2010

The effects of using screencasting as a multimedia pre-training tool to manage the intrinsic cognitive load of chemical equilibrium instruction for advanced high school chemistry students

Ramsey Musallam

Recommended Citation
Musallam, Ramsey, "The effects of using screencasting as a multimedia pre-training tool to manage the intrinsic cognitive load of chemical equilibrium instruction for advanced high school chemistry students" (2010). *Doctoral Dissertations*. 381.
https://repository.usfca.edu/diss/381

The University of San Francisco

THE EFFECTS OF USING SCREENCASTING AS A MULTIMEDIA PRE-TRAINING TOOL TO MANAGE THE INTRINSIC COGNITIVE LOAD OF CHEMICAL EQUILIBRIUM INSTRUCTION FOR ADVANCED HIGH SCHOOL CHEMISTRY STUDENTS

A Dissertation Presented
to

The Faculty of the School of Education
Learning and Instruction Department

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Education

by
Ramsey Musallam
San Francisco
May 2010

THE UNIVERSITY OF SAN FRANCISCO
Dissertation Abstract

The Effects of Using Screencasting as a Multimedia Pre-Training Tool to Manage the Intrinsic Cognitive Load of Chemical Equilibrium Instruction for Advanced High School Chemistry Students

Chemistry is a complex knowledge domain. Specifically, research notes that Chemical Equilibrium presents greater cognitive challenges than other topics in chemistry. Cognitive Load Theory describes the impact a subject, and the learning environment, have on working memory. Intrinsic load is the facet of Cognitive Load Theory that explains the complexity innate to complex subjects. The purpose of this study was to build on the limited research into intrinsic cognitive load, by examining the effects of using multimedia screencasts as a pre-training technique to manage the intrinsic cognitive load of chemical equilibrium instruction for advanced high school chemistry students.

A convenience sample of 62 fourth-year high school students enrolled in an advanced chemistry course from a co-ed high school in urban San Francisco were given a chemical equilibrium concept pre-test. Upon conclusion of the pre-test, students were randomly assigned to two groups: pre-training and no pre-training. The pre-training group received a 10 minute and 52 second pre-training screencast that provided definitions, concepts and an overview of chemical equilibrium. After pre-training both groups received the same 50-minute instructional lecture. After instruction, all students were given a chemical equilibrium concept post-test.

Independent sample t-tests were conducted to examine differences in performance and intrinsic load. No significant differences in performance or intrinsic load, as measured by ratings of mental effort, were observed on the pre-test. Significant differences in performance, $t(60) = 3.70$, $p = .0005$, and intrinsic load, $t(60) = 5.34$, $p = .0001$, were observed on the post-test. A significant correlation between total performance scores and total mental effort ratings was also observed, $r(60) = -0.44$, $p = .0003$. Because no significant differences in prior knowledge were observed, it can be concluded that pre-training was successful at reducing intrinsic load. Moreover, a significant correlation between performance and mental effort strengthens the argument that performance measures can be used to approximate intrinsic cognitive load.

This dissertation, written under the direction of the candidate's dissertation committee and approved by the members of the committee, has been presented to and accepted by the Faculty of the School of Education in partial fulfillment of the requirements for the degree of Doctor of Education. The content and research methodologies presented in this work represent the work of the candidate alone.

Candidate, Ramsey Musallam April 27, 2010

Dissertation Committee

Chairperson, Dr. Xornam Apedoe April 27, 2010

Dr. Mathew Mitchell April 27, 2010

Dr. Susan Prion April 27, 2010

Acknowledgements

I would like to express my deepest gratitude to Dr. Xornam Apedoe who guided me through the analysis and write up of this study. Dr. Apedoe's thorough and timely responses to my questions, and her confidence in me as a novice researcher, was incredibly empowering.

I would like to thank Dr. Mathew Mitchell for introducing me to the intricacies of Cognitive Load Theory, and for modeling how to design and organize innovative and cutting-edge learning environments. Dr. Mitchell's use of technology has expanded the way I see the classroom, and has opened new and exciting doors for me as an educator.

I would like to thank Dr. Susan Prion for serving as a reader on my dissertation committee. As a nursing educator, her insight into the applications of chemical phenomena and background of this study were invaluable.

I would like to thank my family, namely my mother, Sarah Musallam, my father, Nabil Musallam, and my sister, Mariam Musallam, for their selfless love and support. My family's strong commitment to me as an individual has encouraged me to explore various career opportunities, and has amplified my curiosity and love for the world around me.

I would like to thank mother in-law, Patricia Gosa, and my father in-law, Jake Gosa, for taking a genuine interest in my personal and professional pursuits. They have both inspired me to approach my life in a holistic fashion, and to maximize all of the opportunities that cross my path.

Most importantly, I am deeply grateful to my loving wife Jessica, for her generous love, patience, and unwavering support throughout this process. Jessica, your presence as a partner, friend, and fellow educator inspired this work. Thank you for making it possible for me to embrace a career I love, and standing by my side every step of the way. I love you.

Dedication

To my wife, Jess.

TABLE OF CONTENTS

Tables

Figures

CHAPTER I

INTRODUCTION

A course in chemistry is a necessary first step for students who wish to pursue a career in science or health. Moreover, because chemistry is often the initial course taken by science majors at the college level, the subject is a filter for future study in science (Tai, Sadler, & Loehr, 2005). Despite the integral role that chemistry education plays in academics, there is a steady decline in the number of students choosing chemistry as a post-secondary major. Along with lack of interest, the course traditionally features low success rates, amplifying its role in limiting access to the sciences and related careers (Tai, Sadler, & Mintzes, 2006).

The complexity associated with learning chemistry is an active area of research (Colburn, 2009; Gabel & Bunce, 1994; Krajcik, 1991; Nakkleh, 1992; Stavy, 1995; Wandersee, Mintzes, & Novak, 1994). The research suggests that student misconceptions, both at the secondary and post-secondary levels, are born out of the complex skills required and such misconceptions could be catalysts for low performance (Banerjee, 1991; Hackling and Garnett, 1985; Tyson, Treagust, & Bucat, 1999). Keeping this in mind, movements in chemistry education are focused on the design of instruction that helps students negotiate the difficult concepts the subject presents (Johnstone, 2000; de Jong, 2000).

From a cognitive perspective, the complex nature of chemistry can be understood in the context of Cognitive Load Theory (CLT) (Sweller, 1988). According to CLT, working memory is limited in its ability to process information (Baddeley & Hitch, 1974; Miller, 1956). If processing demands exceed a learner’s cognitive capacity, meaningful learning will not occur (Chandler & Sweller, 1991; Mayer & Moreno, 2003). This observation is especially true with complex knowledge domains, such as chemistry (Ginns, 2005; Sweller, 1999; Sweller & Chandler, 1994). CLT suggests that the limited capacity of working memory is impacted by three different processing demands. The three demands, or *loads* are termed: intrinsic, extraneous, and germane load (Chandler & Sweller, 1991). *Intrinsic load* is a function of the complexity of the learning material (Paas et al., 2003; Sweller & Chandler, 1994). *Extraneous load* is created by the learning environment, and includes both the space where learning occurs and the mode of information presentation. (Carlson, Chandler & Sweller, 2003). *Germane load* is created while the learner processes information. Germane load is often considered to be useful load, that relates to the use of net working memory space after both intrinsic and extraneous load are accounted for (Paas & van Merriënboer, 1994).

Relative to chemistry education, intrinsic cognitive load describes the source of complexity innate to the subject. A subject has high intrinsic cognitive load, not because of the number of items that must be learned, but due to the interdependence of the items (Sweller, 1999; Sweller & Chandler, 1994). Ginns (2005) notes that basic techniques such as balancing chemical equations, which require learners to simultaneously predict the products of a reaction, and account for the relative numbers of chemicals involved, possess a high level of element interactivity. Through a more subject specific lens, when explaining the phenomenon of chemical equilibrium, a student could choose one of three different theoretical approaches: 1) Le Chatelier’s Principle, a conceptual approach; 2) reaction rates, an approach that merges equilibrium with chemical kinetics; and 3) equilibrium quotient, a more algorithmic strategy. While each of the three approaches explain chemical equilibrium from a different lens, a simultaneous understanding of each is necessary for meaningful learning to occur (Tyson et al., 1999).

As compared to extraneous and germane load, helping students manage intrinsic cognitive load is a new and promising area of research (Ayres, 2006; Gerjets, Scheiter & Catrambone, 2004, 2006; Kirschner, Paas, & Kirschner, 2009). Much of the limited research on intrinsic cognitive load involves modifications of instructional sequencing as a means of developing prior knowledge schema and decrease information complexity (van Merriënboer, Kirschner, & Kester, 2003; van Merriënboer , Kester, & Paas, 2006). The results thus far are particularly encouraging because they contradict the previously held assumption that intrinsic cognitive load cannot be manipulated by instruction (Sweller, van Merriënboer, & Paas, 1998).

The impact of instructional sequencing on intrinsic cognitive load has been explored using both traditional and multimedia-enhanced materials. In the multimedia learning literature, instructional sequencing is defined as *pre-training*. Mayer (2001) defined a multimedia instructional message as one that presents both words and pictures. According to the *pre-training principle* of multimedia learning, students learn more deeply from a multimedia message when they are exposed to the names and basic characteristics of a concept before instruction (Mayer, 2005a). For example, providing students with a summary of the major concepts of chemical equilibrium prior to instruction could facilitate deeper and more meaningful learning.

van Merriënboer et al. (2003, 2006) suggest that whole-task sequencing, where learner’s are exposed to a summary of the over arching concept prior to instruction is an effective tool at managing intrinsic cognitive load in complex learning domains such as chemistry. For the purposes of the current study, Mayer’s (2005a) multimedia definition of pre-training and the van Merriënboer et al. (2003, 2006) description of whole-task instructional sequencing are coordinated to yield new definition of pre-training that incorporates aspects of both interventions. Thus, in the current study, the term *pre-training* is used to described instructional sequencing in which the learner is introduced to not only the names and basic definitions of the concept at hand, but also is given a general, yet holistic introduction of the primary phenomena.

Research into instructional design that explores the efficacy of pre-training is limited, yet the results are consistent (Mayer, Mathias, & Wetzell, 2002; Mayer, Mautone, & Prothero, 2002; Pollack, Chandler, & Sweller, 2002). Despite promising results, the majority of pre-training research involves the use of short multimedia interventions in controlled laboratory environments. Mayer (2005a) indicated that there is a need for research in which the pre-training principle is tested with students in their own classrooms. Furthermore, research into pre-training only involves the analysis of cause-and-effect mechanical systems and physical systems in engineering and earth science fields and does not determine whether similar benefits occur in other knowledge domains.

A virtually unexplored multimedia technique that is gaining popularity as a pre-training vehicle is screencasting. A screencast is an audio and video recording of on-screen computer activity (Richardson, 2009). Given the ability to share a screencast online, the pre-training principle can manifest itself in a variety of environmental contexts, including homes and mobile devices (Bergman & Sams, 2008). Moreover, the ability to include audio narration and digital pen annotation increases learner control and makes it easier for an instructor to *off-load* text from the visual to the auditory channel in the working memory (Mayer, 2005).

Keeping with the above suggestions, the complexities associated with learning chemistry make the subject a suitable candidate for multimedia interventions aimed at manipulating intrinsic cognitive load. Of the limited research into intrinsic cognitive load management, no studies intentionally analyze the effects of pre-training, or other types of instructional sequencing in the chemistry classroom. Additionally, given the useful design features and lack of efficacy research, there is a need for studies that examine the use of screencasts as a pre-training tool in education. Mayer (2005c) echoes this gap: "…there is an urgent need for more research in the area of multimedia learning in chemistry" (p. 424).

