

Running head: COGNITIVE LOAD THEORY AND EXPERIENCE

Article Analysis:

Cognitive Load Theory and the Role of Learner Experience

Cognition and Instruction Comprehensive Exam

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As part of a larger class of limited capacity theories (Goldman, 1991), cognitive load theory (CLT) provides a framework for designing complex instructional materials. The basic premise of CLT is that learners have a working memory with very limited capacity when dealing with new information (Sweller, van Merriënboer, & Paas, 1998). Moreover, CLT assumes that learners have “an effectively unlimited long-term memory holding cognitive schemas that vary in their degree of complexity and automation” (van Merriënboer & Ayres, 2005, p. 6). The implication of these assumptions is that learning will be hindered if instructional materials overwhelm a learner’s limited working memory resources. Accordingly, early CLT research focused on identifying instructional designs that can effectively reduce unnecessary cognitive burden on working memory, thereby supporting improved learning efficiency (van Merriënboer & Sweller, 2005). More recently, cognitive load theorists have shifted their attention to how learner characteristics, such as prior knowledge and motivational beliefs, interact with instructional designs to influence the effectiveness of CLT methods (Moreno, 2006).

The purpose of this paper is to describe, in brief, CLT and its major implications for learning. To achieve this objective, the paper includes a short description of human cognitive architecture as conceived by cognitive load theorists. Following this overview, the paper provides a description of what makes CLT different from other cognitive theories. Included in this section is a summary of the predictions about learning and novel instructional designs that CLT has produced. Next, the paper presents a discussion of learner experience and how different levels of prior knowledge can interact with various instructional methods to differentially influence learning outcomes. Finally, the paper ends with a brief description of an experiment designed to assess the role of learner experience in CLT.

### Components of Human Cognitive Architecture

#### *Working Memory*

According to Sweller et al. (1998), humans are only conscious of the information currently being held and processed in working memory and are essentially oblivious to the enormous amount of information stored in long-term memory. Furthermore, when handling new information, working memory is severely limited in both capacity and duration; that is, working memory can only hold about seven

(plus or minus two) items, or chunks of information, at a time (Miller, 1956). Additionally, when *processing* information (i.e., organizing, contrasting, and comparing), rather than just storing it, humans are probably only able to manage two or three items of information simultaneously, depending on the type of processing required (Kirschner, Sweller, & Clark, 2006). Finally, new information held in working memory, if not rehearsed, is lost within about 15 to 30 seconds (Driscoll, 2005).

Another important characteristic of working memory is that its capacity is distributed over two, partially independent processors (Sweller et al., 1998). This dual-processing assumption is based, in part, on Pavio's (1986) dual-coding theory and Baddeley's (1998) theory of working memory, both of which suggest that there are two separate channels for processing visual and auditory information. The implication of this dual-processing model is that limited working memory capacity can be effectively expanded by utilizing both visual and auditory channels rather than either processing channel alone (Sweller et al., 1998). Known as the *modality effect* (Mousavi, Low, & Sweller, 1995), this result has important implications for instructional designers (see discussion regarding CLT predictions below).<sup>1</sup>

#### *Long-Term Memory, Schema Construction, and Schema Automation*

Unlike working memory, the capacity of long-term memory is essentially limitless. Furthermore, information held in long-term memory is organized and stored in the form of domain-specific knowledge structures known as schemas (van Merriënboer & Ayres, 2005). Schemas categorize elements of information according to how they will be used, thereby facilitating schema accessibility later when they are needed for related tasks (Sweller et al., 1998). Thus, from the CLT perspective, "human expertise comes from knowledge stored in these schemata, *not* from an ability to engage in reasoning with many elements that have not been organized in long-term memory" (van Merriënboer & Sweller, 2005, p. 149).

