® 8.8. Figure 4-1 shows the measurement model and its estimated parameters.


Figure 4-1. Model 1: Estimated parameters for the measurement model
Testing of the measurement model obtained an insignificant chi-square 
($\chi^2_{SB}=20.51; \ df=14; \ p=.11$), the RMSEA (.046) less than .06, the CFI (.99) greater than .95, and the SRMR (.026) less than .08 (see Table 4-4). Thus, the fit indices indicated an adequate fit of the measurement model. This test and the following tests used the Satorra-Bentler statistics (Satorra & Bentler, 1994) which adjust the maximum likelihood statistics based on the level of nonnormality.

<p>| Model Fit Indices of the Measurement Model |
|------------------|------------------|------------------|------------------|------------------|------------------|</p>
<table>
<thead>
<tr>
<th>$\chi^2_{NT}$ (P-value)</th>
<th>$\chi^2_{SB}$ (P-value)</th>
<th>$df$</th>
<th>CFI</th>
<th>RMSEA (90% CI)</th>
<th>SRMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Model</td>
<td>20.14 (.13)</td>
<td>20.51 (.11)</td>
<td>14</td>
<td>.99</td>
<td>.046 (.00 ; .086)</td>
</tr>
</tbody>
</table>

Note. $\chi^2_{NT}$: Normal Theory Weighted Least Squares Chi-Square  
$\chi^2_{SB}$: Satorra-Bentler Scaled Chi-Square

Standardized factor loadings of the observed variables and squared multiple correlations for each latent variable appear in Table 4-5. All path estimates of each observed variable to underlying latent variables were statistically significant ($p < .05$), thus all observed variables are significant indicators of this measurement model.
Analysis of the Initial Structural Equation Model

The first analysis evaluated the initial structural equation model including all paths from three exogenous variables—g1, g2, and prior knowledge as covariate—to four endogenous variables—self-regulation, the quality of overt use of generative learning strategies, recall, and comprehension. The results of the initial structural equation model analysis appear in Figure 4-2.
The test of the initial structural equation model obtained a significant chi-square ($\chi^2_{SB}=46.54; df=26; p=.01$), the CFI (.99) greater than .95, and the RMSEA (.06) and the SRMR (.029) equal to or less than .06 (see Table 4-6). The initial structural equation model yielded a good fit to the data except the significance of the chi-square. However,
chi-square test tends to increase the probability of rejecting null hypothesis with a large sample size. Thus, this initial structural equation model, overall, fits well with the data.

| Table 4-6. Model Fit Indices of the Initial Structural Equation Model |
|------------------------------|-------------|----------|------|-------------|-------------|
|                      | $\chi^2_{NT}$ | $\chi^2_{SB}$ | df | CFI | RMSEA (90% CI) | SRMR |
| Measurement Model | 45.58 (.01) | 46.54 (.008) | 26 | .99 | .06 (.030 ; .087) | .029 |

Note. $\chi^2_{NT}$: Normal Theory Weighted Least Squares Chi-Square | $\chi^2_{SB}$: Satorra-Bentler Scaled Chi-Square

Analysis of Hypotheses

Main Effects of Generative Learning Strategy Prompts and Generative Learning Strategy Prompts with Metacognitive Feedback

To answer the first research question, effects of treatments—generative learning strategy prompts and generative learning strategy prompts with metacognitive feedback—were tested after controlling for learner’s prior knowledge. As described in Chapter 3, a pseudovariable, CONST, was added to the initial structural model.

A chi-square difference test between a full model and the other restricted model which set the paths from the dummy exogenous variables to the dependent latent variables equal to 0 (i.e., $\gamma_{11}^* = \gamma_{12}^* = \gamma_{13}^* = \gamma_{14}^* = 0$ and $\gamma_{21}^* = \gamma_{22}^* = \gamma_{23}^* = \gamma_{24}^* = 0$) provides a test of omnibus MANCOVA (Kaplan, 2000). The reparameterized full model of this study appears in Figure 4-3.
The chi-square statistics of the full model, allowing for the difference in means as specified in Figure 4-3, and the restricted model, constraining the mean difference parameters to zero, appear in Table 4-7.
The Satorra-Bentler scaled chi-square difference test provided the following results: chi-square (8) = 164.00; \( p < .001 \), and this result suggested rejecting the null hypothesis of equal means. After rejecting the null hypothesis, a significant test of each regression coefficient linking the dummy variables to the dependent latent variables examined which group affected which criteria. This test is analogous to the univariate ANOVA on the dependent variables but holding other variables in the model constant. Thus, the regression coefficients from the dummy variables to the latent variables were inspected. Table 4-8 presents the unstandardized regression coefficient, standard error, and \( t \)-value of Model 3, structural model for one-way MANCOVA.

<table>
<thead>
<tr>
<th></th>
<th>( \chi^2_{NT} )</th>
<th>( p )-value</th>
<th>( \chi^2_{SB} )</th>
<th>( p )-value</th>
<th>( df )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Model</td>
<td>78.10</td>
<td>0.00</td>
<td>78.26</td>
<td>0.00</td>
<td>30</td>
</tr>
<tr>
<td>Restricted Model</td>
<td>220.77</td>
<td>0.00</td>
<td>227.36</td>
<td>0.00</td>
<td>38</td>
</tr>
</tbody>
</table>

Note. \( \chi^2_{NT} \): Normal Theory Weighted Least Squares Chi-Square  
\( \chi^2_{SB} \): Satorra-Bentler Scaled Chi-Square
Hypothesis Testing

Based on the analysis, evaluations of hypotheses are;

Hypothesis 1.1.1: Learners receiving generative learning strategy prompts will demonstrate significantly higher scores on a post-survey for self-regulation (cognitive control and metacognitive control) than learners who do not receive the prompts after controlling for learners’ prior knowledge.

The data did not support this hypothesis. The result revealed no statistically significant effect of generative learning strategy prompts on learners’ self-regulation, indicating that the path from Dummy 1 to self-regulation was not statistically significant with a path coefficient of .12 (S.E. = .14; t-value = .87). That is, there was not enough evidence to support the notion that learners who received generative learning strategy

Table 4-8. Path Coefficients, Standard Error, and t-value of Treatments

<table>
<thead>
<tr>
<th>Latent Variable</th>
<th>Dummy 1 (g1): Control vs. Generative Learning Strategy (GLS) Prompts Group</th>
<th>Dummy 2 (g2): Control vs. GLS Prompts with Metacognitive Feedback Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Path Coefficient</td>
<td>t-value</td>
</tr>
<tr>
<td>Self-Regulation</td>
<td>.12 (.14)</td>
<td>.87</td>
</tr>
<tr>
<td>The Quality of Overt Use of Generative Learning Strategy</td>
<td>20.69 (1.40)</td>
<td>14.83*</td>
</tr>
<tr>
<td>Recall</td>
<td>0.48 (.37)</td>
<td>1.31</td>
</tr>
<tr>
<td>Comprehension</td>
<td>0.66 (.38)</td>
<td>1.76</td>
</tr>
</tbody>
</table>

* Standard errors are in parenthesis
*p < .05

Note

Hypothesis Testing

Based on the analysis, evaluations of hypotheses are;

Hypothesis 1.1.1: Learners receiving generative learning strategy prompts will demonstrate significantly higher scores on a post-survey for self-regulation (cognitive control and metacognitive control) than learners who do not receive the prompts after controlling for learners’ prior knowledge.

The data did not support this hypothesis. The result revealed no statistically significant effect of generative learning strategy prompts on learners’ self-regulation, indicating that the path from Dummy 1 to self-regulation was not statistically significant with a path coefficient of .12 (S.E. = .14; t-value = .87). That is, there was not enough evidence to support the notion that learners who received generative learning strategy
prompts scored significantly higher than the control group learners on self-regulation survey.

Hypothesis 1.1.2: Learners receiving generative learning strategy prompts with metacognitive feedback will show significantly higher scores on a post-survey for self-regulation (cognitive control and metacognitive control) than learners who do not receive the prompts and feedback after controlling for learners’ prior knowledge.

The data supported this hypothesis. The result revealed a significant effect of generative learning strategy prompts with metacognitive feedback on learners’ self-regulation, indicating that the path from Dummy 2 to self-regulation was statistically significant with a path coefficient of .25 ($S.E. = .13; t$-value $= 1.97$). That is, the result supported the notion that learners who received generative learning strategy prompts with metacognitive feedback scored significantly higher than the control group learners on self-regulation survey.

Hypothesis 1.2.1: Learners receiving generative learning strategy prompts will demonstrate significantly higher scores on the quality of overt use of generative learning strategies than learners who do not receive the prompts after controlling for learners’ prior knowledge.

The data supported this hypothesis. The result revealed a significant effect of generative learning strategy prompts on the quality of learners’ use of the generative learning strategies, indicating that the path from Dummy 1 to the quality of overt use of generative learning strategy was statistically significant with a path coefficient of 20.69
Hypothesis 1.2.2: Learners receiving generative learning strategy prompts with metacognitive feedback will demonstrate significantly higher scores on the quality of overt use of generative learning strategies than learners who do not receive the prompts and feedback after controlling for learners’ prior knowledge.

The data supported this hypothesis. The result revealed a significant effect of generative learning strategy prompts with metacognitive feedback on learners’ use of the generative learning strategies, indicating that the path from Dummy 2 to the quality of overt use of generative learning strategy was statistically significant with a path coefficient of 23.15 ($S.E. = 1.35; t$-value $= 17.09$). That is, the result supported the notion that learners who received generative learning strategy prompts with metacognitive feedback scored significantly higher than the control group learners on the quality of overt use of generative learning strategies.

Hypothesis 1.3.1: Learners receiving generative learning strategy prompts will perform significantly better on a post-test for recall than learners who do not receive the prompts after controlling for learners’ prior knowledge.