Purpose of the Study

The purpose of the study was to examine the effects of screencasting as a pre-training technique to manage the intrinsic cognitive load of chemistry instruction to advanced high school chemistry students. Specifically, the treatment took place prior to a lesson on the major concepts of chemical equilibrium. The concept of chemical equilibrium was chosen because it is identified in the literature as a topic that is particularly complex (Banerjee, 1996; Tyson et al.,1999). Intrinsic cognitive load was measured by ratings of mental effort and performance on an equilibrium knowledge assessment (Paas & van Merriënboer, 1993).

Significance of the Problem

The problem identified in the study was significant for three primary reasons. First, it identifies a need for more studies that challenge the suggestion that intrinsic cognitive load cannot be manipulated by instruction (Sweller et al., 1998). Next, it calls for specific research that helps chemistry students negotiate the subject's high intrinsic cognitive load. Given the significant role chemistry plays in the sciences and health professional development, chemistry represents a logical avenue for more CLT research. Last, it responds to Mayer's (2005) call for more multimedia studies in chemistry by proposing an initial examination of screencasting as a pre-training intervention.

Theoretical Rationale

Mayer's (2001) Cognitive Theory of Multimedia Learning (CTML) outlines the cognitive context for the multimedia learning interventions used in this study. A thorough understanding of CTML requires an initial discussion of Sweller's (1998) Cognitive Load Theory (CLT). With CTML as the overarching framework, these two theories provide the theoretical rationale for this study.

Cognitive Load Theory

Cognitive Load refers to the impact or *load* new information has on working memory. The roots of CLT can be traced to Miller's (1956) hypothesis that working memory has a very limited capacity. Baddeley (1986), and Baddeley and Hitch (1974), corroborate the work by Miller, by proposing a theory of working memory based on the assumption that the capacity to hold and process information is limited. Initially proposed by Sweller (1988), Chandler and Sweller (1991) further developed CLT as a framework for instructional designers to follow when helping learners optimize performance during instruction.

Since its initial conception, CLT has evolved through the work of the original authors and other researchers who aim to optimize the limited capacity of working memory during instruction (Ayres, 2006; Chandler & Sweller, 1992; Sweller & Chandler, 1994). Chandler and Sweller (1991) differentiate between three types of cognitive load: extraneous, intrinsic and germane. *Extraneous cognitive load* is a function of how information is presented. The name of the term itself brings to light that which is unconnected to the subject, and is a sole function of the materials used and all that contributes to the design of the classroom environment. Extraneous cognitive load does not add to an understanding of the topic at hand, and unlike cognitive processes such as schema formation and automation, extraneous cognitive load is a load that is not necessary for learning. Examples of instructional techniques that could impose extraneous cognitive load include using weak problem solving methods such as working backward using means-end-analysis, or creating a setting where the learner has to search for information that is needed to complete a task. Related to the current study, overloading the working memory's ability to process information by presenting multiple sources in the visual form can induce extraneous cognitive load. By using interventions such as screencasts, the instructor can divert some of the written text towards the verbal channel via narration, thus enabling some of the cognitive load to be shifted to the auditory processor (van Merriënboer & Sweller, 2005).

Specific to the dependent variable of the current study, the term *intrinsic cognitive load* relates to the natural complexity that a specific knowledge domain offers. Intrinsic cognitive load is a function of the element interactivity a subject, or topic of information presents. Element interactivity refers to the ways in which the individual learning tasks required by a subject interact with one another (Ayres, 2006). Topics like chemistry are complex, and thus possess high intrinsic cognitive load, because multiple learning elements must be simultaneously assimilated in the working memory (Ayres, 2006; Ginns, 2005).

As expertise in a subject develops, multiple elements are incorporated into schema in the long-term memory. When this occurs, the learner can treat elements that were once interacting, as one unit, and thus the overall element interactivity (intrinsic cognitive load) decreases. This observation is central to the assumption that measurement of cognitive load requires a complete understanding of learner prior knowledge. Learners with more prior knowledge in a subject possess more domain specific schema helping them negotiate a high level of interacting elements (Kalyuga, Ayres, Chandler, & Sweller, 2003; Renkl & Atkinson, 2003). Past studies conducted in learning in complex learning domains provide an estimate of 6 or more interacting elements as being considered high (Ginns, 2005; Sweller, 2003).

Originally seen as the only static cognitive load subsystem, this study builds on recent research into intrinsic cognitive load aimed at making complex domains, such as chemistry, more accessible by helping students manage intrinsic cognitive load. The specific mechanism used in this study encouraged long-term memory schema formation using a form of instructional sequencing or *pre-training* (Renkl & Atkinson, 2003; Kalyuga, 2005; Mayer, 2005; van Merriënboer et al., 2003, 2006). Once extraneous and intrinsic cognitive load are accounted for, *germane cognitive load* is devoted to using available working memory space to process information, build schema and facilitate meaningful learning (Mayer & Moreno, 2003). In contrast to both extraneous and intrinsic cognitive load, germane cognitive load is a load that is effective for learning.

Similar to extraneous load, germane load is imposed by the method of instructional design (Sweller, 1988; Sweller et al., 1998).

Sweller (2005) argues that these three facets of cognitive load are additive. That is, the overall cognitive load placed on a learner can be calculated by summing extraneous, intrinsic and germane cognitive loads respectively. Although extraneous cognitive load does not hamper learning when tasks are low in element interactivity, it does interrupt when tasks are high in element interactivity and thus have high intrinsic cognitive load. Because intrinsic cognitive load is traditionally assumed to be the only load that is task based, and thus, not a function of the instructor, and was initially assumed to be a constant for a particular knowledge domain, research has placed an emphasis on reducing extraneous load, leaving more space for the learner to build germane load in the working memory (van Merriënboer & Sweller, 2005).

A review of the CLT literature revealed that much of the existing body of research on cognitive load management, specifically intrinsic cognitive load, places an emphasis on learning interventions that are that are text based (Ayres, 2006; Carlson, Chandler, & Sweller, 2003). Relative to the current study, less is known about the cognitive load in visual displays such as screencasts. Keeping this in mind, the following section represents a theoretical merger between CLT and the presentation of learning materials in a multimedia format.

Cognitive Theory of Multimedia Learning

Developed by Mayer (1997), a Cognitive Theory of Multimedia Learning (CTML) heavily builds upon the facets of CLT that relate to the limited capacity of working memory (Baddeley, 1986; Baddeley and Hitch, 1974; Miller, 1956)

Additionally, CTML draws on the *Dual Coding Theory* (Paivio, 1986), by proposing that visual and verbal information enter and are processed along different channels in the working memory. Thus, given a working memory foundation, using CLT as a framework for multimedia instructional design limits the potential for cognitive overload of either channel (Mayer, 2001).

Multimedia is defined as the presentation of information using both words and pictures. Keeping in mind CLT, a CTML embodies three major assumptions. First, the *dual-channel* assumption states that visual and verbal information is processed via separate channels in the working memory. Next, the *limited capacity* assumption notes that each channel in the working memory is limited in its ability to process new information. Finally, the *active processing* assumption posits that the working memory is actively trying to create coherent mental representations from information processed through each channel (Mayer, 2001).

Essentially, CTML details the steps that the learner must go through in processing visual and verbal information. According to CTML, the learner must first select relevant verbal and visual information from a presentation display. Next, the information is organized and processed into coherent mental representations in the working memory. Last, the mental representations are then integrated into existing knowledge in the long-term memory where they will be incorporated into prior knowledge next time the same information is presented (Mayer, 2001; Mayer & Moreno; 2002; Plass, Chun, Mayer, & Leutner, 1998, 2003). Thus, this model overlaps well with CLT, specifically intrinsic cognitive load management, in that overall element interactivity is decreased as information is processed in the working memory, and integrated into schema for future use. Figure 1 below shows a model of Mayer's (2001) proposed CTML architecture.

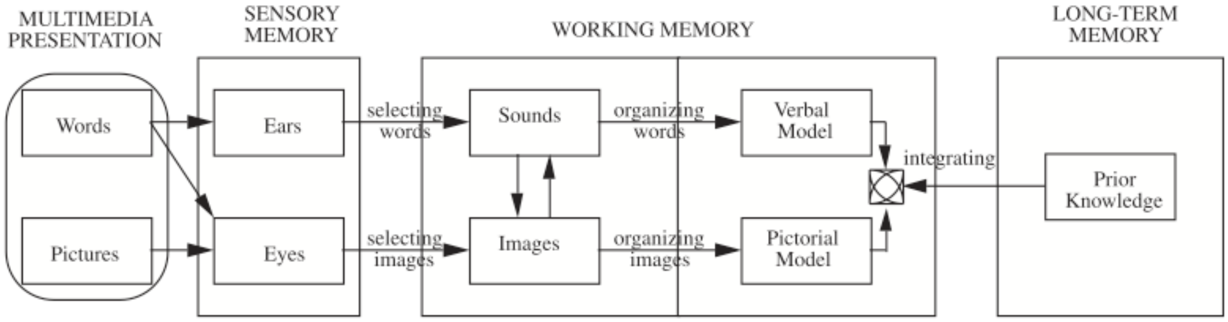


Figure 1. Mayer's CTML model (Mayer, 2001, p. 44).

With the three over arching CTML assumptions, and the learning architecture outlined in the above model, Mayer (2005a) identifies numerous design principles meant to assist instructors in creating multimedia interventions that are sensitive to cognitive overload. Specific to the current study, the *pre-training principle* provides the rationale behind using instructional sequencing to manage the intrinsic cognitive load of chemistry instruction through building prior knowledge, and thus domain specific schema. Other major principles include the *modality principle*, in which students learn better from animation and narration, rather than animation and text, and the *redundancy principle*, stating that students learn better from animation and narration than from animation, narration, and text.

Unlike CLT, or theories related to dual coding and working memory, CTML was a theory developed specifically for learning from multimedia instructional materials. However, the architecture of CTML is grounded in the work of dual coding by Paivio (1969), working memory by Baddeley (1986) and Baddeley and Hitch (1974), limited capacity by Miller (1956). Most significantly, the relationship between the facets of cognitive load introduced by Sweller (1988), provide the theoretical infrastructure for this current study. Given the use of screencasting as a multimedia tool to create domain specific schema, and thus help the learner manage high element interactivity, Mayer's (1997) CTML offers a theoretical reference point for the intervention, results and implications of this study.

Background and Need

Successful completion of a course in chemistry is a requirement for the majority of high school students in the United States. Over 60 % of all US public schools offer a Chemistry or Advanced Placement Chemistry program. Since 1998, the number of students taking the AP Chemistry Exam has risen from 1 million, to approaching 2.7 million in 2008 (College Board, 2008). Moreover, completing a post-secondary course in chemistry is a necessary first step for most careers in science or health (Tai et al., 2005).

Despite the large number of students taking chemistry nationwide and the inclusion of chemistry as a pre-requisite for the many careers in the health sciences, a significant drop in the number of students choosing chemistry as an undergraduate major is noted in the literature (Habraken, 1996). Keeping with this trend, understanding the mechanisms behind student performance and perception of chemistry has been an active area of research over the past ten years (Wandersee et al., 1994).

De Vos, van Berkel, and Verdonk (1993, 1994) argue that this downward trend is catalyzed by a growing disconnect between traditional high school chemistry curriculum, and recent movements in modern chemical research, technology and teaching pedagogy. This hypothesis is corroborated by Birk and Foster (1993) and Mills and Sweeney (2009) who claim that the traditional lecture method of teaching pervasive in American schools results in minimal learning and low performance.

Moving beyond the current didactic instructional paradigm, the inclusion of different instructional strategies into the chemistry classroom will help instructors access the cognitive strengths of all students (Francisco, Nicoll, & Trautmann, 1998). Chemistry educators and researchers will be challenged to familiarize themselves with the cognitive sciences, grounding pedagogy in useful theory and relevant to the known learning differences in the subject (Herron & Nurrenbern, 1999).