As indicated by Sweller (2004), the relationship between working memory and schemas stored in long-term memory may be even more important than the processing limitations of working memory. This is because schemas do more than just organize and store information; they also effectively augment

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<sup>1</sup> The modality effect is not limited to CLT; it has been confirmed by numerous researchers from a variety of theoretical perspectives (e.g., Mayer, 2001; Mayer & Moreno, 2003; Penny, 1989; Reed, 2006).

working memory capacity. Although working memory can hold only a limited *number* of items at a time, the size and complexity of those elements are unlimited (Sweller et al., 1998). Therefore, complex schemas consisting of huge arrays of interrelated elements can be held in working memory as a single entity. As a result, a student dealing with previously learned material that has been stored in long-term memory is, in effect, freed from the processing limitations of working memory – limitations that only apply to novel materials that have no associated schemas (Kirschner et al., 2006). In sum, schemas serve two functions in CLT: the organization and storage of information in long-term memory and the expansion of working memory capacity (Sweller et al., 1998).

Automation is another critical component of schema construction. Automation occurs when information stored in schemas can be processed automatically and without conscious effort, thereby freeing up working memory resources. Constructed schemas become automated after extensive practice, and existing schemas will vary in their degree of automation (van Merriënboer & Sweller, 2005). As Sweller et al. (1998) described, “with automation, familiar tasks are performed accurately and fluidly, whereas unfamiliar tasks – that partially require the automated processes – can be learned with maximum efficiency because maximum working memory capacity is available” (p. 258). On the other hand, without schema automation, a previously encountered task might be completed, but the process will likely be slow and awkward. Furthermore, consistent with CLT, entirely new tasks may be impossible to complete until prerequisite skills have been automated because there simply may not be enough working memory capacity available for learning (van Merriënboer & Sweller, 2005). Ultimately, in view of these theoretical assumptions, schema construction and automation become the major goals for instructional systems that are developed from a cognitive load perspective (Sweller et al., 1998).

#### Different Types of Cognitive Load

Although schemas are stored in long-term memory, their construction occurs in working memory. Specifically, when learning new material, students must attend to and manipulate relevant pieces of information in working memory before it can be stored in long-term memory (Sweller et al., 1998). Consequently, of primary importance to cognitive load theorists is the ease with which information can be

processed in working memory; that is, the *cognitive load* imposed on working memory. According to CLT, three different types of cognitive load can be distinguished:

(1) *Intrinsic cognitive load* refers to the number of elements that must be processed simultaneously in working memory for schema construction (i.e., *element interactivity*). Element interactivity is dependent on both the complexity of the to-be-learned material and the learners' expertise (i.e., their schema availability and automaticity; Gerjets & Scheiter, 2003). Stated another way, "intrinsic cognitive load through element interactivity is determined by an interaction between the nature of the material being learned and the expertise of the learners" (Sweller et al., 1998, p. 262).

(2) *Extraneous cognitive load* – also known as ineffective cognitive load – is the result of instructional techniques that require learners to engage in working memory activities that are not directly related to schema construction or automation (Sweller, 1994). Much of the early research in CLT revealed that many commonly used instructional designs require learners to use cognitive resources that are not related to, or helpful for, learning (e.g., searching for information that is needed to complete a learning task). Furthermore, because intrinsic cognitive load due to element interactivity and extraneous cognitive load due to instructional design are additive (Sweller et al., 1998), the end result may be fewer cognitive resources left in working memory to devote to schema construction and automation during learning. Consequently, learning may suffer (Sweller, 1994).

(3) *Germane cognitive load* – also known as effective cognitive load – is the result of beneficial cognitive processes such as abstractions and elaborations that are promoted by the instructional presentation (Gerjets & Scheiter, 2003). When intrinsic and extraneous cognitive load leave sufficient working memory resources, learners may "invest extra effort in processes that are directly relevant to learning, such as schema construction. These processes also increase cognitive load, but it is germane cognitive load that contributes to, rather than interferes with, learning" (Sweller et al., 1998, p. 264).

In summary, based on the cognitive demands imposed on working memory from the three sources of cognitive load, CLT suggests that instructional designers should focus on two tasks: (1) reduce

extraneous cognitive load, and (2) encourage learners to apply available resources to advanced cognitive processes that are associated with germane cognitive load (Gerjets & Scheiter, 2003).