The data did not support this hypothesis. The result revealed no statistically significant effect of generative learning strategy prompts on learners’ recall, indicating that the path from Dummy 1 to recall was not statistically significant with a path coefficient of 23.15 ($S.E. = 1.35; t$-value $= 17.09$). That is, the result supported the notion that learners who received generative learning strategy prompts with metacognitive feedback scored significantly higher than the control group learners on the quality of overt use of generative learning strategies.
coefficient .48 ($S.E. = .37; t$-value $= 1.31$). That is, there was not enough evidence to support the notion that learners who received generative learning strategy prompts performed significantly better than the control group learners on the recall test.

Hypothesis 1.3.2: Learners receiving generative learning strategy prompts with metacognitive feedback will perform significantly better on a post-test for recall than learners who do not receive the prompts and feedback after controlling for learners’ prior knowledge.

The data supported this hypothesis. The result revealed a significant effect of generative learning strategy prompts with metacognitive feedback on learners’ recall, indicating that the path from Dummy 2 to recall was statistically significant with a path coefficient 1.14 ($S.E. = .37; t$-value $= 3.03$). That is, the result supported the notion that learners who received generative learning strategy prompts with metacognitive feedback performed significantly better than the control group learners on the recall test.

Hypothesis 1.4.1: Learners receiving generative learning strategy prompts will perform significantly better on a post-test for comprehension than learners who do not receive the prompts after controlling for learners’ prior knowledge.

The data did not support this hypothesis. The result revealed no statistically significant effect of generative learning strategy prompts on learners’ comprehension, indicating that the path from Dummy 1 to comprehension was not statistically significant with a path coefficient .66 ($S.E. = .38; t$-value $= 1.76$). That is, there was not enough evidence to support the notion that learners who received generative learning strategy prompts performed significantly better than the control group learners on the comprehension test.
prompts performed significantly better than the control group learners on the comprehension test.

Hypothesis 1.4.2: Students receiving generative learning strategy prompts with metacognitive feedback will perform significantly better on a post-test for comprehension than learners who do not receive the prompts and feedback after controlling for learners’ prior knowledge.

The data supported this hypothesis. The result revealed a significant effect of generative learning strategy prompts with metacognitive feedback on learners’ comprehension, indicating that the path from Dummy 2 to comprehension was statistically significant with a path coefficient 1.42 (S.E. = .40; \( t \)-value = 3.52). That is, the result supported the notion that learners who received generative learning strategy prompts with metacognitive feedback performed significantly better than the control group learners on the comprehension test.

Indirect Effects of Generative Learning Strategy Prompts and Generative Learning Strategy Prompts with Metacognitive Feedback on Learners’ Performance in Recall and Comprehension through Learners’ Self-Regulation (Cognitive Control and Metacognitive Control) and Learners’ Overt Use of Generative Learning Strategies

The second research question examined whether or not variation in learners’ performance in recall and comprehension is due to a direct association with the treatments or to its dependence on learners’ self-regulation or overt use of generative learning strategies.
As described in the previous section, the first research question’s results rejected the null hypothesis of equal means of the dependent latent variables across the three groups. Also, five significant paths, linking treatments to four dependent variables including from the generative learning strategy prompts group to USE and from the generative learning strategy prompts with metacognitive feedback group to four dependent variables, were identified. Conversely, three paths, linking the generative learning strategy prompts group to self-regulation, recall, and comprehension, were not significant. Thus, these insignificant paths were removed and the modified structural model was estimated with only statistically significant paths, as recommended by Kline (2005) and Kaplan (2000). Also, the pseudovariable, CONST, was removed from the model, because the mean structure was not necessary to answer this second research question (see Figure 4-4). The modified model obtained a significant chi-square ($\chi^2_{SB}=49.79; df=29; p = .0095$), the CFI = .98; the RMSEA = .057, and the SRMR = .039. Even though, the chi-square was significant, other fit indices satisfied the criteria suggesting acceptable model fit.
According to this model, the group given the generative learning strategy prompts and metacognitive feedback differed from the control group on recall and comprehension.

To test whether or not these differences were affected directly by the treatment or indirectly as a result of a causal ordering among the dependent variables, three paths, linking self-regulation to learners’ use of generative learning strategies and learners’ use

Figure 4-4. Model 4: Structural model with significant paths


Note. all disturbances of latent variables—SR, USE, REC, and COM—are correlated
of generative learning strategies to recall and comprehension, replaced error covariances between them, as hypothesized (see Figure 4-5).


Note. the disturbances between SR and REC, SR and COM, and REC and COM are correlated

Figure 4-5. Model 5: Structural equation model with hypothesized causal paths

To test the mediation effect of learner’s use of generative learning strategies, the scaled chi-square difference, comparing model 5 that includes direct effects of generative learning strategy prompts with metacognitive feedback (g2) on recall and comprehension
to the first restricted model that does not include these direct paths (i.e., \( \gamma_{23}^* = \gamma_{24}^* = 0 \)), was tested. Also, to test the mediation effect of self-regulation, the scaled chi-square difference, comparing the first restricted model that included direct effects of generative learning strategy prompts with metacognitive feedback (\( g2 \)) on learners’ use of generative learning strategies to the second restricted model that did not include this direct path (i.e., \( \gamma_{22}^* = 0 \)), was tested. The chi-square statistics of these three models appear in Table 4-9.

<table>
<thead>
<tr>
<th>Model Description</th>
<th>( \chi^2_{NT} )</th>
<th>( p )-value</th>
<th>( \chi^2_{SB} )</th>
<th>( p )-value</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Model (Model 5)</td>
<td>63.78</td>
<td>0.000</td>
<td>64.68</td>
<td>0.00</td>
<td>29</td>
</tr>
<tr>
<td>The First Restricted Model with ( \gamma_{23}^* = \gamma_{24}^* = 0 )</td>
<td>64.84</td>
<td>0.000</td>
<td>65.56</td>
<td>0.00</td>
<td>31</td>
</tr>
<tr>
<td>The Second Restricted Model with ( \gamma_{22}^* = \gamma_{23}^* = \gamma_{24}^* = 0 )</td>
<td>182.03</td>
<td>0.000</td>
<td>189.35</td>
<td>0.000</td>
<td>32</td>
</tr>
</tbody>
</table>

Note. \( \chi^2_{NT} \): Normal Theory Weighted Least Squares Chi-Square  
\( \chi^2_{SB} \): Satorra-Bentler Scaled Chi-Square

The Satorra-Bentler scaled chi-square difference test between the full model and the first restricted model provided the following results: chi-square (2) = 1.02, \( p > .05 \), and this result supported that direct effects of generative learning strategy prompts with metacognitive feedback on recall and comprehension were not necessary. That is, the improvement of learners who received generative learning strategy prompts with metacognitive feedback over the control group learners on recall and comprehension can
be explained with the improvement of the quality of their overt use of generative learning strategies, supporting the mediation effect of learners’ use of generative learning strategies. However, the Satorra-Bentler scaled chi-square difference test between the first restricted model and the second restricted model provided the following results: chi-square (1) = 1134.9, \( p < .01 \), and this result suggested rejecting the null hypothesis of non-direct effects of generative learning strategy prompts with metacognitive feedback on learners’ use of generative learning strategies. That is, there is not enough evidence to ignore the direct effect of generative learning strategy prompts with metacognitive feedback on learners’ use of generative learning strategies, even though there is the indirect effect of generative learning strategy prompts with metacognitive feedback on learners’ use of generative learning strategies through learners’ self-regulation. Based on this result, the final structural equation model appears in Figure 4-6.
The final model obtained a significant chi-square ($\chi^2_{SB}=65.56; df=31; p < .001$), the CFI = .97; the RMSEA = .071 (90% CI: .047 - .095), and the SRMR = .043. Even though, the chi-square was significant and RMSEA is slightly greater than the criteria (.06), other fit indices satisfied the criteria, suggesting acceptable model fit.


Note. the disturbances between SR and REC, SR and COM, and REC and COM are correlated

Figure 4-6. Model 6: Final structural equation model
To answer the research questions regarding the individual effect of treatments on the dependent variables, the standardized direct, indirect, and total effects implied by the model appear in Table 4-10.

<table>
<thead>
<tr>
<th>Table 4-10. Standardized Causal Effects of the Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effects</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>GLS Prompts</td>
</tr>
<tr>
<td>Direct</td>
</tr>
<tr>
<td>Indirect</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>GLS Prompts with Metacognitive Feedback</td>
</tr>
<tr>
<td>Direct</td>
</tr>
<tr>
<td>Indirect</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Prior Knowledge</td>
</tr>
<tr>
<td>Direct</td>
</tr>
<tr>
<td>Indirect</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Self-Regulation</td>
</tr>
<tr>
<td>Direct</td>
</tr>
<tr>
<td>Indirect</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>The quality of Overt Use of GLS</td>
</tr>
<tr>
<td>Direct</td>
</tr>
<tr>
<td>Indirect</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

*Note. GLS: Generative Learning Strategy; R² from structural equations; *: p < .05

Hypothesis Testing

Based on the analysis, evaluations of the hypotheses are;
Hypothesis 2.1: Generative learning strategy prompts will have significant, indirect, positive effects on performance in recall and comprehension through the quality of overt use of generative learning strategies.

The data supported this hypothesis. Generative learning strategy prompts had a significant, positive, direct effect on the quality of overt use of generative learning strategies with a path coefficient of .79. Also, the quality of overt use of generative learning strategies had significant, positive effects on recall and comprehension with path coefficients of .29 and .33 respectively. Thus, generative learning strategy prompts had significant, indirect effects on recall and comprehension through the quality of overt use of generative learning strategies (Standardized indirect effect = .23 on recall, and =.26 on comprehension).

Hypothesis 2.2: Generative learning strategy prompts with metacognitive feedback will have significant, indirect, positive effects on performance in recall and comprehension through the quality of overt use of generative learning strategies.

The data supported this hypothesis. Generative learning strategy prompts with metacognitive feedback had a significant, positive, direct effect on the quality of overt use of generative learning strategies with a path coefficient of .86. Also, the quality of overt use of generative learning strategies had significant, positive effects on recall and comprehension with path coefficients of .29 and .33 respectively. Thus, generative learning strategy prompts with metacognitive feedback had significant, indirect effects on recall and comprehension through the quality of overt use of generative learning strategies (Standardized indirect effect = .26 on recall, and =.29 on comprehension).
Hypothesis 2.3: Learners’ self-regulation (cognitive control and metacognitive control) will have significant, indirect, positive effects on performance in recall and comprehension through the quality of overt use of generative learning strategies.