This strong relationship between chemistry education and human cognition is well documented in the literature. Not only is chemistry identified as a subject that is difficult to learn, the simultaneous conceptual and algorithmic thinking required further intensifies the complex problem solving and critical reasoning skills needed for success. Moreover, the intrinsic complexity of chemistry creates many student misconceptions that hinder performance (Colburn, 2009; Hackling and Garnett, 1985; Wandersee et al., 1994). Specifically, of the 96,458 secondary students who took the Advanced Placement (AP) Chemistry Exam last year, less than 60% received a score that would be deemed passing by colleges and universities nationwide (3 to 5 out of a maximum score of 5). The AP Chemistry passing rate noted places chemistry passing rates among the bottom third of all subjects tested (College Board, 2008).

From a cognitive perspective, it is argued that the need to coordinate and assimilate concepts or *elements* into knowledge constructs is the primary generator of information complexity in subjects like chemistry (Paas, Renkl, & Sweller, 2003; Sweller & Chandler, 1994; Tyson et al., 1999). Simple tasks are said to have low *element interactivity*, and contain elements that can be learned in isolation, whereas complex tasks contain elements that must be learned in concert with one another. A subject is complex, not because of the number of elements to be learned, but the need to simultaneously assimilate the many elements before meaningful learning can occur (Sweller, 1999; Sweller & Chandler, 1994).

Element interactivity is a term that comes from Cognitive load theory (CLT) (Chandler & Sweller, 1991; Sweller, 1988). The central tenant of CLT is that the human cognitive architecture contains a working memory that is limited in its ability to process new information (Baddeley and Hitch, 1974; Miller, 1956). CLT theory assumes that learning occurs through this limited working memory and an unlimited long-term memory that is structured into a hierarchy of knowledge constructs or *schemas* (Baddeley, 1986; Baddeley and Hitch, 1974). Mayer (2005b) refers to the processing capabilities of the working memory as the *cognitive capacity.* By designing instruction in a way that is sensitive to the cognitive capacity, *overload* can be avoided and meaningful learning can occur (Chandler & Sweller, 1992; Sweller & Chandler, 1991; Sweller & Chandler,1994; Sweller, 1999; Sweller et al, 1998). Sweller (2003) indicates that chemistry is a good example of a subject that possesses a high level of element interactivity.

Chandler and Sweller (1991) identified three different types of load that place processing demands on the working memory: intrinsic, extraneous and germane. *Intrinsic load* is caused by the natural complexity of material to be learned, and as discussed above, is directly proportional to element interactivity (Paas et al., 2003; Sweller & Chandler, 1994). *Extraneous load* relates to the manner in which information is presented. When a learner devotes working memory space to a task not directly related to the learning task, extraneous load is increased (Carlson et al., 2003). *Germane load* refers to the load created during schema formation and automation. Germane load is often considered to be useful load on working memory, while intrinsic and extraneous load are thought of as roadblocks to meaningful learning (Paas & van Merriënboer, 1994).

CLT researchers argue that the three sources of cognitive load are additive. For example, if extraneous and/or intrinsic cognitive are too high, the potential for *cognitive overload* in the working memory exists. Likewise, if the sum of extraneous and intrinsic load is reduced, more germane load can be directed towards active processing in the working memory (Ayres, 2006). CLT theory suggests that when complex information is delivered, such as that presented during a chemistry lesson, minimizing extraneous and intrinsic cognitive load allows for greater working memory allocation to germane load, and thus more meaningful learning (Carlson et al., 2003).

Due to the intimate relationship between extraneous cognitive load and instructional design, much of the past CLT research has focused on managing extraneous load. Instructional interventions that have been effective at reducing extraneous load include worked examples, establishing goal-free activities, imaging strategies, and interventions designed around the completion, modality and redundancy effects (Cooper, Tindall-Ford, Chandler, & Sweller, 2001; Ginns, 2005; Kalyuga, Chandler, Touvinen, & Sweller, 2001; Mayer & Moreno, 2003; Sweller, 1999; van Merriënboer, Schuurman, de Croock, & Paas, 2002). Despite the volume of the research devoted towards managing extraneous load in complex knowledge domains such as chemistry, the element interactivity of the material, and thus intrinsic cognitive load, may still occupy such a large portion of the limited working memory, that meaningful learning will not occur (van Merriënboer & Sweller, 2005).

Keeping the literature noted above in mind, the additive nature of extraneous and intrinsic load has been a deceiving equation for CLT researchers. Unlike extraneous load, research into instructional design has operated from the assumption that the intrinsic load of a subject cannot be decreased when learner prior knowledge is addressed. That is, element interactivity is inherent to the material and the learner's prior knowledge and is not a function of the environment or instruction (Sweller et al., 1998; Sweller & Chandler, 1994; Paas et al., 2003; Pollock et al., 2002). Subsequently, optimizing germane load by reducing only the extraneous load of the instructional environment has been a major theme in the CLT literature over the past decade (Ayres & Sweller, 2005; Low & Sweller, 2005; Mayer & Moreno, 2003).

Recently, CLT research has begun to shift its attention towards intrinsic cognitive load. Kalyuga, Ayres, Chandler and Sweller (2003) noticed that as a learner develops content expertise, the element activity of a task decreases as the interactions become incorporated into long-term memory schema. Thus, if a learner possesses long-term memory schema for a particular task, he or she is able to treat multiple interacting elements as single entities or *chunks*, resulting in a decrease in element interactivity (Ayres, 2006). For example, studies have shown that instructional sequencing, where instruction is broken up into two instructional segments, has been effective as a schema acquisition method **(**Pollock et al., 2002; van Merriënboer et al, 2003, 2006).

As mentioned earlier, *whole-task sequencing* has shown promise as an intrinsic cognitive load management technique for learning materials that are particularly complex (van Merriënboer et al., 2003, 2006). In whole-task sequencing, instruction is segmented into two phases. During the first phase, elements that are most fundamental to the whole complex task are presented. During the second phase of instruction, the entire task is presented in its full complexity. Whole-task sequencing provides learners with a quick impression of the learning material, which can be further elaborated during the second phase of instruction. In contrast to *part-task sequencing* where interacting elements are isolated during the initial instructional phase, whole-task sequencing progresses from simplified to more complex versions of the whole learning task (Pollock et al., 2002; van Merriënboer, 1997; van Merriënboer et al., 2003, 2006; van Merriënboer & Sweller, 2005).

Whole-task sequencing is described in the multimedia learning literature as *pre-training* (Pollack et al., 2002; Mayer et al., 2002). Similar to the methods outlined above, the *pre-training principle* of multimedia learning notes that deeper and more meaningful learning occurs when students are exposed to the main concepts and ideas before instruction (Mayer, 2005a). Whereas the CLT literature base refers to the management of *elements* in the working memory as intrinsic cognitive load, multimedia learning researchers use the term *essential processing* to describe the integration and organization needed to support meaningful learning (Mayer, 2005a; Sweller & Chandler, 1994; Sweller, 1999). Although semantic differences exist, the pre-training research base represents a promising medium for designing instruction in subjects, such as chemistry, that present high levels of element interactivity. In the current study, information complexity was described through a CLT lens, and the term *intrinsic cognitive load* was utilized.

As stated earlier, the current study uses an alternative definition of pre-training that represents a merger of Mayer's (2005a) general definition of pre-training and the van Merriënboer et al (2003, 2006) definition of whole-task instructional sequencing. Pre-Training is defined in the current study as instructional sequencing in which the learner is introduced to not only the names and basic definitions of a concept, but also is given a a holistic introduction of the primary phenomena being studied.

Although pre-training represents a promising merger between the multimedia learning and cognitive load literature, more research is needed that studies the effects of multimedia at managing the specific complexities inherent to learning chemistry (Mayer, 2005c). The call for research in the area of multimedia is corroborated by current trends in culture and society (Richardson, 2009). According to a recent survey, 62% of all adult Americans are part of a wireless, mobile population that participates in digital activities from home or work. Furthermore, 58% of all adult Americans have used a cell phone to do non-voice related activities, and 41% have logged onto the internet on-the-go from a wireless device (Pew, 2009).

Over the past few years, *screencasts* have emerged as commonly used multimedia instructional tools (Richardson, 2009). Screencasts are recordings of all computer on-screen activity including mouse movements, clicks and audio, that can be saved as a video file and distributed online to an intended audience (Peterson, 2007; Richardson, 2009). Keeping in mind the accessibility data noted above, the distribution of screencasts online makes them a potentially useful medium for pre-training. For example, students could access a screencast of a simplified version of a chemistry lecture prior to instruction from a home computer, laptop, or a mobile device. Teachers could include voice narration to accompany diagrams and add digital annotations using tablet pen technology to scaffold problem-solving techniques for students. (Bergman & Sams, 2008).

The use of screencasts in education is also supported by the *personalization, voice* and *image* principles of multimedia learning (Mayer, 2001). The personalization and voice principles state that deeper learning occurs when words are in conversational tone rather than formal and/or computer generated. The narrated feature of a screencast gives the instructor freedom to personalize his or her accordingly. The image principle provides rationale for the *on-screen* recording facet of a screencasts indicating the students do not necessarily learn more when the narrator's image is visible on the screen.

The personalization, voice and image principles are supported by a *Social Agency Theory of Multimedia Learning* (Mayer et al, 2003). Viewed as an enhancement to the CTML, social agency theory posits that multimedia learning environments can be designed to encourage learners to operate under the assumption that their relationship with the computer is a social one, in which the conventions of human-to-human relationships exist. Once this social partnership exists, learners can rely on basic social rules that guide their interaction with the multimedia learning environment (Mayer, et al., 2003).

Despite the promising characteristics of screencasts as multimedia interventions to address the complexity of learning chemistry, a review of the research literature revealed limited research into the efficacy of using screencasts in the classroom and only one study that took place in the chemistry learning environment specifically (Peterson, 2007). Moreover, no studies that intentionally harnessed screencasts as intrinsic load management tools surfaced form the literature. As CLT research continues to address the management of intrinsic cognitive load through pre-training, a clear need exists for research into the efficacy of using screencasts to improve learning in complex knowledge domains such as chemistry.

Research Questions

The research questions are as follows:

1. What are the effects of pre-training on the intrinsic cognitive load of chemical equilibrium instruction for advanced high school students as measured by ratings of mental effort?
2. What are the effects of pre-training on advanced high school chemistry students' performance on an equilibrium concept assessment?
3. What is the relationship between intrinsic cognitive load, as measured by ratings of mental effort and advanced high school chemistry students' performance on an equilibrium concept assessment?

Definition of Terms

Chemical Kinetics: The study of rates of reaction collisions in a chemical process (Zumndhal, 2007).

Chemical Equilibrium: The branch of chemistry that describes a dynamic condition when the concentration of reactants and products in a chemical reaction remain constant as a function of time (Zumdahl, 2007).

Cognitive Load Theory: A learning theory that is based on the assumption that a human's working memory has only a limited capacity to store information. Cognitive load theory describes the distribution of working memory resources during the learning process (Sweller, 1988).

Cognitive Theory of Multimedia Learning: A learning theory based on the assumption that people possess dual channels for processing verbal and visual information, that each channel is limited in how much information it can process, and that meaningful learning involves engaging and actively processing information appropriately (Mayer, 2001).

Dual Coding Theory: A learning theory that is based on the assumption that both visual and verbal information is processed along different channels in the brain (Paivio, 1986).

Element Interactivity: Refers to the way individual elements of a task interact with one another (Ayres, 2006).

Equilibrium Quotient: A mathematical expression used to describe the equilibrium position of a chemical reaction (Zumdhal, 2007).