#### Unique Contributions: Learning Predictions and Novel Instructional Designs

Cognitive load theory suggests that learning happens best when instructional materials align with human cognitive architecture (Sweller et al., 1998). Thus, “by simultaneously considering the structure of information and the cognitive architecture that allows learners to process that information, cognitive load theorists have been able to generate a unique variety of new and sometimes counterintuitive instructional designs and procedures” (Paas, Renkle, & Sweller, 2003, p. 1). In many ways, this focus on information *and* cognitive structures – as well as the ultimate goal of generating new and efficient instructional techniques (Sweller, 1991) – has distinguished CLT from many other cognitive theories. This is not to say that all other theories have failed to consider the interaction between external instructional presentation and internal cognitive structures and function. Certainly Gagne’s (2005) theory, among others, was sensitive to the idea that if learning is to occur, instructors must deliberately arrange the external and internal *conditions of learning*. However, it seems that more than any other,<sup>2</sup> CLT has focused on understanding this interaction from a theoretical perspective and then has applied that understanding to the development of instructional methods. In particular, over the last 30 years, cognitive load theorists have systematically developed hypotheses, generated and tested novel instructional methods based on those hypotheses, and modified their original theory as necessary to account for unexpected findings (Dixon, 1991). This underlying CLT approach is exemplified in a statement from Sweller and Chandler (1991) in reply to critiques by Dixon (1991) and Goldman (1991): “a theory of cognition and instruction that does not lead to novel instructional procedures is a deficient theory. Our field is an applied field and that means theory application” (p. 358).

As a result of their focus on theory application, CLT has made many predictions regarding how people learn, and those predictions have led to numerous instructional design techniques aimed at keeping

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<sup>2</sup> Mayer’s (2001) cognitive theory of multimedia learning (CTML) also has focused on theory application, and the result has been numerous instructional recommendations based on CTML. However, Mayer’s CTML adopted many of the assumptions of CLT and, as a result, his theory is *closely* related to CLT (see discussion in Reed, 2006).

extraneous cognitive load as low as possible during learning. Appendix A includes a summary of the learning effects that have emerged from this initial emphasis on reducing extraneous cognitive load. More recently, CLT researchers have recognized that simply freeing working memory capacity by reducing extraneous load may not be a sufficient condition for instruction to be effective (Paas, Renkl, & Sweller, 2004). Accordingly, investigators have begun studying other techniques meant to *optimize* cognitive load; that is, methods designed to decrease intrinsic load and bolster germane load (Paas et al., 2003).

#### The Role of Experience and Learning: The Expertise Reversal Effect

As interest in optimizing cognitive load has increased, so too has a more dynamic approach to CLT (e.g., Kalyuga & Sweller, 2004, 2005). This dynamic approach recognizes that the effectiveness of an instructional design depends, in part, on the learner's experience in the domain being taught (Kalyuga, Ayres, Chandler, & Sweller, 2003).

Because novices lack the schemas necessary to process complex material in working memory, instructional guidance can act as a surrogate for these missing schemas, thereby promoting schema construction (Sweller et al., 1998). Without instructional guidance, novices quickly succumb to heavy cognitive load, and very inefficient learning, if any at all, will occur. In contrast, more experienced learners are able to activate relevant schemas and, as such, may not require additional instructional guidance. If, nevertheless, instructional guidance is provided to more experienced learners, and they are unable to avoid attending to this information, "there will be an overlap between scheme-based and the redundant instruction-based components of guidance" (Kalyuga et al., 2003, p. 24). As a result of this redundancy, more experienced learners may face cognitive overload as additional working memory resources are consumed trying to deal with the same information. For more experienced learners, then, it may be preferable to eliminate the instruction-based guidance, thereby reducing cognitive load and improving learning efficiency. Considering these mechanisms, it becomes apparent that instructional techniques that are highly effective for novices can lose their effectiveness, and can even have negative consequences for learning, when used with more experienced learners. This idea is known as the *expertise reversal effect* (Kalyuga et al., 2003).

The expertise reversal effect is a clear example of an aptitude-treatment interaction (Cronbach & Snow, 1977), and numerous studies have provided evidence that this effect generalizes across a wide range of learners and instructional methods (Kalyuga et al., 2003; Kalyuga, Chandler, & Sweller, 2000). The instructional design implication of the expertise reversal effect is conceptually straightforward but technically difficult to implement; simply stated, effective instructional materials must be tailored to the learner's level of expertise (Kalyuga & Sweller, 2004, 2005).