The data supported this hypothesis. Self-regulation had a significant, positive, direct effect on the quality of overt use of generative learning strategies with a path coefficient of .22. Also, the quality of overt use of generative learning strategies had significant, positive effects on recall and comprehension with path coefficients of .29 and .33 respectively. Thus, self-regulation had significant, indirect effects on recall and comprehension through the quality of overt use of generative learning strategies. (Indirect effect = .07 on recall, and = .07 on comprehension)
Summary of the Results

The results of the tested hypotheses based on the specified model and estimated parameters are summarized in Table 4-11.

<table>
<thead>
<tr>
<th>Hypotheses</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1.1. Learners receiving <em>generative learning strategy prompts</em> will demonstrate significantly higher scores on a post-survey for <em>self-regulation</em> (cognitive control and metacognitive control) than learners who do not receive the prompts after controlling for learners prior knowledge.</td>
<td>Non-significant</td>
</tr>
<tr>
<td>1.1.2. Learners receiving <em>generative learning strategy prompts with metacognitive feedback</em> will show significantly higher scores on a post-survey for <em>self-regulation</em> (cognitive control and metacognitive control) than learners who do not receive the prompts and feedback after controlling for learners prior knowledge.</td>
<td>Significant, Positive</td>
</tr>
<tr>
<td>1.2.1. Learners receiving <em>generative learning strategy prompts</em> will demonstrate significantly higher scores on the quality of overt use of generative learning strategies than learners who do not receive the prompts after controlling for learners prior knowledge.</td>
<td>Significant, Positive</td>
</tr>
<tr>
<td>1.2.2. Learners receiving <em>generative learning strategy prompts with metacognitive feedback</em> will demonstrate significantly higher scores on the quality of overt use of generative learning strategies than learners who do not receive the prompts and feedback after controlling for learners prior knowledge.</td>
<td>Significant, Positive</td>
</tr>
<tr>
<td>1.3.1. Learners receiving <em>generative learning strategy prompts</em> will perform significantly better on a post-test for <em>recall</em> than learners who do not receive the prompts.</td>
<td>Non-significant</td>
</tr>
<tr>
<td>1.3.2. Learners receiving <em>generative learning strategy prompts with metacognitive feedback</em> will perform significantly better on a post-test for <em>recall</em> than learners who do not receive the prompts and feedback after controlling for learners prior knowledge.</td>
<td>Significant, Positive</td>
</tr>
<tr>
<td>Hypotheses</td>
<td>Results</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>1.4.1. Learners receiving <em>generative learning strategy prompts</em> will perform significantly better on a post-test for <em>comprehension</em> than learners who do not receive the prompts after controlling for learners prior knowledge.</td>
<td>Non-significant</td>
</tr>
<tr>
<td>1.4.2. Students receiving <em>generative learning strategy prompts with metacognitive feedback</em> will perform significantly better on a post-test for <em>comprehension</em> than learners who do not receive the prompts and feedback after controlling for learners prior knowledge.</td>
<td>Significant, Positive</td>
</tr>
<tr>
<td>2.1. <em>Generative learning strategy prompts</em> will have significant, indirect, positive effects on performance in recall and comprehension through <em>the quality of overt use of generative learning strategies</em>.</td>
<td>Significant, Positive</td>
</tr>
<tr>
<td>2.2. <em>Generative learning strategy prompts with metacognitive feedback</em> will have significant, indirect, positive effects on performance in recall and comprehension through <em>the quality of overt use of generative learning strategies</em>.</td>
<td>Significant, Positive</td>
</tr>
<tr>
<td>2.3. <em>Learners’ self-regulation</em> (cognitive control and metacognitive control) will have significant, indirect, positive effects on performance in recall and comprehension through <em>the quality of overt use of generative learning strategies</em>.</td>
<td>Significant, Positive</td>
</tr>
</tbody>
</table>
Chapter 5

DISCUSSION

The purpose of this study was to investigate whether using generative learning strategy prompts and metacognitive feedback in a computer-based learning environment facilitates learners’ recall and comprehension and whether learners’ self-regulation and the quality of their use of generative learning strategies mediate that facilitation.

Thus, the current study developed the instructional interventions, including generative learning strategy prompts and metacognitive feedback, to enhance learning by prompting learners to regulate, monitor, and refine their learning strategy use and affect the quality of generative learning strategy use. A total of 223 college students in a 2008 spring semester participated in examinations of the instructional interventions, and Structural Equation Modeling (SEM) allowed investigating both the direct effects of generative learning strategy prompts and metacognitive feedback on learning and their indirect effects through learners’ self-regulation and generative learning strategy use.

The study found that generative learning strategy prompts positively affect learners’ overt use of generative learning strategies but neither their self-regulation nor learning performance. On the other hand, generative learning strategy prompts with metacognitive feedback positively affected learners’ self-regulation, overt use of generative learning strategies, and recall and comprehension. This result supported the notion that generative learning strategy prompts was not enough to improve learners’
learning, and adding metacognitive feedback to generative learning strategy prompts improved learners’ self-regulation as well as their learning.

This study also found that learners’ use of generative learning strategies mediated the effect of generative learning strategy prompts and metacognitive feedback on learners’ recall and comprehension, and learners’ self-regulation partially mediated the effect of generative learning strategy prompts with metacognitive feedback on their use of generative learning strategies. This result supported the existence of mediation processes of self-regulation and the use of generative learning strategies.

The following discussion of the current study’s results is in three parts. First, the findings and implications for instructional design are discussed. The second part discusses how Structural Equation Modeling (SEM) can be employed as a statistical method for analyzing experimental studies and its implications for educational research practice. The final section concludes this discussion with suggestions for further research.

**Discussion of the Findings**

**Discussion of Generative Learning**

The generative learning conceptual framework, as proposed in Figure 1-1, suggests that learners’ generative activities help them create relationships among or between new information and their prior knowledge. This process results in the acquisition of new knowledge that is necessary for subsequent knowledge generation. Also, learners’ self-regulation guides their generative activities. However, learners are
not always successful controlling their learning processes, and accordingly they may need more support (Barab, Young, & Wang, 1999; Hmelo-Silver & Azevedo, 2006; Land, 2000). Thus, this study employed generative learning strategy prompts and metacognitive feedback to enhance learners ability to regulate, monitor, and refine their strategy use, and in turn, improve their use of generative learning strategies. A revised generative learning conceptual framework as shown in Figure 5-1 is supported by the results of this study. The following sections discuss the relationships shown based on these results.

![Revised generative learning conceptual framework](image)

Figure 5-1. Revised generative learning conceptual framework

**Effects of Generative Learning Strategy Prompts and Metacognitive Feedback**

**Self-Regulation and Generative Activity**
The results of this study found that generative learning strategy prompts with metacognitive feedback significantly increased learners’ self-regulation while they were studying, but generative learning strategy prompts without metacognitive feedback did not. The prediction was that learners who received generative learning strategy prompts would also use more cognitive strategies and control metacognition than the learners who received only generative learning strategy tools. Even though the learners who received generative learning strategy prompts showed higher scores on the self-regulation survey than the learners who received only generative learning strategy tools, the data failed to show a statistically significant difference between the two groups.

This result was not consistent with the theories found in the literature reviewed in this study, but cognitive development theory may explain this result. According to cognitive development theory, college students are different from elementary students regarding their cognitive development. College students have better capabilities for self-regulation than younger students. The older students have an already established way of using cognitive strategies based on prior experiences (Hofer, Yu, & Pintrich, 1998; Wigfield, Eccles, & Pintrich, 1996). Thus, in this study, the learners who were in the control group might have some degree of self-regulation ability already to regulate their own learning without any prompts. Consequently, the difference between the two groups (control group vs. generative learning strategy prompts group) might be minimal.

However, adding metacognitive feedback to generative learning strategy prompts did increase learners’ cognitive and metacognitive self-regulation over the control group. Metacognitive feedback reminded learners to monitor and refine their cognitive strategy use after they answer a question. This short reminder may encourage learners to take
control over their learning by reconsidering what they have learned. In a post survey, learners who were given generative learning strategy prompts with metacognitive feedback agreed significantly more (M = 4.97 of 7) than the learners who were only given generative learning strategy prompts (M=4.067 of 7) that they reviewed previous pages. That is, the learners who received metacognitive feedback tended to go back and refine their understanding more. This result is encouraging in that college students’ self-regulation can possibly be improved by combining strategy prompts with metacognitive feedback.

The results of this study found that both generative learning strategy prompts and generative learning strategy prompts with metacognitive feedback significantly improved the quality of learners’ generative learning strategy use over the control group. The quality of overt use of generative learning strategies measured how well a learner attended to important information by examining the learner’s highlighted sentences to determine how selective they were and whether they highlighted the main idea. Their notes were also examined for evidence suggesting they generated their own understanding by summarizing or paraphrasing relationships and meaning. The results were consistent with the prediction.

Interestingly, the two treatments were equally effective in improving the quality of learners’ generative learning strategy use, even though the generative learning strategy prompts alone were not effective in improving learners’ self-regulation. This result can be explained by the two post survey items which asked whether or not learners changed their highlighting or revised their notes after they responded to the adjunct questions. Those two groups were not significantly different in terms of whether or not they revised
their highlighted sentences ($M_{T2}=2.20; M_{T3}=2.29; F=.114; p=.736$) and whether or not they revised their notes taken ($M_{T2}=2.71; M_{T3}=2.96; F=.648; p=.422$). That is, learners were not more likely to revise their notes or what they had already highlighted.

This result provides a significant explanation for the above two results regarding self-regulation and the quality of overt use of generative learning strategies.

Metacognitive feedback enhanced learners monitoring and refinement of their learning more in covert way, thus the learners who were given generative learning strategy prompts with metacognitive feedback group achieved higher scores on their self-regulation survey. But these cognitive processes were not necessarily represented as overt behavior—the quality of overt use of generative learning strategies.