Essential Processing: The cognitive processing that is required to make sense out of words and pictures needed to achieve an instructional objective (Mayer, 2005).

Extraneous Cognitive Load: The load placed on working memory created by the instructional conditions and learning environment (Ayres, 2006).

Germane Cognitive Load: The load placed on working memory during schema formation and automation (Sweller, van Merriënboer, & Paas, 1998).

Intrinsic Cognitive Load: The load placed on working memory by the element interactivity of the learning material (Ayres, 2006).

Le Chatelier's Principle: A theory used to predict the effect of change in conditions on a chemical equilibrium (Zumdhal, 2007).

Mental Effort: A measure of the perceived level of cognitive energy that must be spent when performing an instructional task (Paas & van Merriënboer, 1993).

Multimedia: A form of communication that uses words and pictures to foster meaningful learning (Mayer, 2001).

Pre-training: Pre-Training is defined in the current study as instructional sequencing in which the learner is introduced to not only the names and characteristics of a concept, but also are given a holistic introduction to the primary phenomena.

Pre-training Principle: An instructional design principle that states that people learn more deeply from a multimedia message when they know the name and characters of the main concepts (Mayer, 2005a).

Schema: A long-term memory structure that is the basis for content expertise and meaningful learning (Kalyuga, Ayeres, Chandler, & Sweller, 2003).

Screencast: A digital recording of computer screen output, often containing audio narration (Richardson, 2009).

Working Memory: A limited and multifaceted cognitive information storage and processing system (Baddeley, 1986).

Summary

Despite the crucial role a chemistry education plays in training science and health professionals, the literature notes dropping enrollment and low success rates both at the secondary and post-secondary level (Habraken, 1996). The innate complexity of the chemistry is often cited as a catalyst for low performance and lack of interest (Tai, et al., 2006). From a cognitive perspective, the complexity of chemistry can be understood in the context of cognitive load theory (Sweller, 1988). Due to the need to coordinate and assimilate various concepts for meaningful learning, chemistry is said to have a high intrinsic cognitive load (Chandler & Sweller, 1991). Although limited, the CLT and multimedia literature note that pre-training has been successful at managing intrinsic cognitive load (Mayer et al, 2002; Pollack et al, 2002). This study examined efficacy of using screencasts, a new emerging type of multimedia, to manage the intrinsic cognitive load of chemistry instruction.

CHAPTER II

REVIEW OF THE LITERATURE

The purpose of this study was to assess the effects of pre-training on the intrinsic cognitive load of chemistry instruction for advanced high school students. The review of the literature focused on four major areas relevant to the research questions. The first section explores misconceptions in chemistry instruction that further intensify the complexities the subject presents. Specifically, *chemical equilibrium* is used as a lens because the topic is identified in the research literature as being particularly complex (Banerjee, 1995; Tyson et al.,1999). The second section provides a review of general characteristics of pre-training as discussed in the literature, and the third section addresses studies aimed at managing intrinsic cognitive load through pre-training. Given the complex knowledge domain of the current study, the term *pre-training* is ultimately expanded to include both Mayer's (2005a) definition, and the van Merriënboer et al. (2003, 2006) description of *whole-task instructional sequencing*. This section highlights literature that has utilized pre-training as a technique to decrease the element interactivity of complex knowledge domains such as chemistry. The fourth section provides a review of various multimedia learning principles that present a case for the use of screencasts as an intrinsic cognitive load management tool for chemistry instruction.

Chemistry Education

Past research has shown that chemistry is a complex knowledge domain. The concepts in chemistry are abstract, and students struggle to coordinate the many symbolic representations needed for meaningful learning (Colburn, 2009). Consequently, students develop misconceptions that can hinder performance (Wandersee et al., 1994). Breuer

(2002) noted that the widely accepted paradigm that *chemistry is difficult* can be attributed to the diversity of activities and skills, both algorithmic and conceptual, that the learner must coordinate. Such requirements could be a significant catalyst for the decrease in interest and post-secondary enrollment noted in the literature over the past three decades (Tai et al., 2006).

Related to the current study, a thorough review of the literature revealed chemical equilibrium to be a content area that contains a high level of complexity for both secondary and post-secondary students. Hackling and Garnett (1985) note that chemical equilibrium is an important concept that underlies much of the chemistry curriculum for advanced high school students and college students. Voska and Heikkinen (2000) corroborated this observation, and specifically pointed to a necessary interdependence between chemical equilibrium and essential topics, such as acid-base chemistry and electrochemistry. Despite the central role that chemical equilibrium plays in a thorough chemistry education, various student surveys have revealed chemical equilibrium as the most difficult concept to understand (Niaz, 1995). Kempa (1991) identified that a learning difficulty exists whenever students fail to grasp a concept as a result of prior knowledge and ideas held by the learner. The following sections provide a review of the major research studies that identify and address common misconceptions in chemical equilibrium, specifically with the concept of *equilibrium shifts,* defined as *Le Chatelier's Principle.*

Chemical Equilibrium Misconceptions

A study conducted by Banerjee (1995) investigated conceptual difficulties of students when learning about chemical equilibrium. Participants in the study were 60 students enrolled in an undergraduate chemistry course. Students were administered a 20-item paper-pencil achievement test on various aspects of chemical equilibrium after a series of 36 chemical equilibrium lectures. Similar to the current study, the instrument was constructed by the author, and validated by a group of colleagues. During a 16-week period, the author lectured on the qualitative and quantitative aspects of chemical equilibrium. Analysis of written responses on the achievement test and student interviews revealed widespread misconceptions and difficulties. Student misconceptions centered on the difference between equilibrium and non-equilibrium concentrations, and an incorrect use of Le Chatelier's Principle in explaining equilibrium shifts. Le Chatelier's Principle describes the way in which a chemical reaction at equilibrium shifts in response to environmental strain. Changes in pressure, temperature and concentration are all ways of manipulating the environment of a reaction at equilibrium according to this principle (Zumndahl, 2007). Given the diversity of possible manipulations, and the intrinsic concepts associated with each, Le Chatelier's Principle is a logical place for such misconceptions to exist (Hackling and Garnett, 1985). Consequently, this study focused on building prior knowledge schema in both the area of equilibrium and non-equilibrium concentrations and equilibrium shifts.

The misconceptions identified by Banerjee (1995) corroborated some of his pervious work (Banerjee, 1991). In a study designed to identify student misconceptions about chemical equilibrium, a 21- item diagnostic test was delivered to 120 chemistry students enrolled in a science teacher preparation course after a series of lectures on chemical equilibrium. Student responses indicated extensive misconceptions in applying and interpreting Le Chatelier's Principle, solving quantitative equilibrium problems, and relating the rate of a reaction to the concept of equilibrium. For example, 35% of students felt that when the temperature of an exothermic reaction at equilibrium is decreased the rate of the forward reaction is decreased. This conceptual difficulty was also noted by Hackling and Garnett (1985), and represents a classic misinterpretation that arises from the complexity and need to coordinate various concepts such as temperature, concentration, and reaction rates when studying chemical equilibrium (Banerjee, 1991).

Pardo and Portholes (1995) investigated the reasons, strategies and procedures that students use when solving problems related to Le Chatelier's Principle. A group of 170 university students were administered a 5-item test after a 1- hour instructional phase on the basic concepts of chemical equilibrium. Each item focused on various aspects of interpreting chemical Le Chatelier's Principle. Students' written responses were categorized according to their reasoning and arguments. Results indicated that students had difficulties relating prior knowledge in chemistry to the equilibrium concept at large, specifically Le Chatelier's Principle. Students also struggled in using a quantitative approach to solving problems relating to equilibrium shifts. Rather than apply a numerical approach students chose the more conceptual Le Chatelier's Principle, but widespread misconception regarding its use led students to various incorrect assumptions. Coordinating the relationship between reaction rate, and equilibrium from the content of Le Chatelier's Principle proved to be a particular challenge. This problem has surfaced frequently in the literature (Banerjee 1995; Hackling & Garnett, 1985; Tyson & Treagust, 1999).

The Pardo and Portoles (1995) study noted particular student difficulties in negotiating the conceptual and algorithmic challenges of chemical equilibrium. For example, students favored the use of the very conceptual Le Chatelier's Principle, but misuse of the principle led to incorrect quantitative application. Niaz (1995) focused on this tension between the conceptual and algorithmic by comparing the performance on problems requiring both strategies. Seventy-eight undergraduate freshman chemistry students were administered an 11-item assessment based on different aspects of chemical equilibrium, both conceptual and algorithmic. Results indicated that students who did well on items conceptual in nature, on average, performed well on algorithmic items. Conversely, students who did well on algorithmic items did not show significant conceptual problem proficiency. This study provides evidence against a prevalent idea in chemistry education that the ability to solve computational (algorithmic) problems leads to conceptual understanding. This study supports research, such as that conducted in this study, designed to address misconceptions that arise from the complexity of conceptual approaches such as Le Chatelier's Principle.

This study operated from the assumption, as supported by the above studies, that chemical equilibrium is a complex knowledge domain for students and teachers. Specifically, chemical equilibrium contains a high level of element interactivity in that meaningful learning requires integration of quantitative concepts such as kinetics, stoichiometry and gas laws (Chandler & Sweller, 1991; Sweller, 1988; Tyson and Treagust, 1999). Erdemir, Geban, and Uzuntirayaki (2000) investigated misconceptions that surface from the interdependence between chemical equilibrium, and overlapping concepts such as reaction rates. In their study, 143 freshman science majors taking a general chemistry participated in the study. Upon conclusion of a 2-week unit on chemical equilibrium including lecture and lab, a 25-item multiple-choice concept assessment developed by the authors was administered. From an element interactivity perspective, students performed poorly on items that required an integration of equilibrium and reaction rates. Moreover, students demonstrated difficulty in solving intermediate steps, such as performing metric conversions.

Keeping in mind the integration of concepts needed in solving chemical equilibrium problems, Voska and Heikkinen (2000) attempted to quantify the techniques students used when negotiating the complexity of equilibrium, specifically Le Chatelier's Principle. A 10-item instrument, Test to Identify Student Conceptualizations (TISC), was administered to a group of second-semester general chemistry students at a university. Voska and Heikkinen's (2000) results mirrored that of previous work done to identify procedures that students use to negotiate the complexity of chemical equilibrium (Hackling & Garnett, 1985; Tsparlis, Kousathana, & Niaz, 1998). The following logical schemata of chemical equilibrium problem-solving was discovered: 1) Establishing equilibrium, 2) analysis of equilibrium conditions, 3) analysis of partial pressures, 4) response to disturbance/Le Chatelier's Principle. Kousathana and Tsaparlis (2002) note that, depending on the equilibrium conditions, various other concepts such as ideal gas laws, density, and stoichiometry add to the element interactivity of the problem-solving schema outlined.

Kousathan and Tsaparlis (2002) investigated errors made in the application of the above problem-solving schema. In-line with the current study, the sample included 148 secondary advanced high school chemistry students (age 17-18). Instruction on chemical equilibrium designed and delivered by the authors was given to the students. As part of the instructional sequence, students were first taught the commonly used schemata described above. Afterwards, when solving example problems, students were called to try and identify the schemata for a particular problem, and then were asked to write on a diagram the data according to the relevant steps. Students were then tested with 9 composite problems that assessed all the schemata described. Results indicated that students often failed to establish the correct equilibrium expression, often using the wrong numerical values in the expression. Consistent with past research, students also demonstrated misconceptions around the use of Le Chatelier's Principle as it applied to the disturbance of a reaction at equilibrium. Additional student difficulty was noted with extraneous concepts such as stoichioimetry, ideal gas laws, and reaction rates.