#### Proposed Experiment: Assessing the Role of Learner Experience in CLT

Current views of learning and instruction tend to focus on the use of minimally guided, authentic tasks to enhance student learning and motivation (Reigeluth, 1999; van Merriënboer, Kirschner, & Kester, 2003). These approaches, which include discovery learning (Bruner, 1961), anchored instruction (Cognition and Technology Group at Vanderbilt, 1997), problem-based learning (Evenson & Hmelo, 2000), and constructivist learning (Jonassen, 1999), to name just a few, all assume that such pedagogical techniques help learners integrate the knowledge, attitudes, and behaviors necessary for effective performance; enhance student motivation by providing an authentic context for learning; and, ultimately, enable students to transfer what is learned to novel problems encountered elsewhere (Kirschner et al., 2006). However, when considered from a CLT perspective, all of these approaches suffer from at least one significant flaw; specifically, that the working memory resources of learners, particularly novices, can quickly become overwhelmed by task complexity and, as a result, learning will suffer.

In an effort to manage intrinsic cognitive load when teaching complex material, Pollock, Chandler, and Sweller (2002) developed an instructional technique that artificially reduces element interactivity in to-be-learned material such that novices can circumvent working memory limitations and begin developing partial, rudimentary schemas. This technique, known as the “isolated elements” procedure, is used in the first phase of a training program and is followed by an “interacting elements” phase, which is characterized by the inclusion of all elements necessary for understanding. In a series of experiments, Pollock et al. (2002) found that a mixed instructional design (isolated elements followed by

interacting elements instruction) was superior to a conventional method (interacting elements used in both stages of instruction) for novice trade school students.<sup>3</sup>

### *Purpose of the Study*

Using a CLT framework, the proposed study will assess the role of learner experience on schema construction, transfer of learning, cognitive load, and motivational beliefs in the context of a computer-based, multimedia learning environment. In particular, the proposed study is designed to investigate the potential interaction between two instructional methods (mixed instructional design and conventional instructional design) and learner experience in a domain with high element interactivity – the human circulatory system. The study will address the following research questions and associated hypotheses:

RQ1: What are the comparative effects of the mixed instructional design condition versus the conventional condition on: (a) performance, as measured by students' mental model representations and scores on a transfer test; (b) cognitive load during instruction; and (c) self-efficacy beliefs?

H1: The mixed instructional design (i.e., the method aimed at reducing intrinsic cognitive load) will be more beneficial in terms of enhancing performance, reducing self-reported cognitive load, and raising self-efficacy as compared to the conventional instructional design (Pollock et al., 2002).

RQ2: Does learner experience interact with instructional method to differently influence performance, cognitive load, and self-efficacy beliefs?

H2: There will be a significant interaction between learner experience and instructional design method (i.e., learners' prior knowledge will moderate the effectiveness of the mixed instructional method). Stated another way, the benefits of the mixed instructional design will be stronger for low prior knowledge learners than for high prior knowledge learners. However, based on the findings of Pollock et al. (2002) and Lee, Plass, and Homer (2006), the mixed instructional design is not expected to *negatively* impact more advanced learners (i.e., full reversal is not expected).

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<sup>3</sup> Pollock et al.'s (2002) mixed versus conventional instructional designs are conceptually similar to Mayer and Chandler's (2001) distinction between part-whole and whole-whole instructional presentations.

### *Methods*

The proposed study uses an experimental design with two conditions: treatment group (mixed instructional design) versus comparison group (conventional instructional design). Students will be randomly assigned to a condition, and their scores on a pretest (mental model representations) will be used to assess their prior knowledge in the domain of circulatory physiology. A multiple regression analysis will be employed to investigate the relationship between the independent and dependent variables. Multiple regression was chosen primarily because of its inherent flexibility as an analysis technique (Cohen, Cohen, West, & Aiken, 2003; Judd & Kenny, 1981). Additionally, multiple regression allows one to investigate interaction effects without having to use the extreme groups approach and subsequent dichotomization of continuous variables, a potentially problematic statistical practice (Cohen, 1983; Preacher, Rucker, MacCallum, & Nicewander, 2005).