Recall and Comprehension

The results of this study found that learners who received generative learning strategy prompts with metacognitive feedback performed better in recall and comprehension over the control group. However, learners who received generative learning strategy prompts alone did not perform better in recall and comprehension over the control group.

Interestingly, previous research has shown the effectiveness of generative learning strategy prompts (Barnett, DiVesta, & Rogonzenski, 1981; Davis & Hult, 1997; King, 1992). However, those studies provided prompts in paper-based activities to improve learners’ recall and comprehension. More recent studies emphasize the role of learners’ regulatory processes in computer-based learning environments (Azevedo & Cromley,
2004; Kramarski & Mevarech, 2003). Therefore, simple prompting may not be enough
instructional help for learners in computer-based learning environments, because learners
need to monitor, be aware of, and adjust their learning processes according to how well
they are learning in computer-based learning environments. Thus, metacognitive
feedback is one possible strategy to remind learners to regulate their learning and
enhance the function of the generative learning strategy prompts to improve learners’
achievement.

Mediating Processes

The results of this study found that generative learning strategy prompts with
metacognitive feedback improved learners’ achievement in recall and comprehension by
enhancing learners’ self-regulation and the use of generative learning strategies, as
predicted.

Many previous studies found that learners’ self-regulating skills related to
academic achievement (Azevedo & Cromley, 2004; Kramarski & Gutman, 2006; Pintrich
& De Groot, 1990; Zimmerman, 1998b; Zimmerman & Schunk, 2001). However, little
research attempted to identify mediation effects of learners’ self-regulatory processes and
their actual use of learning strategies. The results of this current study supported the
mediation effects of learners’ use of generative learning strategies on recall and
comprehension and of learners’ self-regulation on their use of generative learning
strategies. Generative learning strategy prompts with metacognitive feedback enhanced
learners’ recall and comprehension by improving their learning strategy use in combination with increased learners’ self-regulation. This is the most important finding of this study. That is, learners who were given generative learning strategy prompts and metacognitive feedback used more cognitive and metacognitive control, used generative learning strategies better, and accordingly performed better in recall and comprehension. It is implied that learners’ covert self-regulation refines the learning outcomes from their overt use of learning strategies, and this refinement positively affects learning. Therefore, instructional strategies should take into account learners’ overt use of strategies and learners’ covert self-regulation.

**Implications for Instructional Design**

Implications from the results of this study for instructional design of computer-based learning environment are:

**Mediators in Learning**

Students’ learning processes involve various cognitive as well as behavioral processes in technology-enriched learning environments. Accordingly, instructional designers should identify the intermediate processes between instruction and learning, which mediate the effect of instructional interventions on learning. Learners’ learning can be enhanced effectively by dealing with the mediators. For example, this study identified learners’ self-regulation and use of generative learning strategies as mediating processes,
and provided instructional interventions—generative learning strategy prompts and metacognitive feedback—that attempted to improve those identified mediating processes. As the results revealed, the generative learning strategy prompts with metacognitive feedback improved learners’ self-regulation as well as the quality of learners’ overt use of generative learning strategies and accordingly improved learners’ learning performance.

Therefore, in computer-based learning environments, instructional designers need to employ strategies that can facilitate learners’ regulation, monitoring, and refinement of their use of learning strategies. Also, usually many instructional materials presented via computer screens may inhibit learners’ use of generative learning strategies. Current technologies allow incorporating generative learning strategies such as highlighting and summarizing. Thus, instructional designers or instructors need to design computer-based learning environments that help learners regulate and monitor their learning processes and allow learners using generative learning strategies in better way.

**Generative Learning Strategy Prompts and Metacognitive Feedback**

The current study showed that generative learning strategy prompts alone may not be sufficient to facilitate learners’ self-regulatory processes and improve their learning performance. This study suggests supporting and guiding learners’ metacognitive control in order to remind learners to self-regulate in order to affect learning.

Thus, instructional designers or instructors should include metacognitive supports which remind learners to evaluate the adequacy of their cognitive strategy use and correct the execution of the learning strategies. Learners are assumed to be active participants in
the learning processes and they have the potential to monitor, control and regulate their own cognition. However, this does not mean learners will accomplish this regulatory process in all contexts or at all times. Therefore, supporting and guiding learners’ metacognitive control is necessary, and this support should allow students to monitor, to be aware of, and to adjust their learning activities recursively.

Discussion of the Research Methods

Learners’ Overt Use of Strategies

This study gathered and analyzed overt evidence of generative learning from learners’ highlighting and note-taking products. This method allowed researchers to examine how learners actually interacted with the instructional interventions. Currently many studies analyze log files to track learners’ activities while they are studying, but those logs do not necessarily reveal learners’ actual interaction.

Furthermore, this study developed a rubric for assessing the quality of learner’s overt use of generative learning strategies and applied generalizability theory in order to verify the reliability. Frequently many studies report inter-rater reliability for this type of performance-based assessments, which use parallel test forms’ reliability based on classical reliability theory (e.g. Pearson’s r) (Nynnally & Bernstein, 1994). However, performance-based assessments involve multiple sources of errors which may operate in a measure such as raters, criteria, or tasks. Thus, generalizability theory, which accounts for more sources of variation and provides more information of potential error variances
of an observed score, is more appropriate for verifying the reliability of this type of rubric (De Gruijter & Van der Kamp, 2003).

**Structural Equation Modeling**

This study employed a comprehensive statistical analysis, Structural Equation Modeling (SEM), which is a methodology combining factor analysis and path analysis (Bollen, 1989; Kline, 2005; Russell, Kahn, & Altmaier, 1998). This SEM approach was used to accomplish the main purpose of this study, examining how generative learning strategy prompts and metacognitive feedback affect learning through an examination of the indirect effect of learners’ self-regulation and improving generative learning strategy use.

Even though educational studies have used this SEM approach extensively, the majority of the studies used this method for analyzing non-experimental survey data. Marketing and biomedical research have been using this method for analyzing experimental data for more than a decade (Bagozzi & Yi, 1989; Kahn & Altmaier, 1998; Kühnel, 1988; Russell, Kahn, & Altmaier, 1998), and developed a model specification to analyze experimental data. This study adopted the model specification which is analogous to traditional MANCOVA analysis.

The advantages of using SEM with experimental data over traditional MANOVA/MANCOVA analyses are: 1) estimating and removing both random and correlated measurement errors, and 2) examining mediating processes (Bagozzi & Yi, 1989; Kahn & Altmaier, 1998). First, the traditional MANOVA/MANCOVA analysis
assumes the dependent variables have no measurement errors. Ignoring measurement errors of dependent variables increases the chances of making Type II errors. On the other hand, SEM using latent variables allows estimation and corrects the measurement errors. As a result, the latent variable SEM approach estimates the experimental intervention effects more accurately than traditional methods (Kahn & Altmaier, 1998).

Second, as this study formulated, SEM can test factors that hypothesize mediation of the effects of treatments on the dependent variables. This allows uncovering underlying processes of treatment influences. Obviously, the traditional approach has been successful in finding the effectiveness of interventions, but it was not successful for understanding how the interventions are effective. Analyses of the processes underlying a treatment may allow researchers to design more effective instructional treatments by refining the treatments to focus on processes that are positively related to the treatment outcome (Kahn & Altmaier, 1998).

However, two important issues remain to be considered before applying this alternative procedure. First, a path analysis in SEM involves the estimation of causal relations among variables with correlational data. However, correlation does not imply causation, thereby not enabling statistical causal modeling to prove causation either. Inferring causation from correlation requires a solid theoretical base and careful specification of variables and predictive directions. For example, this study hypothesized that learners’ self-regulation would cause learners’ improved overt use of generative learning strategies with theoretical basis, and the final model (see Figure 4-6) supported this hypothesis. However, an alternative hypothesis which predicts effects from the opposite direction (i.e., from learners’ overt use of generative learning strategies to
learners’ self-regulation) is possible as an equivalent model. This alternative model obtained worse model fit indices ($\chi^2_{SB}=72.06; df=31; p=.000; CFI = .97; \text{RMSEA} = .077$; and SRMR = .043) than the final model. Thus, the direction from learners’ self-regulation to learners’ overt use of generative learning strategies was supported by the model, but caution is still advised that SEM itself can not prove any causal relationships.

Second, an SEM analysis with latent variables needs more than 200 cases to produce accurate estimates (Kline, 2005). Also the number of parameters being estimated should be considered along with the sample size. Bentler and Chou (1988) suggested that the ratio of participants to parameters should be at least 5:1 and 10:1 for appropriate estimation. Obtaining the appropriate number of research participants can often be challenging for educational researcher.

**Implications for Research Practice**

The major goal of instructional systems or educational technology is designing learning environments, providing instructional interventions to help learners learn meaningfully. Accordingly, examining the effectiveness of the instructional interventions has been a prime concern of research (Koetting & Malisa, 2004). Conventionally, research studies have used statistical techniques to test mean differences between groups such as t-test, analysis of variance (ANOVA) and analysis of covariance (ANCOVA) to determine the effects of interventions. However, as current technology-enriched learning environments and theoretical constructs involved in instructional design and development
become more sophisticated and more complex, a need arises for equally sophisticated analytic methods to research these environments, theories, and models.

Cognitive functioning and processes related to learning are intricate and human learning involves various psychological constructs. Theoretical advances for understanding human cognition and learning processes require considering more psychological constructs when designing learning environments. In addition, with technological advances, educators infuse more technologies into learning environments, but the effectiveness of these innovations are not simply explained by testing mean differences, since these interventions could relate to underlying mediating processes that may be responsible for the desired outcomes.

Therefore, researchers in the field of instructional systems and educational technology are encouraged to assess learners’ actual interaction with instructional interventions in technology-enriched environments. Current technologies permit developing user-centered web instruction that allows users to manipulate web pages and record all activities that learners have done while they were interacting with the web pages, such as times of visits and revision of notes taken. In this way, future investigation may reveal how learners interact with instructional interventions and how these interactions affect their learning.