Addressing Chemical Equilibrium Misconceptions

Since Hackling and Garnett (1985) identified chemical equilibrium, specifically Le Chatelier's Principle, to be a complex and multi-faceted topic, much research has been conducted that supports their findings (Kousathan & Tsaparlis, 2002; Niaz, 1995; Voska & Heikkinen's, 2000). Where Kousathan and Tsaparlis (2002) aimed to identify the specific concepts that challenged chemistry learners, the next phase of research focused on equipping educators with strategies to address misconceptions about chemical equilibrium. As a precursor to this next chapter of literature, Kousathan & Tsaparlis (2002) suggest that teachers should pay special attention to related concepts such as stoichiometry, gas laws, and reaction rates before embarking on a unit in chemical equilibrium. Such concepts can add additional complexity to an equilibrium problem if a solid foundation does not exist. In response, work done by Niaz (1995), suggests that algorithmic problem solving precede conceptual questions, not only because the latter can be more demanding but also because the practice of algorithms can be conducive to the subsequent concept to be learned.

Akkus et al. (2003) conducted a study to investigate the effectiveness of using a constructivist approach over traditional instruction on student understanding of chemical equilibrium. Constructivism is a theory grounded in the work of psychologist Jean Piaget. Constructivism argues that humans construct and organize knowledge as a function of their own experiences (Mayer, 2005). Similar to the current study, the sample consisted of 71 secondary school chemistry students (age 16) from two chemistry classes taught by the same instructor. Students were randomly assigned to a treatment group, where they received constructivist-based instruction for a 5-week period. A 45-item chemical equilibrium concept test developed by the authors was administered as a pre-test to assess prior knowledge in chemical equilibrium and as a post-test to compare levels of conceptual change in the two groups. Results indicated that students with prior knowledge in chemical equilibrium scored higher on the post-test than students without prior knowledge. Similarly, students in the constructivist group also significantly contributed to variation in post-test achievement.

In addition to the wide range of misconceptions with the application of Le Chatelier's Principle, the literature notes a more overarching misconception with the definition of chemical equilibrium as a *dynamic* process. Students fail to understand the dynamic nature, and think that nothing more happens when the system reaches equilibrium. This misconception spans to instructors as well. When teachers are asked to explain that equilibrium is a dynamic process, many of them are not able to provide adequate explanations (Linn, 1987; Tobin and Espinet, 1989; Saricayir, Sahin, & Uce, 2006). The concept of dynamic equilibrium is a complex and symbolic process, and it is difficult to carry out an experiment that helps students and instructors visualize the process. Currently, equilibrium laboratory activities are limited to experiments around the equilibrium constant, and Le Chatlelier's Principle, and do not include hands-on investigations of dynamic equilibrium (Saricayir et al., 2006)

In response to the lack of activities explaining the dynamic nature of equilibrium, Ozdemir and Ardac (2009) added to research done by Saricayir et al. (2006) that investigated the effectiveness of using animated displays to help students understand the dynamic nature of chemical equilibrium. Similar to the current study, the study consisted of a multimedia intervention with 40 advanced secondary school chemistry students in two different classes. Both classes received similar instruction that included an animated computer display showing the molecular representations of the equilibrium state of a common chemical reaction. A pre-test to assess for prior knowledge in chemical equilibrium, an instrument during the animation asking students to explain their observations, and a post-test was administered to the participants. ANCOVA results comparing post performance of groups (treating prior knowledge as a covariate) showed no significant difference in their molecular representations, but did show a statistically significant difference in their ability to verbally explain the dynamic nature of equilibrium, and a difference in transfer scores.

Summary

Research has demonstrated that chemical equilibrium is a complex and multi-faceted topic in chemistry (Hackling and Garnett, 1985; Tyson & Treagust, 1999). Specifically, a large volume of learner and instructor misconceptions exist regarding the appropriate use of Le Chatelier's Principle in explaining the effect of strain on a reaction (e.g. Linn, 1987; Saricayir, Sahin, & Uce, 2006; Tobin and Espinet, 1989; Tsparlis, Kousathana, & Niaz, 1998). Grounding students in the conceptual side of equilibrium, constructivist based pedagogy, and multimedia interventions such as animated displays, have all been used to address misconceptions with Le Chatelier's Principle (Akkus, Kadayifci, & Atasoy, 2003; Harrison & De Jong, 2005; Niaz, 1995; Ozdemir and Ardac, 2009). From a cognitive perspective, an underlying theme that permeates the literature on chemical equilibrium is the high number of concepts students must integrate in order to achieve meaningful learning in the subject (Johnstone, 2000). Keeping this in mind, a review of the cognitive psychology literature involving the management of information complexity is needed.

Pre-Training as an Instructional Method

The intervention utilized in the current study is a process referred to as *pre-training.* Both the CLT literature, and the Multimedia Learning literature discuss the implications of pre-training in education. The term pre-training was first coined by researchers in the area of multimedia learning. In the CLT literature, *instructional sequencing* is the term used to describe the same process. Despite differences in terminology, both fields of research identify pre-training as a process of exposing students to an abbreviated version of a lesson prior to the full instructional phase (Mayer, 2005a; van Merriënboer et al., 2003, 2006). Specific to the methodology of the current study, the intricacies of the multimedia definition of pre-training and a type of instructional sequencing discussed in the CLT literature called *whole-task sequencing,* were merged to form a new definition to be applied in the current study.

Pre-Training in Multimedia Learning

Mayer (2005a) articulates pre-training in the realm of multimedia learning as a process that equips the learner with prior knowledge that will make it easier for the learner to process the material presented. Specifically, Mayer's definition of pre-training is a general one that involves providing students with the names and characteristics of the main concepts of a lesson. Mayer's definition is drawn from the Pre-Training Principle of Multimedia Learning that indicates that people learn more deeply from a multimedia message when they are provided the names and characteristics of the main concepts of a particular topic (Mayer, 2005a).

From a theoretical perspective, Mayer and Moreno (2003) note that when material is particularly complex, such as that in a multimedia lesson or chemistry lecture, or the material is presented at a fast pace, the learner may not have enough working memory space to engage in effective processing. Thus, arming students with the names and characteristics of the topic to be studied, will make it easier for them to process complex information by facilitating schema formation in the working memory. Specific examples of pre-training in the field of multimedia learning are outlined and discussed later in this chapter.

Whole-Task Instructional Sequencing

van Merriënboer et al. (2003, 2006) defines whole-task instructional sequencing as an abbreviated instructional series, prior to a complete lesson, that attends to the coordination and integration of skills in a holistic and overarching fashion. Because complex information, such as that presented in a lesson on chemical equilibrium, requires integration of skills, knowledge and multiple interacting elements, a whole-task approach is appropriate (van Merriënboer et al. 2003). The whole-task sequencing approach to pre-training stresses that learners quickly develop a holistic vision of the entire task at hand that is gradually embellished during the complete lesson to follow. In contrast to whole-task sequencing, an *isolated-elements* approach, where specific parts of a lesson are presented separately, and then coordinated in a complete instructional moment, will be discussed later in this chapter as well.

From a CLT perspective, complex information is difficult for learners to process because it contains multiple interacting elements that must be coordinated and assimilated simultaneously in the working memory. As previously noted, material high in element interactivity is considered to have high *intrinsic cognitive load*. Whole-task instructional sequencing helps learners process this information, by providing a holistic schema that assists them in *chunking* multiple elements in single units in the working memory, thus decreasing the number of elements interacting during the complete instructional episode (Ayres, 2006). In contrast to Mayer's (2005a) approach to pre-training, whole-task sequencing specifically tackles complex information by helping learners to build a temporary cognitive infrastructure regarding the topic of a lesson that can be used to more efficiently process and organize interacting elements (van Merriënboer et al. 2003, 2006).

Pre-Training in the Current Study

The mode of pre-training utilized in the current study embodies qualities of both Mayer's (2005a) definition, and components of the van Merriënboer et al. (2003, 2006) approach for two reasons. First, chemistry is a complex knowledge domain, and given the many interacting elements required for meaningful learning, a whole-task approach where students are presented a summary of the major concepts through a holistic lens, is appropriate (Colburn, 2009; van Merriënboer et al. 2003, 2006). Second, screencasting, a multimedia intervention, is used as the medium for pre-training in the current study. Because Mayer's (2005a) Pre-Training Principle states that exposure to the names and characteristics of the main concepts of lesson is an effective tool in multimedia learning environments, characteristics of this definition are incorporated as well.

Keeping the above logic in mind, pre-training is defined in the current study as instructional sequencing in which the learner is introduced to, not only the names and characteristics of a concept, but is also given a holistic introduction to the primary phenomena prior to instruction. To this end, students quickly develop the abbreviated, yet overarching cognitive infrastructure intrinsic to the van Merriënboer et al. (2003, 2006) definition, and also exploit the benefits of Mayer's (2005a) multimedia pre-training approach of exposure to names and characteristics. Figure 2 below outlines the differences and similarities between the Mayer's definition of pre-training, the van Merriënboer et al. definition of whole-task sequencing, and the definition of pre-training used in the current study.

Category	Pre-Training Components
Mayer (2005a)	Exposure to names and characteristics of main concepts only
van Merriënboer et al (2005, 2006)	Exposure to overarching principles and holistic summary of main concepts
Current Study	Exposure to names and characteristics, as well as overarching principles and holistic summary of main concepts

Figure 2. Pre-training according to Mayer (2005a), van Merriënboer et al. (2005, 2006), and the current study.

Intrinsic Cognitive Load

Central to Cognitive Load Theory (CLT) is an understanding that teaching complex information, such as chemical equilibrium, can lead to working memory overload. Therefore, in order to facilitate meaningful learning, cognitive load must be manipulated in such a way that working memory space can be allotted for information processing (Ayres, 2006). CLT researchers have identified three different sources of cognitive load during the presentation of information (Sweller, 1988; Chandler & Sweller, 1991). *Intrinsic cognitive load* is a function of the natural complexity of the information presented. The level of task integration, or element interactivity, is the main generator of high intrinsic cognitive load (Paas, Renkl, & Sweller, 2003; Sweller & Chandler, 1994). *Extraneous cognitive load* is created by the instructional mode and the conditions of the learning environment. Given the additive nature of intrinsic and extraneous load, *germane cognitive load* refers to the use of remaining working memory space for schema processing and schema automation (Paas, Renkl, & Sweller, 2003; Sweller, van Merriënboer , & Paas, 1998).

Ayres (2006) indicates that if the sum of intrinsic and extraneous cognitive load exceeds the parameters of working memory, cognitive overload can occur and meaningful learning will be inhibited. Over the past decade, a large number of studies testing the efficacy of strategies aimed at managing extraneous cognitive load have dominated the CLT literature base (e.g. Ginns, 2005; Sweller, 1999; van Merriënboer & Ayres, 2005). Given the previously held assumption that intrinsic cognitive load is solely a function of the learner's prior knowledge and cannot be manipulated by instruction, studies designed to lower intrinsic cognitive load are less prevalent (Ayres, 2006; Sweller, van Merriënboer, & Paas, 1998). Related to the current study, a review of recent literature focused on managing intrinsic cognitive load, specifically in complex areas such as chemical equilibrium, is necessary.

Managing Intrinsic Cognitive Load Through Pre-Training

Kalyuga et al. (2003) observed that as learners develop prior knowledge, the ability to develop domain specific schema also increases. Thus, the learner is capable of *chunking* multiple elements into smaller units in working memory, decreasing the overall element interactivity (Ayres, 2006). Variations of instructional sequencing, in which students are encouraged to build prior knowledge in a domain prior to instruction forms the majority of the intrinsic cognitive load management literature base. The multimedia learning literature refers to instructional sequencing as *pre-training* (Mayer, 2005a). Additionally, for the purpose of the current study, the term pre-training initially described by Mayer (2005a), is expanded to include the intricacies of whole-task instructional sequencing articulated by van Merriënboer et al. (2003, 2006).