*Participants.* A power analysis was conducted for the multiple regression with three independent variables (condition, prior knowledge, condition X prior knowledge interaction term) used to predict performance on the transfer task. Results indicated that a minimum of 84 participants will be needed to obtain a power of .80, at  $\alpha = .05$ , and with an expected moderate effect size of  $R^2 = .12$  (Cohen, 1988). Based on these results, a convenience sample of approximately 100 undergraduates (freshmen and sophomores) from the Department of Physiology and Neurobiology at the University of Connecticut will participate in the study. This particular sample was selected in an attempt to maximize variation in students' experience with, and conceptual understanding of, the circulatory system. The sample will include novices whose exposure to the circulatory system is limited to their primary and secondary school education, as well as more advanced students who have completed at least one introductory, college-level course in human anatomy and physiology.

*Measures.* All measurements will be administered using a computer-based, multimedia program.

(1) *Mental model representations.* Prior to completing their assigned course, students will take a pretest adapted from Azevedo and Cromley (2004). The pretest will be designed to assess students' initial mental model representations (i.e., schemas) of the circulatory system. Students will be given the

following instructions for completing their essay: “Please discuss everything you can about the circulatory system. Make sure you include the different parts of the system and their purpose, how they work individually and together, and how they support the human body.” Essays will be coded in accordance with the procedures outlined in Azevedo and Cromley (2004), and students will receive a score ranging from 1 (*no understanding*) to 12 (*advanced double-loop model*). An identical assessment will be used as a posttest measure of students’ mental model representations, and interrater reliability will be established by having two physiology instructors independently score all pre and posttest essays.

(2) *Transfer test*. After completing their assigned course, students will take a transfer test consisting of 15 multiple-choice questions. These items will require that students extend the concepts learned in the multimedia course to answer a set of novel questions about the circulatory system. Sample items include: “As central venous pressure increases, what happens to the heart’s stroke volume?” and “Which of the following blood vessels carries deoxygenated blood?”

(3) *Perceived cognitive load*. Immediately after completing their assigned course, students will respond to a single, self-report item designed to assess their invested mental effort (adapted from Paas & van Merriënboer, 1994). Participants will be asked: “Overall, how easy or difficult was it for you to learn about the circulatory system from the course you just completed? Click your answer.” The 7-point, Likert-type response scale will range from 1 (*extremely easy*) to 7 (*extremely difficult*). Subjective self-ratings of cognitive load were chosen because they are easy to implement, do not interfere with the primary instructional task, and have been used successfully in previous CLT research (Kalyuga et al., 2000; Paas & van Merriënboer, 1994).

(4) *Academic self-efficacy*. After completing their assigned course, but before taking the posttest, students will complete a 5-item, *academic self-efficacy* scale. The self-efficacy scale will be developed in accordance with Bandura’s (2006) guidelines and will assess students’ confidence in their ability to answer questions about the human circulatory system (see Appendix B).<sup>4</sup> The 7-point, Likert-type

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<sup>4</sup> Prior to its use, a pilot study will be conducted to explore reliability and validity evidence for the self-efficacy scale.

response scale will range from 1 (*not at all confident*) to 7 (*extremely confident*). Perceived self-efficacy is being used in the proposed study to address recent appeals to include measures of motivation in studies that utilize a CLT framework (e.g., Gerjets & Scheiter, 2003; Moreno, 2005, 2006; Paas, Tuovinen, van Merriënboer, & Darabi, 2005). As Paas et al. (2005) have noted, “cognitive load researchers need to determine the motivational effects of instructional conditions...as well as assist instructional designers to recognize the power of authentic learning environments in enhancing the motivation of learners” (p. 27).

*Instructional Conditions.* The proposed study will use two instructional conditions.

(1) *Mixed instructional design.* The mixed instructional design version of the multimedia lesson will be developed to artificially reduce element interactivity. Following the isolated elements technique of Pollock et al. (2002), the lesson will be delivered in two, 25-minute phases. In phase 1, students will be presented with isolated elements of the to-be-learned material. In this portion of the training, interactions between components of the circulatory system *are not* emphasized, thereby reducing working memory load for novice learners and aiding with schema development (Pollock et al., 2002). In phase 2, students will be presented with interacting elements instruction that *does* emphasize the interactions between elements of the material and, as such, will provide students with all the information needed to gain meaningful understanding of the circulatory system as a whole.