Also, incorporating structural equation modeling for the analyses of experimental investigation is recommended because this method informs instructional designers about direct and indirect effects of instructional interventions and intervening psychological constructs affecting learning rather than just focusing on the direct effects. Accordingly
this method enables instructional designers to identify problems in the mechanism of
treatment effects and fix those problems more appropriately.

Further Research

The current study investigated whether using generative learning strategy prompts
and metacognitive feedback in a computer-based learning environment facilitates
learners’ recall and comprehension and whether learners’ self-regulation and the quality
of their use of generative learning strategies mediate that facilitation. The results
suggested that generative learning strategy prompts with metacognitive feedback
enhanced learning through increasing learners’ self-regulation and improving learners’
use of generative learning strategies. Based on the procedures and results of the current
study, further research is suggested.

Adaptive Metacognitive Feedback

The current study found a significant effect from generative learning strategy
prompts with metacognitive feedback that was generic and single format that reminded
learners to monitor and regulate learning. Learners, however, have different levels of
self-regulatory skills and prior domain knowledge, thus, perhaps an even more effective
technique may involve support with adaptive metacognitive feedback (Aleven et al.,
2006). Therefore, a worthwhile future investigation would test an adaptive metacognitive
feedback system and its effects on learners’ cognitive and metacognitive processes, and,
accordingly, on learners’ knowledge generation processes and outcomes. Moreover, Structural Equation Modeling is strongly recommended for analyzing results of such system, because it allows identifying underlying mediating processes, diagnosing individual or situational conditions, and testing the effects of the various adaptive metacognitive feedback.

**Observational Learning as an Instructional Strategy**

This study found that learners’ use of generative learning strategies positively affect recall and comprehension. Thus, developing a strategy to facilitate improvement of learners’ use of generative learning strategies is meaningful. As mentioned in Chapter 3, to minimize the possibility of interference between different treatment groups, the computer lab for the experiment was divided into three sections (e.g. the first two rows for Group 1, the fourth and fifth rows for Group 2, and the sixth and seventh rows for Group 3). This formation was successful in preventing the control group participants from seeing the other two treatment groups’ computer screens. However, it failed to eliminate sounds from typing on keyboards of other groups. Even though the participants in the control group were not able to see the computer screens of the other two treatment groups, they could listen to the sounds from typing. Some participants began note taking after hearing the sound of other participants’ typing. In this way, observational learning (Bandura, 1986) might have occurred for the control group participants who were only given generative learning strategy tools. This modeling process might have unnaturally affected their use of note taking tools. Thus, a meaningful investigation would involve
investigating the effects of generative learning strategy prompts by isolating each group from the others. Comparing the outcomes of the isolated control group to the outcomes of the other control group participating in a combined session with the treatment group may detect the effect of observational learning. Second, if the result supports evidence of observational learning, incorporating a strategy for enhancing learners’ observational learning might be effective and another worthwhile investigation involving the effects of the strategy.

**Conclusion**

Instructional designers need to understand the internal processes of learning, identify learners’ cognitive difficulties with those processes, and create strategies to overcome the difficulties. Generative learning theory explains comprehension and understanding that results from generation of relations both among concepts and between experience or prior learning and information. Knowledge generation and learner’s cognitive and metacognitive control over their learning are the key processes of learning.

The current study promotes the need for a combination of generative learning strategy prompts and metacognitive feedback to improve learning. Generative learning strategy prompts with metacognitive feedback support learners comprehending complex topics through facilitating their regulation, monitoring, and refinement of their learning processes and, in turn, improving their use of generative learning strategies.

This study extends the understanding of generative learning theory emphasizing the mediation effects of learners’ self-regulation and use of strategies. This study, also
contributes to educational research practice by demonstrating how to gather and analyze overt evidence of learners’ actual interactions with the instructional interventions and by employing Structural Equation Modeling for experimental research to investigate intervening processes of learning. This approach may stimulate future research in instructional design and development for more complex, technology-enriched learning environments.

**Limitations of the Study**

The participants of this study were undergraduate students enrolled in general education courses in a large land grant university in northeastern United States. The results of the study are limited to the population of undergraduate students with similar characteristics such as prior domain knowledge or self-regulation skill. Further this study was delimited to visualized computer-based instruction for complex science topic. Therefore, generalizations beyond this population, content, or context should be taken cautiously.
REFERENCES


of metacognition (pp. 43-97). Lincoln, NE: Boros Institute of Mental Measurements.


Appendix A

Informed Consent Form

Informed Consent Form for Social Science Research
The Pennsylvania State University
(Course Credit + Gift)

Title of Project: SCLE (Scaffolding in Computer-based Learning Environments)

Principal Investigator: Hyeon Woo Lee, Graduate Student
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University Park, PA 16802
(814) 865-6292; hwlee@psu.edu

Advisor: Dr. Barbara Grabowski
310E Keller Building
University Park, PA 16802
(814) 863-7380; bgrabowski@psu.edu

1. Purpose of the Study: The purpose of this research study is to explore the effects of feedback on skill and comprehension of college students with different level of prior knowledge when learning complex science topic using learning strategies in computer-based learning environments.

2. Procedures to be followed: You will be asked to answer multiple-choice questions on a human physiology quiz. You will then interact with a computer-based instructional unit on the parts and function of the human heart. Following this task, you will be asked to answer another survey and 40 multiple-choice questions on a human heart quiz.

3. Duration/Time: The above-mentioned research activities should take about 1 hour.
4. **Statement of Confidentiality:** Your participation in this research is confidential. The data will be stored and secured on the researcher’s laptop in a password protected file. In the event of a publication or presentation resulting from the research, no personally identifiable information will be shared. Your confidentiality will be kept to the degree permitted by the technology used. The following may review and copy records related to this research: The Office of Human Research Protections in the U.S. Department of Health and Human Services, the Social Science Institutional Review Board and the PSU Office for Research Protections.

5. **Right to Ask Questions:** Please contact Hyeon Woo Lee at (814) 865-6292 with questions or concerns about this study. You may also call this number if you feel you have been harmed by your participation in this study. If you have questions regarding your rights as research participant, please call the Office for Research Protections at (814) 865-1775.

6. **Payment for participation:** Participants will receive 1.5% extra credit if in the IST 110 course OR 1.0% extra credit if in the EDPSY 014 course. There is another option to participating to receive the extra credit. This option is submitting a report on a topic that will be given by the instructor. In addition, one participant who gets the highest score of each treatment group in each course on the human heart quiz will receive a $20 gift certificate (This study involves three treatment groups and two courses. Thus total six certificates will be given). If there are more than two participants who get the same highest score, they will be entered in a drawing for a certificate. Winners will be notified within a month after their participation via email.

7. **Voluntary Participation:** Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive otherwise.

You must be 18 years of age or older to consent to take part in this research study.

If you agree to take part in this research study and the information outlined above, please sign your name and indicate the date below.

You will be given a copy of this form for your records.

________________________________________  _____________________
Participant Signature       Date

________________________________________  _____________________
Person Obtaining Consent      Date
Appendix B

Training Tutorial
**Directions**

Please check if you open this file in Adobe Acrobat Professional. If not, please reopen this file with Adobe Acrobat Professional 8.0 (or 7.0).

While studying this material, you are able to use a highlighter tool and a note taking tool.

First, check your menu bar for the hand tool and highlighter tool.

If you can not find the highlighter tool, you can click “View” in the menu bar and click “Toolbars”. Make sure “Comment & Markup” is checked.

If you have any problems, please raise your hand.
To highlight, you need to click the highlighter tool first, and drag mouse over the sentences that you want to highlight.

To delete the highlight from the sentences, just click the highlight over the sentences and press the delete key.

Let’s try!

Please highlight this sentence.
And delete the highlight!
Click “Hand Tool” again.

To take notes, you need to click hand tool first, then click inside the designated note box, and then type.

Let’s try!

Please write your name in the box below.

If you have any question, please raise your hand.

Are you ready?

Let’s start to learn about human heart. Please go to the next page.
Appendix C

Prior Knowledge Test

Please understand that you are not required to complete this questionnaire. Your grade in this course will not be affected whether you take this test or not.

Directions: Select the answer you feel best answers the question

1. The part of the tooth which contains the hardest substance in the body is the:
   a. root
   b. dentine
   c. cement
   d. enamel *

2. The digestion of food occurs principally in the:
   a. stomach
   b. small intestine *
   c. mouth
   d. large intestine

3. Contraction of the smooth muscle of the alimentary canal is called:
   a. peristalsis *
   b. digestion
   c. absorption
   d. assimilation

4. Worn-out red blood cells are decomposed in the:
   a. heart
   b. lungs
   c. kidneys
   d. liver *

5. "Swollen glands" means an enlargement of the:
   a. lymph nodes *
   b. heart valves
   c. vena cava
   d. portal vein

6. The chief value of perspiration is that it
   a. eliminates body odors
   b. opens the pores
   c. reduces weight
   d. regulates body temperature *

7. Endocrine glands produce:
   a. chyme
   b. endoplasm
   c. hormones *
   d. serums

8. The body is stimulated to unusual activity by increased secretion from the:
   a. pancreas
   b. adrenal glands *
   c. thyroid gland
   d. thymus gland

9. The spinal cord is made up of:
   a. bone tissue
   b. cartilage tissue
   c. connective tissue
   d. nerve tissue *

10. Nerves from the eyes and ears are connected to the:
    a. cerebellum
    b. cerebrum
    c. medulla *
    d. spinal cord
11. The chromosome number of the body cells of identical human twins is:
   a. 12
   b. 24
   c. 46 *
   d. 92

12. The person who can give blood to any other person but can receive only his own type blood has blood type:
   a. A
   b. O *
   c. AB
   d. B

13. The ribs are attached to the spine and meet in front of the body at the:
   a. skull
   b. limbs
   c. joints
   d. breastbone *

14. The ribs protect the:
   a. stomach
   b. breastbone
   c. spinal cord
   d. lungs *

15. The hollow interior of the long bones is filled with:
   a. marrow *
   b. minerals
   c. red and white corpuscles
   d. haversian canals