Pollock et al. (2002) investigated the impact of managing intrinsic cognitive load in a highly complex learning domain. During the study, electrical engineering apprentices were exposed, in a laboratory setting, to two different phases of multimedia instruction on how to perform safety tests for electric appliances. In the first phase, the isolated components of each appliance were presented. This phase was followed by a second phase in which all the components and their necessary interactions were presented. After treatment, all students were scored on a problem solving transfer test concerning how the various elements of each appliance worked in concert with one another. Assessment results showed that learners who received pre-training performed better than students who did not receive pre-training. Keeping with the inverse relationship between prior-knowledge and element interactivity, the results of the study were specific to low-experienced learners. Learners with significant content expertise did not show positive effects (Mayer, 2005a).

The *isolated-elements* method of pre-training proposed by Pollock et al. (2002) represents an initial attempt at managing intrinsic cognitive load for beginning learners who still possess limited domain specific schema. In a similar study conducted by Mayer et al. (2002), some students received pre-training on the working of a car braking system or a bicycle tire pump prior to an animated multimedia narration explaining the topic. Pre-training followed the same method described by Pollock et al. (2002) in that the intricacies of the parts were explained in isolation first. For example, students learned about the workings of the piston, the characteristics of brake fluid, or the mechanism of a bike pump. Students were administered tests designed to assess problem-solving transfer. Although conducted in a laboratory setting, all students who received pre-training outperformed those who did not receive pre-training. In another laboratory multimedia intervention, Mayer et al. (2002) investigated the effects of pre-training on geology students. Specifically, students participated in a geology multimedia simulation in which they were to identify which geological feature was present on the earth's surface. Students assigned to the treatment group were shown illustrations of major geological features prior to participation in the simulation. Keeping with the results of previous studies, students in the pre-training group preformed better on a test of problem-solving transfer than did the non pre-training groups.

The three studies described above represent initial research into using pre-training as a tool for intrinsic cognitive load management. Given the multimedia, laboratory nature of each study, results indicate a need for tests within more valid learning environments such as with students in their native classrooms. Moreover, these initial studies all took place with students in similar, physical science knowledge domains. A need for research in other subjects such as mathematics and the social science was implicit in the discussion of the studies (Mayer, 2005a).

Ayres (2006) expanded upon the isolated-elements pre-training strategy initially proposed by Pollack et al. (2002). In response to recommendations from the literature, Ayres (2006) investigated the efficacy of pre-training in a mathematical domain. The participants were 78 eighth-grade female students (mean age 13.1). In this experiment, three different strategies were compared. The first strategy was an integrated approach in which a math problem was presented in its entirety. The second strategy was consistent with the pre-training phase implemented by Pollock et al. (2002) in which the individual calculations (isolated elements) were given, and sequentially completed. Of particular interest to the current study was the third strategy, based on the pre-training principles previously discussed (Mayer et al., 2002; Pollock et al. 2002). In this strategy, students moved from a pre-training phase in which elements were presented in isolation, and then an integrated mode in which they were given a problem in its full complexity. Results showed that this transition from isolated-elements to a more integrated form of pre-training strategy was not effective at managing intrinsic cognitive load. Given the data in support of the whole-task pre-training model up to this point (Mayer et al., 2002; Pollack et al., 2002) this outcome was surprising,

van Merriënboer et al. (2003) analyzed pre-training modules, with the goal of providing a model for managing intrinsic cognitive load in complex learning environments. In learning complex material, such as chemical equilibrium, learning is inhibited by the limited capacity of working memory, amplifying the role of intrinsic cognitive load management. The isolated-elements strategy is discussed in which complex learning tasks are broken down into simpler tasks, and are gradually combined into whole-task performances. The authors argue that, while successful for more simple learning environments, the integrated nature of complex learning tasks, such as with chemical equilibrium problems, does not respond well to the fragmented nature of such a pre-training method.

van Merriënboer et al. (2003) note that with complex learning environments, a *whole-task* pre-training approach is more suitable form of pre-training. In such a method, learners are exposed to simplified, but holistic pre-training sequences allowing for general connections to be made between interacting elements that can later be expanded upon during a more thorough instructional phase. In general, the authors suggest that the "whole-task approach…implies that recurrent aspects of performance are not trained separately but only practiced in the context of whole learning tasks" (van Merriënboer et al., 2003, p. 11). Despite this claim, van Merriënboer et al. (2003) state that an isolated-elements strategy should be used in concert with a whole-task approach for complex learning if a high level of repetition and automaticity is required for meaningful learning. In this case, a hybrid model is suggested by the authors.

The whole-task approach as a means of negotiating material containing high element interactivity is corroborated by van Merriënboer et al. (2006) as well. One method of emphasizing whole-task complexity during pre-training is to constrain learner performance by forcing them to behave as an expert. This is accomplished by requiring that they complete a complex task prior to entering an instructional phase. Additional methods such as worked examples or completion tasks are also suggested. Worked examples focus the learner on elements related to the solution, and completion tasks present the learner with partial tasks that must be completed. As low-expertise learners benefit from such strategies, task formats with low-element interactivity (worked examples, completion tasks) should be gradually replaced with conventional tasks that contain high levels of element interactivity. This method of moving from completion tasks to conventional tasks is referred to as *completion strategy* by the researchers (Renkl & Atkinson, 2003).

Research conducted by Gerjets et al. (2004) argues for the whole-task approach to complex problem solving suggested by van Merriënboer et al. (2003). The authors state that shifting from a *molar* to a *modular* approach is effective at negotiating the material that has high intrinsic cognitive load. In a molar view, similar to the isolated-elements method discussed, problems are broken down into individual categories and associated overall solutions strategies. In contrast, a modular approach mirrors the whole-task pre-training approach in that complex solutions are not divided into categories, but represented in smaller, holistic units that can be conveyed separately. The modular approach suggested differs greatly from the isolated-elements strategies discussed because it, much like a whole-task method, focuses on the total complex task rather than smaller subtasks. The modular approach also differs from the whole-task approach in that there is no alteration of learning task difficulty, as problems are still presented in their full complexity during pre-training, just broken into smaller, modular units (Gerjets et al., 2004).

To test the effect a molar vs. modular pre-training approach has on intrinsic cognitive load, Gerjets et al. (2004) conducted a study to test the efficacy of probability theory worked examples presented in the molar or modular format. The sample consisted of 68 post-secondary students from a technology institute. In addition to the molar/modular independent variable, the researchers also varied the degree of instructional explanations between the subjects. Half of the students in the study learned from elaborated examples of the problems and half learned from condensed worked examples that did not include instructional explanations. Analysis of data demonstrated that the example format influenced perceived intrinsic cognitive load, whereas the instructional explanations did not have a significant effect. Consistent with previous research conducted by the authors, participants who learned via the modular approach outperformed those students from the molar treatment group on problem solving transfer assessments.

In another examination using modular examples to manage intrinsic cognitive load, Gerjets et al. (2006) exposed 96 university students to a multimedia learning and problem-solving environment (HYPERCOMB) that teaches students how to calculate the probability of complex events. After taking a concept assessment used to assess for prior knowledge in the multimedia environment, problem examples were either presented in the more categorical, molar format, or with the holistic, modular approach. From an intrinsic cognitive load perspective, learners studying modular examples reported lower mental demands than did their molar counterparts. Additionally, participants in the modular group rated themselves as being more successful in learning the content presented. These results, and further variations of the HYPERCOMB environment, agree with results confirmed in previous research conducted on the difference between molar and modular worked examples as intrinsic cognitive load management strategies (Gerjets et al., 2004).

A possible critique of the research cited thus far is the narrow range of knowledge domains that have participated. All studies thus far have been restricted to specific areas of the physical sciences (engineering, geology, etc.) and probability theory. Gerjets et al. (2006) refutes this subject-specific criticism in stating that they "…are convinced that this approach might be extended to other well-structured domains…" (p.55). In response to this claim, and related to this study, research addressing the effects of using the various forms of pre-training discussed as intrinsic cognitive load management techniques in chemistry education is severely limited. Furthermore, a review of the literature revealed no studies that intentionally attempt to manage the high element interactivity inherent to the topic of chemical equilibrium. Although not within the realm of pre-training, the literature does cite a few studies in which intrinsic cognitive load was directly managed in the subject of chemistry.

Carlson et al. (2003) conducted two separate experiments in which diagrams of molecular models were used to decrease the overall element interactivity of a learning task. In the first experiment, 24 high school students were asked to construct two sets of molecular models through either diagrammatic or text-based instructions. The first sets of models were low in complexity, while the second set contained numerous interacting elements. Results indicated that as the complexity of the task increased, students benefitted from the use of diagrams. The group who received diagrammatic instruction for the complex model set reported lower perceived intrinsic cognitive load, and faster mean completion time than the non-diagrammatic group. The findings of the second experiment replicated the first, with diagrammatic format resulting in more learning than the equivalent text based instruction.

Similar to the methods of this study, Lee, Plass, and Homer (2006) measured the effects of intrinsic cognitive load management techniques in a multimedia chemistry environment. The study investigated the effects of using computer simulations to decrease the element interactivity of a lesson on gas laws in chemistry. The sample was 257 middle school students (ages 13-15). As in the current study, participants were chosen because while they possessed rudimentary skills in basic chemistry, they lacked prior knowledge in the specific topic used in the treatment. With respect to the treatment directly aimed at reducing intrinsic cognitive load, students were randomly assigned to groups representing visual displays of high or low complexity. Intrinsic cognitive load was altered by intentionally changing the number of interacting elements in the computer display. Specifically, high element interactivity explanations of the ideal gas law were separated into two lower element interactivity concepts on two different computer screens (pressure vs. volume, and temperature vs. volume categories). The group receiving treatment of high complexity received a variation of the display that required them to coordinate the relationships between temperature, pressure and volume simultaneously on a single computer display. The study found both greater comprehension and transfer when the element interactivity of the computer display was decreased by allocating components of the ideal gas law over two screens. These results indicate that it is possible to manage intrinsic cognitive load by, similar to the Carlson et al. (2003) study, manipulating the display of chemistry information.

In a recent study, Kirschner et al. (2009) investigated intrinsic cognitive load using student groups to negotiate information complexity. Although another non pre-training based technique, the intervention took place in a biology classroom, representing a knowledge domain similar to this study. The participants were 70 high school students enrolled in a biology course. Much like the sample in the current study, students were assumed to have the same prior knowledge because they all had followed the same course of study using the aligned instructional materials in previous years. All participants were given introductory instructional materials on the basic concepts of heredity to review individually. Students were then randomly assigned to either individual or group treatments where they worked on subsequent heredity learning tasks. Analysis of cognitive load and transfer measures indicated that group-based learning was favorable in managing complex learning tasks.

Measuring Cognitive Load

Regardless of the method, common to all the literature described above is an attempt to manage intrinsic the intrinsic cognitive load of a learning task. However, the measurement technique used to detect variations in intrinsic cognitive load are not included as part of the review above. The purpose of this section is to outline the major methods for measuring intrinsic cognitive load noted in the literature, with an emphasis on those techniques that were used in this study.

Brunken et al. (2003) indicate that cognitive load measurement can be categorized into *subjective* and *objective* measures. Subjective and objective assessment techniques can then be further sub-divided into indirect or direct measures of cognitive load. Indirect subjective measures primarily involve ratings of mental effort as a way to indirectly assess perceived difficulty of the learning material (Paas, 1992). Direct subjective measures ask students to comment on the difficulty of material as a way to directly measure the cognitive load imposed (Kalyuga, Chandler, Touvinene, & Sweller, 2001; Sweller, 1999).