(2) *Conventional instructional design.* The conventional instructional design version of the multimedia lesson will use the interactive elements instruction during *both* 25-minute phases (Pollock et al., 2002). That is, in both phases students will be presented with instruction that emphasizes the interactions between components of the circulatory system, thereby providing students with all the information needed to gain meaningful understanding of the entire system.

*Procedures.* The experiment will be conducted over the course of two days. On day one, participants will be randomly assigned to a computer station loaded with either the mixed or conventional instructional design program. Students will be provided with an overview of the entire study and will complete a questionnaire containing background and demographic items. Next, students will be given 15 minutes to complete the pretest (mental modal representation).

On day two, students will complete their assigned instructional program. Each multimedia lesson will be administered over two, 25-minute phases with a 10-minute break between phases. After completing phase 2 of the lesson, students will complete the perceived cognitive load scale, followed by the self-efficacy scale. Next, students will be given 30 minutes to complete the posttest: 15 minutes for the mental modal representation task and 15 minutes for the transfer test. See Appendix C for a graphic overview of the experimental procedures.

*Statistical Analyses.* A multiple regression analysis will be used to answer both research questions. Four separate regression analyses will be conducted for each dependent variable (mental modal representation, transfer test, cognitive load, and self-efficacy). Following the recommendations of Aiken and West (1991), the prior knowledge variable (pretest score on the mental model representation) will be centered and the categorical variable (condition) will be dummy coded (mixed instructional design = 0; conventional instructional design = 1). Additionally, an interaction term will be created by computing the cross-product of the condition and prior knowledge variables. For each of the four regression models analyzed, the three independent variables (condition, prior knowledge, condition X prior knowledge interaction term) will be entered together in one block. Main effects due to condition and prior knowledge will be assessed by inspecting the regression coefficients for the simple terms. An interaction effect will be assessed by inspecting the regression coefficient for the interaction term. If the regression coefficient for the interaction term is found to be statistically significant, post hoc probing will be conducted by graphing the simple slopes and testing their significance (Aiken & West, 1991).

### Summary

The purpose of this paper was to provide a summary of CLT and its major pedagogical implications. The paper included a short description of human cognitive architecture and a description of what makes CLT different from other cognitive theories; namely, its focus on theory application. Next, the paper presented a discussion of the expertise reversal effect – the CLT notion that the effectiveness of certain instructional techniques depends, in part, on the learner’s experience. Finally, the paper ended with a brief description of an experiment designed to assess the role of learner experience in CLT.

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## Appendix A

Some CLT Effects and How They Reduce Extraneous Cognitive Load (adapted from Sweller et al., 1998)

Table A1

CLT Effect	Instructional Description	Extraneous Load
Goal-Free Effect	Replace conventional problems with goal-free problems that provide learners with a non-specific goal	Reduces extraneous load caused by relating a current problem state to a goal state and attempting to reduce the difference between them
Worked Example Effect	Replace conventional problems with worked examples that must be carefully studied	Reduces extraneous load caused by weak-method problem solving
Completion Problem Effect	Replace conventional problems with completion problems, providing a partial solution that must be completed by the learner	Reduces extraneous load because giving part of the solution reduces the size of the problem space
Split Attention Effect	Replace multiple sources of information (i.e., separate pictures and text) with a single, integrated source of information	Reduces extraneous load because there is no need to mentally integrate the information sources
Modality Effect	Replace a written explanatory text and another source of visual information (e.g., a diagram) with a spoken explanatory text and a visual source of information (i.e., use multiple modalities)	Reduces extraneous load because multimodal presentation uses both the visual and auditory processors of working memory
Redundancy Effect	Replace multiple sources of information that are self-contained (i.e., they can be understood on their own) with one source of information	Reduces extraneous load caused by unnecessary processing of redundant information

## Appendix B

## Academic Self-Efficacy Scale (adapted from Bandura, 2006)

Please rate how confident you are that you can answer questions about the human circulatory system at each of the levels described below.