16. The windpipe is located ------- the esophagus:
   a. in front of *
   b. behind
   c. to the left of
   d. to the right of

17. The carbon dioxide-oxygen exchange with the atmosphere occurs in the:
   a. nose
   b. trachea
   c. lungs *
   d. bronchi

18. Blood is oxygenated in the capillaries of:
   a. air sacs *
   b. heart
   c. muscle
   d. liver

19. During inspiration, the ribs:
   a. do not move
   b. move downward
   c. move inward
   d. move upward *

20. The part of the brain that controls respiration is the:
   a. medulla *
   b. cerebellum
   c. cerebrum
   d. spinal cord

21. A defense of the body against bacteria is:
   a. hemoglobin
   b. phagocytes *
   c. red blood cells
   d. blood platelets

22. The disease hemophilia is associated with
   a. the bone structure
   b. blood clotting *
   c. the structure of nervous tissue
   d. the formation of red corpuscles

23. The liquid that bathes every cell and acts as a medium of exchanges:
   a. cell sap
   b. fibrinogen
   c. lymph *
   d. fibrin

24. Urine is stored in an organ called the:
   a. diaphragm
   b. kidney
   c. bladder *
   d. lungs

25. Secretions of the ductless glands pass:
   a. into tubes or ducts
   b. directly into the blood *
   c. directly into the organs where they are used
   d. out of the body

26. Inactivity of the thyroid gland from infancy may produce a condition known as:
   a. diabetes
   b. beriberi
   c. cretinism
   d. Addison's disease *
27. The concentration of sodium and potassium in the blood is controlled by:
   a. adrenin
   b. cortin
   c. insulin
   d. secretin *

28. Diabetes is caused by the improper functioning of the:
   a. parathyroids
   b. thyroids
   c. pancreas *
   d. adrenals

29. The adult human heart is said to beat approximately ----- times per minute.
   a. 85
   b. 72 *
   c. 60
   d. 58

30. Growth and repair of body tissue involves:
   a. protein *
   b. fats
   c. starch
   d. sugar

31. Blood enters the heart through:
   a. arteries
   b. vena cavas *
   c. the aortic arch
   d. pulmonary veins

32. Blood leaves the heart through the:
   a. tricuspid valve
   b. aorta *
   c. superior vena cava
   d. mitral valve

33. The portion of the heart which divides longitudinally into 2 halves is called the:
   a. myocardium
   b. tendons
   c. pericardium
   d. septum *

34. A blood vessel which carries deoxygenated blood is the:
   a. aorta
   b. pulmonary artery *
   c. hepatic artery
   d. pulmonary vein

35. The backward flow of blood in the veins is prevented by:
   a. muscles
   b. valves *
   c. the heart beat
   d. the lymphatics

36. The chamber of the heart which pumps oxygenated blood to all the parts of the body is the:
   a. left auricle
   b. right ventricle
   c. right auricle
   d. left ventricle *
## Appendix D

### Item Analysis of Prior Knowledge Test

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Appendix E

Self-Regulation Questionnaire

Please understand that you are not required to complete this questionnaire. Your grade in this course will not be affected whether you take this questionnaire or not. If you do take the survey, you will receive individual feedback on different learning traits and skills upon request.

If you have any questions, please email the principal investigator, Hyeon Woo Lee at hwlee@psu.edu

The following questions ask about your study habits and learning skills in this instruction. Remember there are no right or wrong answers, just answer as accurately as possible reflecting your own attitudes and behaviors in this instruction. This is not a test. If you think the statement is very true of you, click the circle on 7; if a statement is not at all true of you, click on 1. If the statement is more or less true of you, find the number between 1 and 7 that best describes you.

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>not at all true of me</th>
<th>very true of me</th>
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<tbody>
<tr>
<td>1</td>
<td>When I studied this material, I outline the material to help me organize my thoughts.</td>
<td>1 2 3 4 5 6 7</td>
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</tr>
<tr>
<td>2</td>
<td>During reading this material I often missed important points because I was thinking of other things.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>3</td>
<td>When reading this material, I made up questions to help focus my reading.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>4</td>
<td>I often find myself questioning things I read in this material to decide if I find them convincing.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>5</td>
<td>When I studied this material, I practiced saying the important facts to myself over and over.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>6</td>
<td>When I became confused about something I was reading this material, I went back and tried to figure it out.</td>
<td>1 2 3 4 5 6 7</td>
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<td>7</td>
<td>When I studied each page of this material, I go through the page and tried to find the most important ideas.</td>
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<td>8</td>
<td>If the contents of the material were difficult to understand, I changed the way I studied the material.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<td>9</td>
<td>When studying this material, I read the materials over and over again.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<td>10</td>
<td>I made simple charts, diagrams, or tables to help me organize this material.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>11</td>
<td>I treated this material as starting point and try to develop my own ideas about it.</td>
<td>1 2 3 4 5 6 7</td>
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<td>12</td>
<td>When I studied this material, I tried to put together the information from each page.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<tr>
<td>13</td>
<td>I asked myself questions to make sure I understood the material.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<tr>
<td>14</td>
<td>I tried to change the way I study in order to fit this instructional unit.</td>
<td>1 2 3 4 5 6 7</td>
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<td>No.</td>
<td>Question</td>
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<tr>
<td>15</td>
<td>I often found that I had been reading this material but did not know what it was all about.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>16</td>
<td>I tried to memorize key words to remind me of important concepts in this material.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>17</td>
<td>I tried to think through a topic and decide what I was supposed to learn from it rather than just reading it over when studying this material.</td>
<td>1 2 3 4 5 6 7</td>
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<td>18</td>
<td>I tried to relate ideas in this subject to those in other courses whenever possible</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>When I studied this material, I tried to make an outline of important concepts.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<tr>
<td>20</td>
<td>When reading this material, I try to relate the material to what I already know.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<tr>
<td>21</td>
<td>I tried to play around with ideas of my own related to what I am learning in this material.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<tr>
<td>22</td>
<td>When I study this material, I wrote brief summaries of the main ideas and the concepts from each page.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<tr>
<td>23</td>
<td>I tried to understand this material by making connections between the concepts from each page.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>24</td>
<td>Whenever I read an assertion or conclusion in this material, I think about possible alternatives.</td>
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<tr>
<td>25</td>
<td>I made lists of important terms of each page of this material and memorize the lists.</td>
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<tr>
<td>26</td>
<td>When studying this material, I tried to determine which concepts I did not understand well.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>27</td>
<td>When I studied this material, I set goals for myself in order to direct my activities.</td>
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</table>
Appendix F

Recall and Comprehension Tests

Please understand that you are not required to complete this questionnaire. Your grade in this course will not be affected whether you take this test or not.

Directions: Select the answer you feel best answers the question.

Part I: Recall Test

1. ________ is (are) the thickest walled chamber(s) of the heart
   a. AURICLES
   b. MYOCARDIUM
   c. VENTRICLES *
   d. PERICARDIUM
   e. ENDOCARDIUM

2. The contraction of the heart occurs during the phase.
   a. SYSTOLIC *
   b. SYMPATHETIC
   c. DIASTOLIC
   d. PARASYMPATHETIC
   e. SYMPATRIC

3. Lowest blood pressure in the arteries occurs during the --- phase.
   a. SYMPATRIC
   b. SYMPATHETIC
   c. DIASTOLIC *
   d. SYSTOLIC
   e. PARASYMPATHETIC

4. Blood from the right ventricle goes to the lungs through the
   a. TRICUSPID VALVE
   b. AORTIC ARTERY
   c. PULMONARY ARTERY *
   d. PULMONARY VEINS
   e. SUPERIOR VENA CAVA

5. The --- is (are) the strongest section(s) of the heart.
   a. LEFT VENTRICLE *
   b. AORTA
   c. SEPTUM
   d. RIGHT VENTRICLE
   e. TENDONS

6. When blood returns to the heart from the lungs, it enters the ---
   a. LEFT AURICLE *
   b. PULMONARY
   c. LEFT VENTRICLE
   d. RIGHT VENTRICLE ARTERY
   e. PULMONARY VALVE ARTERY

7. Vessels that allow the blood to flow from the heart are called the
   a. VEINS
   b. ARTERIES *
   c. APEX
   d. TENDONS
   e. VALVES

8. Blood passes from the left ventricle out the aortic valve to the
   a. LUNGS
   b. BODY
   c. AORTA *
   d. PULMONARY ARTERY
   e. LEFT AURICLE
9. The chamber of the heart which pumps oxygenated blood to all parts of the body is the ---
   a. RIGHT AURICLE
   b. LEFT AURICLE
   c. AORTA
   d. LEFT VENTRICLE *
   e. RIGHT VENTRICLE

10. The --- is another name for the part of the heart called the heart muscle.
    a. APEX
    b. EPICARDIUM
    c. ENDOCARDIUM
    d. MYOCARDIUM *
    e. SEPTUM

11. --- is (are) the part(s) of the heart which controls its contraction and relaxation.
    a. MYOCARDIUM *
    b. ENDOCARDIUM
    c. VENTRICLES
    d. AURICLES
    e. SEPTUM

12. The --- is the name given to the inside lining of the heart wall.
    a. EPICARDIUM
    b. ENDOCARDIUM *
    c. PERICARDIUM
    d. MYOCARDIUM
    e. SEPTUM

13. Blood from the body enters the heart through the ---
    a. AORTA ARTERY
    b. PULMONARY VEINS
    c. PULMONARY
    d. SUPERIOR AND INFERIOR VENA CAVAS *
    e. SUPERIOR VENA CAVA ONLY

14. The membrane which borders on the inside lining of the pericardium and is connected to the heart muscle is called the ---
    a. EXTOXIM
    b. EPICARDIUM *
    c. ENDOCARDIUM
    d. MYOCARDIUM
    e. ECTOCARDIUM

15. The --- allow(s) blood to travel in one direction only.
    a. SEPTUM
    b. VALVES *
    c. ARTERIES
    d. VEINS
    e. TENDONS