The most common indirect objective method of investigating cognitive load effects is to use performance outcome measures (Mayer, 2001). Analysis of behavior or physiological patterns such as time-on-task and heart rate have also shown to be an objective way to indirectly assess changes in cognitive load (Astleitner & Leutner, 1996; Brunken & Leutner, 2001). Neuroimaging techniques that measure brain activity represent a promising route for direct objective measures of cognitive load (Smith &

Jonides, 1997). Despite the quality of data obtained, technical complexities and limitations of the duration and frequency of measurements make neuroimaging difficult in authentic learning environments (Brunken et al., 2003). *Dual-task-paradigm* use is another approach to directly and objectively measure cognitive load. Dual-task-paradigm is based on the assumption that the limited working memory space must be divided among simultaneous tasks. In this method, variations in either a primary or secondary task occurring simultaneously are measured as a way to assess schema formation and working memory limitations (Baddeley, 1986; Miyake & Shah, 1999).

Indirect subjective measures, such as ratings of mental effort are also commonly used to measure intrinsic cognitive load specifically. Introduced by Paas et al. (1994), based on research by Borg, Bratfisch, and Dornic (1971), ratings of mental effort are based on the assumption that students are capable of understanding their own levels of cognitive processing when reporting the amount of mental effort spent on a particular learning task (Paas, Tuovinene, Tabbers, & Van Gerven, 2003). Despite controversy around the efficacy of mental ratings, research has shown that students are able to assign a numerical value to their perceived level of mental effort (Paas, 1992). While most subjective measures contain multiple facets (i.e., mental effort, fatigue, etc.), Paas et al. (1994) suggest that one-dimensional scales that just ask students to rate mental effort are valid and sensitive to relatively small differences in cognitive load. The majority of the mental effort rating scales use 7 or 9 points ranging from very low to very high mental effort. The current study used a 5-point variation of the scale to match the format of the score-reporting sheet, and mirror cognitive load reporting in a study involving mental effort rating in the chemistry knowledge domain (Knaus et al., 2009).

As indicated above, Knaus et al. (2009) used a 5-point variation of the Paas (1992) mental effort rating scale to measure the cognitive load of a chemistry practice test designed and used by the authors. Similar to the current study, subjective ratings of mental effort were collected from a group of secondary students. Given score reporting parameters, the sample and knowledge domain of this research, this study used a scale identical to that used by Knaus et al. (2009). The scale's five descriptors of mental effort expenditure are: very little, little, moderate amounts, large amounts, and very large amounts. This study represents on of the few intentional attempts at measuring the intrinsic cognitive load of a chemistry learning task.

Although not in a chemistry class specifically, 88 university students of psychology and educational sciences participated in an experiment involving a multimedia intervention involving chemistry related topics of oxidation and reduction reactions occurring in the hemoglobin molecule (Seufert & Brunken, 2006). Performance was assessed using a 14-item post-test including tasks of recall, recognition comprehension and problem solving (an indirect-objective measure of cognitive load). Each assessment item was evaluated by a validity panel in order to determine the relative intrinsic cognitive load of the items. A subjective, 7-point mental effort rating scale was used to detect perceived differences in intrinsic cognitive load. With respect to performance measures, learning outcomes did not differ significantly between the treatment groups in the study. Significant differences were found in perceived intrinsic cognitive load as measured using a mental effort rating scale.

The Carlson et al. (2003) study, also utilized indirect objective and subjective measures of intrinsic cognitive load in chemistry. Mean completion time, and a 7-point mental effort rating scale were used to detect changes in the intrinsic cognitive load of instructions used to create molecular models in chemistry. In the Lee et al. (2006) study used to test the efficacy of animated simulations at managing the intrinsic cognitive load of information pertaining gas laws in chemistry, indirect objective measures of comprehension and transfer were used to measure changes in intrinsic cognitive load. Perceived measures of information difficulty through mental effort ratings were not conducted. However, given the use of performance measures in the current study, the use of comprehension and transfer assessments in a chemistry domain are of interest.

Summary

Measures of cognitive load in the CLT research can be divided into indirect/direct subjective and objective measures. Of these measures, the most common are indirect subjective measures of mental effort and various performance measures such as time-on-task, comprehension, error rates and transfer assessments (Brunken et al., 2003). When both extraneous and germane cognitive load are controlled, research indicates that ratings of mental effort are good indicators of intrinsic cognitive load specifically (Ayres, 2006; Brunken et al., 2003). Of the literature reviewed, the combination of mental effort and performance assessment to yield an instructional efficiency score is a common form of data analysis. However, out of the limited research into intrinsic cognitive load management in chemistry, only two studies report instructional efficiency measures. Keeping in mind the current study, neither investigation involved managing or measuring intrinsic cognitive load in chemistry chemical equilibrium, a topic recognized in the literature as being particularly complex. Moreover, the independent variable used to manage intrinsic cognitive load in each study did not involve the use of pre-training.

Thus, a review of the literature into measuring intrinsic cognitive load only amplifies the need for further research into negotiating and assessing the complexity presented in the chemistry knowledge domain, specifically chemical equilibrium.

Multimedia in Chemistry Education

A common characteristic of recent research that addresses complexity in the topic of chemical equilibrium is the presence of multimedia interventions such as animated displays and computer simulations (Ozdemir et al., 2009). A multimedia instructional message is one that, by definition, includes the presentation of both words and pictures (Mayer, 2001). Keeping in mind the limited capacity of working memory, and the presence of dual channels for visual and verbal information, the exact nature of a multimedia instructional message fits well into cognitive overload prevention techniques (Mayer, 2005c). Despite this connection, and the overwhelming amount of literature that identifies chemical equilibrium as highly complex topic, no studies can be found that intentionally try to manage the intrinsic cognitive load of chemical equilibrium through the use of multimedia. Moreover, none of the studies using the highly effective pre-training method discussed above apply a multimedia learning tool as part of the schema formation technique. Given this gap, a review of the use of multimedia in chemistry will give insight into the use of a multimedia pre-training intervention in this study.

Multimedia Interventions in Chemistry

Russell, Kozma, Becker, and Susskind (2000) used a mulitimedia tool called *SMV: Chem (Synchronized Multiple Representations in Chemistry)*. *SMV: Chem* is a chemical software program designed to show experiments that illustrate key chemistry concepts using molecular-scale animations, models and equations that students can manipulate and interact with. *SMV: Chem* or *4M: Chem* (a prototype of *SMV: Chem*) has been used to specifically help students understand the difficult concepts that underlie Le Chatelier's Principle. Through this software, students were given the ability to manipulate temperature, pressure and concentration values and observe how the equilibrium reacted on a molecular level. Research has shown a statistically significant increase in college students' understanding of the concepts central to Le Chatelier's Principle after engaging in *SMV: Chem* or *4M: Chem* simulations. A significant reduction in misconceptions around Le Chatelier's Principle was also observed (Kozma, Russell, Jones, Marx, & Davis, 1996).

Recently, Russell (2004) conducted a study using *SMV: Chem* as a lecture tool over the course of a semester. Results showed significantly higher scores for students who attended chemistry lectures that were supplemented with *SMV: Chem.* In another study using the *4M: Chem* prototype, Kozma (2000) demonstrated that the specific features of the simulations help students grasp the concepts of chemical equilibrium specifically. As part of this investigation, students were randomly assigned to different groups, where various aspects of the *4M: Chem* model were included or not included. For example, one group had access only to an animation window, another group to a video window, a third group used only the graph window, and a fourth group had access to all features. The animation group outscored all groups on assessment items having to do with the dynamic nature of equilibrium and the graph group outscored the other participants on items related to relative pressures. The group that received all treatments did not outscore any other groups.

Similar to *SMV: Chem* and *4M: Chem*, *Connected Chemistry* is a multimedia simulation project designed to help students better comprehend difficult concepts in chemistry such as Le Chatelier's Principle. Unlike *SMV: Chem*, *Connected Chemistry* is written in a language that allows students to generate authentic data in response to input, instead of using pre-determined graphical responses. Another major difference between *Connected Chemistry* and *SMV: Chem* is the lack of audio or video in the simulations and animations (Stieff & Wilensky, 2003). *Molecular Workbench* is another software interface that is analogous to *Connected Chemistry*. *Molecular Workbench* provides a variety of real-time, interactive simulations, and like *Connected Chemistry*, does not include audio or video feedback (Xie & Tinker, 2005). *ChemSense* is an example of another multimedia chemistry learning environment designed to support an inquiry approach (Mayer, 2005c). During a *ChemSense* simulation, students are offered a choice of various tools that they can use to manipulate, and analyze chemical phenomena. The open-ended nature of the exploration in *ChemSense* is a major difference when compared to the other software packages described.

Schank and Kozma (2002) investigated the use of ChemSense during a three-week unit on solubility with high school students. It was determined that students who created drawings and animations using C*hemSense* developed a deeper understanding of the geometry-related aspects of chemistry. Qualitative analysis of the treatment groups revealed that use of tools prompts students to think more carefully and critically about chemical phenomena. Agapova, Jones, Ushakov, Ratcliffe and Martin (2002), investigated the use of *ChemDiscovery*, another similar inquiry driven simulation software and found similar results. Unlike *ChemSense, ChemDiscovery* is web-based and features interactive pages linked to activities, databases and studies where students can perform and design their own laboratory investigations.

Using another multimedia software program called *Chemical Change*, Ardac and Akaygun (2004) investigated the impact of using the software to view molecular representations of chemical phenomena on eighth-grade science students. The study took place over 10 class periods and included various, introductory chemistry topics. Students in treatment groups worked individually at computers installed with *Chemical Change*, while control group participants received lectures on the same topics accompanied by equations and molecular drawings on the chalkboard. Results indicated that students who used *Chemical Change* scored higher on posttest items that used molecular representations of chemicals, and also demonstrated more conceptual accuracy than students in the control group.

To compare efficacy of using animations similar to that described above, in conjunction with the traditional classroom method of teaching, Yang, Andre, and Greenbow (2003) conducted a study using university students. In their investigation, one group of students who received a lecture on electrochemistry also received animations accompanied by lecture narrations. Participants in a second group received a lecture only accompanied by static representations. As would be predicted by the literature noted previously, students in the animation group outperformed the students who received the static diagrams on a test of topic knowledge. Other experiments conducted by Sanger, Phelps and Fienhold (2000) and Sanger and Badger (2001) strengthen the argument that lecture accompanied by animations improves student learning in chemistry.

Another emerging technology that is being used in chemistry is *interactive molecular modeling*. With this technology, the user can create and rotate a molecular model through three-dimensional space and examine the various structural properties intrinsic to its design. While this technology was designed with the professional chemist in mind, it is starting to be used widely in chemistry education at the university level (Montgomery, 2001). With respect to the population in the current study, Dori and Barak (2001) used computer models with high school students as part of a program to improve student understanding of the concepts surrounding bonding and molecular geometry. Students worked in pairs using a workbook and the modeling program. Participants randomly assigned to the control group used plastic models instead of the interactive approach. Students in the treatment group scored higher on comprehension tests of molecular structure and bonding.

Multimedia Screencasts

As described, a significant amount of work has gone into creating animations and simulations that help students learn chemistry. Advanced multimedia technologies such as real-time animations of molecular systems, and learner directed simulations that help to model phenomena in chemistry have marked the majority of the developments thus far. However, the research base testing the authentic use of multimedia interventions in the chemistry classroom is still severely limited (Mayer, 2005c). Specifically, given the potential for cognitive overload in difficult topics such as chemical equilibrium, a review of the literature revealed a lack of studies that intentionally use multimedia to manage the complexity of the chemistry knowledge domains. This observation is particularly surprising given the overlap between multimedia instructional design principles and the human cognitive architecture.