*Rate your degree of confidence using the following response scale:*

not at all confident 1	2	3	confident 4	5	6	extremely confident 7
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1. Can answer 20% of the questions
2. Can answer 40% of the questions
3. Can answer 60% of the questions
4. Can answer 80% of the questions
5. Can answer 100% of the questions

Appendix C

Overview of the Experimental Procedures

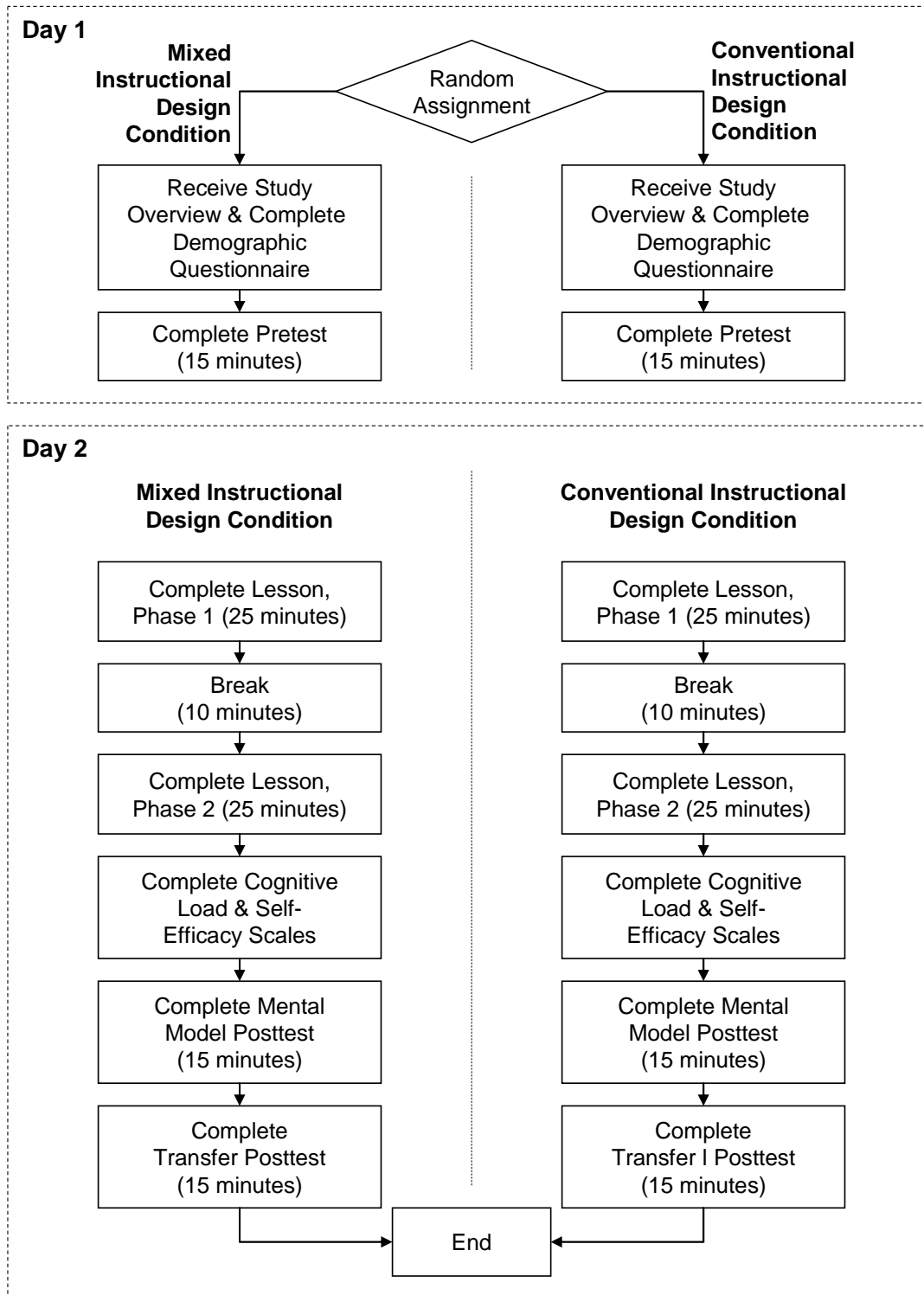


Figure C1. Overview of the experimental procedures.