16. The - is the common opening between the right auricle and the right ventricle.
    a. MITRAL VALVE
    b. TRICUSPID VALVE VALVE *
    c. SEPTIC VALVE
    d. PULMONARY
    e. AORTIC VALVE

17. The - is a triangular flapped valve between the left auricle and the left ventricle.
    a. AORTICVALVE
    b. PULMONARY VALVE
    c. SEPTIC VALVE
    d. TRICUSPID VALVE
    e. MITRAL VALVE *

18. The semi-lunar valves are located at the entrance to the –
    a. PULMONARY VEINS
    b. SUPERIOR AND INFERIOR VENA CAVAS
    c. PULMONARY AND AORTIC ARTERIES *
    d. MITRAL AND TRICUSPID VALVES
    e. VENTRICLES

19. The outside covering of the heart is called the ---
    a. ENDOCARDIUM
    b. EPICARDIUM
    c. PERICARDIUM *
    d. MYOCARDIUM
    e. NONE OF THESE

20. Immediately before entering the aorta, blood must pass through the ---
    a. LEFT VENTRICLE
    b. MITRAL VALVE
    c. LUNGS
    d. SUPERIOR VENA CAVA
    e. AORTIC VALVE *
Part II: Comprehension Test

1. Which valve is most like the tricuspid in function?
   a. PULMONARY
   b. AORTIC
   c. MITRAL *
   d. SUPERIOR VENA CAVA

2. When blood is being forced out the right ventricle, in which position is the tricuspid valve?
   a. BEGINNING TO OPEN
   b. BEGINNING TO CLOSE
   c. OPEN
   d. CLOSED *

3. When the blood is being forced out the aorta, it is also being forced out of the -.
   a. PULMONARY VEINS CAVA
   b. PULMONARY ARTERIES *
   c. SUPERIOR VENA
   d. CARDIAC ARTERY

4. The contraction impulse in the heart starts in?
   a. THE RIGHT AURICLE
   b. BOTH VENTRICLES SIMULTANEOUSLY
   c. BOTH AURICLES SIMULTANEOUSLY *
   d. THE ARTERIES

5. In the diastolic phase the ventricles are
   a. CONTRACTING, FULL OF BLOOD
   b. CONTRACTING, PARTIALLY FULL OF BLOOD
   c. RELAXING, FULL OF BLOOD
   d. RELAXING, PARTIALLY FULL OF BLOOD *

6. During the first contraction of the systolic phase—in what position will the mitral valve be?
   a. BEGINNING TO OPEN
   b. OPEN *
   c. BEGINNING TO CLOSE
   d. CLOSED

7. During the second contraction of the systolic phase, blood is being forced away from the heart through the
   a. PULMONARY AND AORTIC ARTERIES *
   b. SUPERIOR AND INFERIOR VENA CAVAS
   c. TRICUSPID AND MITRAL VALVES
   d. PULMONARY VEINS

8. When blood is entering through the vena cava, it is also entering through the
   a. MITRAL VALVE
   b. PULMONARY VEINS *
   c. PULMONARY ARTERY
   d. AORTA

9. When the heart contracts, the –
   a. AURICLES AND VENTRICLES CONTRACT SIMULTANEOUSLY
   b. VENTRICLES CONTRACT FIRST, THEN THE AURICLES
   c. RIGHT SIDE CONTRACTS FIRST, THEN THE LEFT SIDE
   d. AURICLES CONTRACT FIRST, THEN THE VENTRICLES *

10. While blood from the body is entering the superior vena cava, blood from the body is also entering through the
    a. PULMONARY VEINS
    b. AORTA ARTERY
    c. INFERIOR VENA CAVA *
    d. PULMONARY

11. When the blood leaves the heart through the pulmonary artery, it is also simultaneously leaving the heart through the
    a. TRICUSPID VALVE
    b. PULMONARY VEINS
    c. AORTA *
    d. PULMONARY VALVE

12. When the pressure in the right ventricle is superior to that in the pulmonary artery, in what position is the tricuspid valve?
    a. CLOSED *
    b. OPEN
    c. BEGINNING TO CLOSE
    d. CONFINED BY PRESSURE FROM THE RIGHT AURICLE
13. When the ventricles contract, blood is forced out the
   a. SUPERIOR AND INFERIOR VENA CAVAS
   b. PULMONARY VEINS
   c. TRICUSPID AND MITRAL VALVES *
   d. PULMONARY AND AORTIC VALVES

14. Blood leaving the heart through the aorta had left the heart previously through the -.
   a. VENA CAVAS
   b. PULMONARY
   c. PULMONARY ARTERY *
   d. TRICUSPID AND VEINS MITRAL VALVES

15. When the blood in the aorta is exerting a superior pressure on the aortic valve, what is the position of the mitral valve?
   a. CLOSED
   b. OPEN
   c. BEGINNIGN TO OPEN *
   d. CONFINED BY PRESSURE FROM THE RIGHT VENTRICLE

16. When the tricuspid and mitral valves are forced shut, in what position is the pulmonary valve?
   a. CLOSED
   b. BEGINNING TO OPEN
   c. OPEN *
   d. BEGINNING TO CLOSE

17. During the second contraction of the systolic phase, in what position is the aortic valve?
   a. FULLY OPEN *
   b. PARTIALLY OPEN
   c. PARTIALLY CLOSED
   d. FULLY CLOSED

18. Blood is being forced out the auricles simultaneously as blood is
   a. ENTERING ONLY THE VENA CAVAS
   b. BEING FORCED OUT THE PULMONARY AND AORTIC VALVES
   c. PASSING THROUGH THE TRICUSPID, AND MITRAL VALVES *
   d. BEING FORCED OUT THROUGH THE PULMONARY ARTERY

19. If the aortic valve is completely open, the
   a. SECOND CONTRACTION OF THE SYSTOLIC PHASE IS OCCURRING *
   b. DIASTOLIC PHASE IS OCCURRING
   c. TRICUSPID AND MITRAL VALVES ARE COMPLETELY OPEN
   d. BLOOD IS RUSHING INTO THE RIGHT AND LEFT VENTRICLES

20. When the heart relaxes, the 
   a. AURICLES RELAX FIRST THEN THE VENTRICLES *
   b. RIGHT SIDE RELAXES FIRST, THEN THE LEFT SIDE
   c. LEFT SIDE RELAXES FIRST, THEN THE RIGHT SIDE
   d. VENTRICLES RELAX FIRST, THEN THE AURICLES
Appendix G

Study Procedure Direction

Study Procedure I

Please follow this procedure. If you have any question, just raise your hand. The time to complete all tasks varies with the assigned instructional strategies. So, please don’t push yourself to finish it quickly. Please turn off your cell phone.

1. Provide Consent
   - Read and sign the Informed Consent Form.

2. Log in to ANGEL
   - Find “SCLE IST Group T (S or I)” in My Groups.
   - Read “1. Begin Here – Read This First!” carefully.

3. Take “2. Pre-Test” (Password: edpsy014)
   - The test might be difficult for you but don’t worry about that.

4. Click “3. Instructional Material” (Password: edpsy014)
   - Download “Instructional Material T (S or I).pdf”, and “save as” your name in your desktop.
   - Open it using Adobe Acrobat 8.0 (or 7.0) Professional (Click “Start” – “All Programs” – “Electronic Publication” – “Adobe Acrobat 8.0 (or 7.0) Professional”)
   - Study the Instructional Material.
     : Each participant receives different instructional strategies, so don’t worry about why others are doing something different
     : Remember one $20 gift certificate will be given to one person who scores the highest in each group.
   - Save the Instructional Material you studied again.
   - Upload the saved file to “4. Drop Box for Instructional Material”

Please check if you completed all above the tasks:

☐ signed the informed consent form  ☐ completed the pre-test
☐ studied the instructional material  ☐ saved the instructional material
☐ uploaded the instructional material you saved

If you checked all the boxes above, please raise your hand.
- Submit one copy of the signed informed consent form to the administrator and keep one copy.
- Submit this “Study Procedure I” and get “Study Procedure II” to proceed.
Study Procedure II

5. Please delete the Instructional Material file in your Desktop

6. Take “5. Post-Survey” (Password: 014edpsy)

7. Take “6. Post-Test” (Password: 014edpsy)
   - Do not go back to the instructional material or talk with your neighbors while taking the post test.

8. Check if you complete all tasks.

Please check if you complete all above the tasks:
   □ completed the post-survey   □ completed the post-test

If you checked all the boxes above, please submit this “Study Procedure II” to the administrator. You can leave now.

Thank you so much for your participation!
# Appendix H

## Generative Learning Strategy Prompts and Questions

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<th>Computer Screen</th>
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<th>Summarization Prompt</th>
<th>Adjunct Question</th>
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<tr>
<td>S2</td>
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<td></td>
<td></td>
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<tr>
<td>S3</td>
<td>Highlight one or more sentences that you think are important in this section</td>
<td>Describe the auricles and ventricles</td>
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<tr>
<td>S4</td>
<td>Highlight one or more sentences that you think are important in this section</td>
<td>List the layers of the heart from the outside to the inside</td>
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<tr>
<td>S5</td>
<td>Highlight one or more sentences that you think are important in this section</td>
<td>List two veins which deposit blood in the right auricle</td>
<td>Q. While blood from the body below heart level enters the heart through the a____, blood from the body above heart level enters the heart through the b____.</td>
</tr>
<tr>
<td>S6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S7</td>
<td>Highlight one or more sentences that you think are important in this section</td>
<td>Summarize the blood flow from the right ventricle to the lungs</td>
<td></td>
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<td>Computer Screen</td>
<td>Highlighting Prompt</td>
<td>Summarization Prompt</td>
<td>Adjunct Question</td>
</tr>
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<td>---------------------</td>
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</table>
| S8              | Highlight one or more sentences that you think are important in this section | Summarize the blood flow from the Superior & Inferior Vena Cava to the Left Ventricle | Q. Blood from the right ventricle flows to the left ventricle through:  
- a. Pulmonary Valve - Pulmonary Veins – Lungs – Pulmonary Artery – Left Auricle – Tricuspid Valve  
- b. Pulmonary Valve – Pulmonary Artery – Lungs – Pulmonary Veins – Left Auricle – Mitral Valve  
- c. Tricuspid Valve - Right Auricle – Pulmonary Artery – Lungs – Pulmonary Veins – Mitral Valve  
- d. Mitral Valve - Superior Vena Cava – Lungs – Pulmonary Veins – Left Auricle – Pulmonary Valve  
- e. Tricuspid Valve - Superior Vena Cava – Lungs – Inferior Vena Cava – Left Auricle – Mitral Valve |
| S9              | Highlight one or more sentences that you think are important in this section | Summarize the blood flow from the Left Ventricle to the Body in your own words | Q. Blood in the left ventricle passes through the Aortic Valve and enters the Aorta.  
- a. True  
- b. False |
| S10             | Highlight one or more sentences that you think are important in this section | List four valves of the heart |  |
| S11             | Highlight one or more sentences that you think are important in this section | Summarize the sequence of a wave of muscular contraction of the heart in your own words | Q. A wave of muscular contraction of the heart starts in both Ventricles simultaneously.  
- a. True  
- b. False |
| S12             | Highlight one or more sentences that you think are important in this section | Summarize what happen when the tricuspid and mitral valves are closed in your own words | Q. When the tricuspid and mitral valves are closed, ______________.  
- a. Blood is being forced out the right ventricle  
- b. The pressure in the right ventricle is inferior to that in the pulmonary artery  
- c. The pulmonary valve is open |
<table>
<thead>
<tr>
<th>Computer Screen</th>
<th>Highlighting Prompt</th>
<th>Summarization Prompt</th>
<th>Adjunct Question</th>
</tr>
</thead>
</table>
| S14             | Highlight one or more sentences that you think are important in this section | Summarize what happen when the pulmonary and aortic valves are open in your own words | Q. When the tricuspid and mitral valves are forced shut, in what position is the semi-lunar valves?  
   a. Closed  
   b. Beginning to open  
   c. Open  
   d. Beginning to close |
| S15             | Highlight one or more sentences that you think are important in this section | Explain how the blood flows from the left and right ventricles in your own words | Q. When blood flows from the right ventricle into the pulmonary artery, simultaneously, blood flows from the left ventricle into the aorta.  
   a. True  
   b. False |
| S16             | Highlight one or more sentences that you think are important in this section | Explain the position of valves (Tricuspid, Mitral, Pulmonary, and Aortic) in the diastolic phase in your own words | Q. In the diastolic phase, what is the position of the tricuspid and mitral valves?  
   a. Closed  
   b. Open  
   c. Beginning to open  
   d. Confined by pressure from the Right Ventricle |
| S18             | Highlight one or more sentences that you think are important in this section | Explain the position of valves (Tricuspid, Mitral, Pulmonary, and Aortic) in the diastolic phase in your own words | Q. In the diastolic phase, what is the position of the tricuspid and mitral valves?  
   a. Closed  
   b. Open  
   c. Beginning to open  
   d. Confined by pressure from the Right Ventricle |
| S19             | Highlight one or more sentences that you think are important in this section | Summarize the first and second contraction in the systolic phase | Q. When the aortic valve is fully open, in what phase of blood pressure is the heart?  
   a. Diastolic Phase  
   b. The First Contraction of the Systolic Phase  
   c. The Second Contraction of the Systolic Phase  
   d. The First and Second Contraction of the Systolic Phase |
| S20             | Highlight one or more sentences that you think are important in this section | Summarize the cycle of blood pressure in the heart | Q. Which one is the correct sequence of a heart contraction?  
   a. Auricles contract first, then the Ventricles  
   b. Ventricles contract first, then the Auricles  
   c. Auricles & Ventricles contract simultaneously  
   d. Right side contracts first, then the left side |
## Appendix I

### Correlation Matrix

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### Appendix J

**Augmented Moment Matrix**

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<td>5.991</td>
<td>4.368</td>
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**Mean:**

|       | 0.336 | 0.327 | 11.722 | 4.182 | 3.887 | 24.955 | 26.363 | 4.623 | 5.991 | 4.368 | 5.233 | 1.000 |

**SD:**

|       | 0.474 | 0.470 | 2.687 | 0.867 | 0.852 | 12.384 | 14.106 | 2.690 | 2.556 | 2.378 | 2.871 | 1.000 |
Appendix K

LISREL® Simplis Syntaxes

Model 1: Measurement Model

Observed Variables g1 g2 pre cog meta highl note termi fact conc relat
Covariance Matrix from file GLS.COV
Asymptotic Covariance Matrix from file GLS.AC
Sample Size 223
Latent Variables SR USE REC COM
Relationships
cog = SR
meta = 1*SR
highl = USE
note = 1*USE
termi = 1*REC
fact = REC
conc = COM
relat = 1*COM
Path Diagram
Options: MI SC ME=ML EF
End of Program

Model 2: Initial Structural Model

Observed Variables g1 g2 pre cog meta highl note termi fact conc relat
Covariance Matrix from file GLS.COV
Asymptotic Covariance Matrix from file GLS.AC
Sample Size 223
Latent Variables SR USE REC COM
Relationships
cog = SR
meta = 1*SR
highl = USE
note = 1*USE
termi = 1*REC
fact = REC
conc = COM
relat = 1*COM
SR USE REC COM = pre g1 g2
Set the error covariance of SR and USE free
Set the error covariance of SR and REC free
Set the error covariance of SR and COM free
Model 3: Structural Model for one-way MANCOVA

Observed Variables g1 g2 pre cog meta highl note termi fact conc relat CONST
Augmented Moment Matrix from file GLS.AM
Asymptotic Covariance Matrix from file GLS.AC
Sample Size 223
Latent Variables SR USE REC COM
Relationships
cog = 1*SR
meta = SR
highl = USE
note = 1*USE
termi = REC
fact = 1*REC
cconc = COM
relat = 1*COM
SR USE REC COM = g1 g2 pre CONST
Set the error covariance of SR and USE free
Set the error covariance of SR and REC free
Set the error covariance of SR and COM free
Set the error covariance of USE and REC free
Set the error covariance of USE and COM free
Set the error covariance of REC and COM free
Path Diagram
Options: MI SC ME=ML EF
End of Program

Model 4: Structural Model with Significant Paths

Observed Variables g1 g2 pre cog meta highl note termi fact conc relat
Augmented Moment Matrix from file GLS.COV
Asymptotic Covariance Matrix from file GLS.AC
Sample Size 223
Latent Variables SR USE REC COM
Relationships
cog = 1*SR
meta = SR
highl = USE
note = 1*USE
termi = REC  
fact = 1*REC  
conc = COM  
relat = 1*COM  
SR USE REC COM = g2 pre  
USE = g1  
Set the error covariance of SR and USE free  
Set the error covariance of SR and REC free  
Set the error covariance of SR and COM free  
Set the error covariance of USE and REC free  
Set the error covariance of USE and COM free  
Set the error covariance of REC and COM free  
Path Diagram  
Options: MI SC ME=ML EF  
End of Program

Model 5: Structural Model with Hypothesized Causal Paths: Full Model

Observed Variables g1 g2 pre cog meta highl note termi fact conc relat  
Augmented Moment Matrix from file GLS.COV  
Asymptotic Covariance Matrix from file GLS.AC  
Sample Size 223  
Latent Variables SR USE REC COM  
Relationships  
cog = 1*SR  
meta = SR  
highl = USE  
note = 1*USE  
termi = REC  
fact = 1*REC  
conc = COM  
relat = 1*COM  
SR USE REC COM = g2 pre  
USE = g1  
USE = SR  
REC COM = USE  
Set the error covariance of SR and REC free  
Set the error covariance of SR and COM free  
Set the error covariance of REC and COM free  
Path Diagram  
Options: MI SC ME=ML EF  
End of Program
Model 5-1: Structural Model with Hypothesized Causal Paths: The First Restricted Model

Observed Variables g1 g2 pre cog meta highl note termi fact conc relat
Augmented Moment Matrix from file GLS.COV
Asymptotic Covariance Matrix from file GLS.AC
Sample Size 223
Latent Variables SR USE REC COM
Relationships
cog = 1*SR
meta = SR
highl = USE
note = 1*USE
termi = REC
fact = 1*REC
conc = COM
relat = 1*COM
SR USE REC COM = pre
SR USE = g2
USE = g1
USE = SR
REC COM = USE
Set the error covariance of SR and REC free
Set the error covariance of SR and COM free
Set the error covariance of REC and COM free
Path Diagram
Options: MI SC ME=ML EF
End of Program

Model 5-2: Structural Model with Hypothesized Causal Paths: The Second Restricted Model

Observed Variables g1 g2 pre cog meta highl note termi fact conc relat
Augmented Moment Matrix from file GLS.COV
Asymptotic Covariance Matrix from file GLS.AC
Sample Size 223
Latent Variables SR USE REC COM
Relationships
cog = 1*SR
meta = SR
highl = USE
note = 1*USE
termi = REC
fact = 1*REC
conc = COM
relat = 1*COM
SR USE REC COM = pre
SR = g2
USE = g1
USE = SR
REC COM = USE
Set the error covariance of SR and REC free
Set the error covariance of SR and COM free
Set the error covariance of REC and COM free
Path Diagram
Options: MI SC ME=ML EF
End of Program

Model 6: Final Structural Model

Observed Variables g1 g2 pre cog meta highl note termi fact conc relat
Covariance Matrix from file GLS.COV
Asymptotic Covariance Matrix from file GLS.AC
Sample Size 223
Latent Variables SR USE REC COM
Relationships
cog = SR
meta = 1*SR
highl = USE
note = 1*USE
termi = REC
fact = 1*REC
conc = COM
relat = 1*COM
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SR USE = g2
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USE = SR
REC COM = USE
Set the error covariance of SR and REC free
Set the error covariance of SR and COM free
Set the error covariance of REC and COM free
Path Diagram
Options: MI SC ME=ML EF
End of Program
HYEON WOO LEE
VITA

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SELECTED PUBLICATIONS