Given the need for more research literature that addresses the complexity of chemical equilibrium from an intrinsic cognitive load perspective, one cannot ignore the rapidly changing technology landscape where learning and instruction now occurs. Prensky (2001), in an article titled *Digital Natives, Digital Immigrants* states that "Our students have changed radically. Today's students are no longer the people our educational system was designed to teach"(p. 1). Prensky goes on to state that "…today's students process information fundamentally differently from their predecessors"(p.1). As availability of information over the Internet continues to grow students who are developing in such an infrastructure are developing new cognitive structures (Prensky, 2001).

In the context of Prensky's comments, the National Technology Plan released in 2005 indicated that given current movements in technology and innovation, today's students are far ahead of their teachers with respect to computer literacy (National Educational Technology Plan, 2005). Moreover, Richardson (2009) notes that today's learners prefer to access subject specific information over the Internet, where it is more abundant, more accessible and more up-to-date. According to Richardson, over 60 percent of all adolescents engage in communication over the Internet as the primary source of information transfer. Unlike the technology landscape that embraced the development of such multimedia projects as *ChemSense* and *ChemDiscovery* described above, the development of web-based teaching tools, rather than intricate software packages, is changing the platform and accessibility of multimedia instruction (Richardson, 2009).

Richardson (2009) indicates that *screencasts* are an emerging technology that show promise as an instructional device. Screencasting involves capturing on video, all computer screen activity, including audio, and mouse activity. From an educational standpoint, teachers could create screencasts to support materials when teaching complex skills on the computer. Tablet computer technologies could allow teacher to capture ink annotations or written solutions and share them with students via the Internet (Richardson, 2009). Specifically, Bergman and Sams (2008) investigated the use of using screencasting as a tool to move the lecture component of their chemistry classes to the home or computer lab, thus freeing up time for in-class inquiry and problem solving. Because the screencasts were used as a lecture tool to be viewed before class, Bergman and Sams refer to the process as *pre-casting*. In comparing their scores on semester exams from the previous school year, students who learned via at-home screencast lectures, outperformed students who learned in the traditional lecture setting. Although such research was not done from an intrinsic cognitive load lens, nor was it equilibrium specific, this study does represent an initial look into using screencasts in the chemistry classroom. A comment by one of Bergman and Sams' students operationalizes many multimedia design principles embedded in a screncast: "I think it's the best idea for teaching I've ever had in school. I like being able to work at home in my own way, at my own speed. I have always had trouble keeping up in chemistry class, but being able to pause the teacher and play a part over and over until I get it has helped so much" Bergman and Sams, 2008, p. 23).

The quote above indirectly alludes to four specific multimedia design principles that lend support to the use of screencasts in education. The *voice* and *personalization* principles state that students learn more deeply when words are spoken in a human voice that is familiar to the students and in a conversational style (Mayer, 2005). Given the combination of teacher audio and on-screen activity, the ability to "…pause the teacher and play over…" as noted above, assumes the teacher's authentic voice is present in the multimedia intervention. Research into the efficacy of the personalization principle is small, yet very consistent (Moreno & Mayer, 2001; Moreno & Mayer, 2004; Mayer, Sobko, & Mautone, 2003). Similar to the pre-training literature base, research is limited to various science and math environments, not including the chemistry knowledge domain. Additionally, the interactivity and segmenting principles state that learning is improved when students have command over the multimedia device, and information is presented in learner-controlled segments (Mayer, 2005). Like the voice and personalization principles, efficacy research into the interactivity and segmenting principles is small but stable (Mayer & Chandler, 2001; Mayer, Dow, & Mayer, 2003).

Although not aimed at measuring cognitive load in the area of chemical equilibrium specifically, Franciszkowicz (2008) conducted a study to test the efficacy of using screencasts in a first-year university general chemistry classroom. Franciszkowicz (2008) referred to screencasts as "Video-based Additional Instruction (VAI)" (p. 5). Specifically, the study used researcher-generated screencasts that detailed basic problem solving techniques related to the topic to intentionally foster critical skills, and the conceptual understanding of the course material. The author used surveys and website hit counters to determine when and why students accessed the screencasts. Supporting the pre-training method used in the current study, survey results showed overwhelming use of the resource for pre-class preparation and pre-test review.

Keeping in mind the instructional design principles that speak to the voice and user control aspects of a screencast, the *pre-casting* lecture method embraced by Bergman and Sams (2008), and corroborated by Franciszkowicz (2008), represents only one, of the many possible applications of screencasts in education (Schaffhauser, 2009). Despite such potential, a review of the literature revealed a lack of studies that critically investigate the use of screencasts in chemistry education, or science in general. A few studies conducted in the field of library information and e-learning represent the only other critical research done using a screencast treatment prior to instruction (Flyn, & Penwill, 2008; Roberts, 2005).

Summary

The technology landscape that today's students learn and grow in is an ever changing multimedia infrastructure (Prensky, 2001). *Screencasts*, a relatively new phenomena used to record instructor computer screen activity and audio, are receiving attention as an effective and dynamic media (Bergman and Sams, 2008; Peterson, 2007; Richardson, 2009). Despite such attention, there is a lack of studies that investigate the efficacy of screncasting as an intrinsic cognitive load management technique in chemistry. The complexity of chemical equilibrium specifically, and the demonstrated use of screencasts as a *pre-casting* tool (Bergman and Sams, 2008) make screencasts a potentially effective pre-training strategy to fill the gap between chemical equilibrium complexity and existing CLT research.

Conclusion

An agreement fundamental to the literature reviewed in the field of chemistry education is that *chemical equilibrium* is a highly complex knowledge domain (Banerjee, 1995; Hackling and Garnett, 1985). Specifically, Le Chatelier's Principle, a conceptual approach to assessing how chemical reactions at equilibrium respond to environmental strain, poses unique challenges for learners (Voska and Heikkinen, 2000). The multiple concepts that must be coordinated, both algorithmic and conceptual, increase the difficulty of the learning materials and frequency of student misconceptions. Although its complexity is widely agreed upon, a review of the literature revealed a lack of studies that intentionally address the complexity of chemical equilibrium from a cognitive load perspective.

The CLT literature notes that complex learning material, such as chemical equilibrium has, high intrinsic cognitive load because multiple elements must be simultaneously negotiated in the limited working memory (Paas, Renkl, & Sweller, 2003; Sweller & Chandler, 1994). *Pre-training* is a technique that has shown promise in promoting long-term memory schema that helps learners *chunk* multiple interacting elements into single units, opening up available working memory space for processing (Pollack et al., 2002). Specifically, a type of pre-training referred to as *whole-task* sequencing has shown promise in complex knowledge domains (van Merriënboer et al., 2003). Analysis of CLT literature in the context of the chemical equilibrium research noted clearly points to a need for intrinsic cognitive load management techniques such as pre-training in the teaching of chemical equilibrium.

A common thread to all current research in chemistry education, specifically the investigation of chemical equilibrium, is the use of multimedia (Yang, et al. 2003). Although the current literature base explores ways to improve algorithmic and conceptual comprehension in the field, no studies are aimed at decreasing the high element interactivity that the subject presents. An emerging form of multimedia called *screencasts*, embraces many instructional design techniques developed with the human cognitive architecture in mind (Mayer, 2005a). The intricacies of screencasts align well with the technique of pre-training in the field of chemistry, an instructional sequencing technique that has shown promise as a means to improving schema formation and thus decreasing intrinsic cognitive load in complex knowledge domains (Bergman & Sams, 2008; Franciszkowicz, 2008).

CHAPTER III

METHODOLOGY

This study investigated the effects of using screencasts as a multimedia pre-training tool to manage the intrinsic cognitive load of chemistry instruction at the high school level. In this section the experimental research design is outlined and described. Following a restatement of the research questions, a description of the design, sampling procedures, human subject considerations and data analysis methods are discussed. This section concludes with a description of the treatment, and study limitations, followed by a summary of the overall methodology.

Research Questions

The research questions are as follows:

1. What are the effects of pre-training on the intrinsic cognitive load of chemical equilibrium instruction for advanced high school students as measured by ratings of mental effort?
2. What are the effects of pre-training on advanced high school chemistry students' performance on an equilibrium concept assessment?
3. What is the relationship between intrinsic cognitive load, as measured by ratings of mental effort and advanced high school chemistry students' performance on an equilibrium concept assessment?

Research Design

This study was designed as an experimental investigation and used a sample of students in an advanced placement chemistry program at a co-ed high school. Participants were randomly assigned to one of two groups representing each level of the independent variable: screencast pre-training, and no pre-training. Because changes in intrinsic cognitive load must be measured in the context of prior knowledge, participants were first assessed on the basic concepts of chemical equilibrium to determine if any significant between-group differences existed (Sweller et al., 1998). Along with performance, intrinsic cognitive load, as measured by ratings of mental effort, was assessed on the pre-test. Chemical equilibrium was chosen as the knowledge domain given the topic's complexity and the volume of student misconceptions noted in the literature (Banerjee, 1996; Treagust & Tyson, 1999).

Under the supervision of the researcher, participants in the treatment group were given time to review the screencast pre-training materials in preparation for direct instruction on the basic concepts of chemical equilibrium. After treatment, each group received the same direct instruction on the basic concepts of chemical equilibrium from the lead researcher. Upon conclusion of the instructional phase, all participants were again assessed for differences in intrinsic cognitive load, as measured by ratings of mental effort and performance as measured by score on an equilibrium concept assessment.

According to CLT, extraneous cognitive load is a function of the learning materials and environment (Sweller & Chandler, 1994). Because both groups were exposed to the same learning environment during the instructional phase of the study after pre-training, the impact of extraneous load was limited (Ayres, 2006). Additionally, because participants were instructed to only ask clarifying questions and were not given any additional assistance during pre-training and instruction, it can be assumed that the study did not promote schema formation, and thus facilitate germane cognitive load.

Under the above conditions, it can be argued that extraneous and germane load will be held constant and changes in the dependent variable can be attributed to the intrinsic load (Sweller, 2006). To verify the stability of extraneous and germane cognitive load, participants responded to two survey items designed to monitor each construct periodically throughout the duration of the study (DeLeeuw & Mayer, 2008; Swaak & De Jong, 2001).

The first dependent variable, intrinsic cognitive load, was measured via subjective ratings of mental effort on the items of a chemical equilibrium concept assessment post-test. (Knaus, Murphy, & Holme, 2009; Paas & Van Merriënboer, 1993). The second dependent variable, performance, was measured via the score on the items of the same equilibrium concept assessment post-test. The identical instrument was used as a pre-test to evaluate prior knowledge in chemical equilibrium before treatment.

Sampling Procedure

The participants in this study were a convenience sample of 62 fourth-year high school students enrolled in an advanced placement chemistry program at a co-ed Catholic school in San Francisco. All eligible students participated in the study. Student enrollment for the school is approximately 1,297 (Sacred Heart Cathedral Preparatory, 2010). Advanced Placement Chemistry is a second year chemistry course at the participating institution, and involves a more in-depth exploration of chemistry than the college preparatory course offered to all students during their third year. Students, who receive a grade of *A* in chemistry during their third year, qualify for Advanced Placement Chemistry (Sacred Heart Cathedral Preparatory, 2010).

Of the 62 participants, 41 were male, and 21 were female. The pre-training treatment group consisted of 19 male students and 12 female students. The no pre-training group consisted 22 male students and 9 female students. Thus, each group consisted of roughly an equal number of male and female students. Ages of participants ranged from 17 to 18 years. None of the participants had exposure to the content or the materials used in the study. All eligible Advanced Placement Chemistry students participated in the study. Given the similar academic background of the participants, and the use of an equilibrium prior knowledge pre-test, no other demographic data was collected from the participants.

The study was designed to assess any changes in intrinsic cognitive load and thus, the element interactivity associated with learning chemical equilibrium (Paas et al., 2003; Sweller & Chandler, 1994)**.** Given the complexity of chemical equilibrium noted in the research literature (Banerjee, 1996; Treagust & Tyson, 1999), and the filter used to select students into Advanced Placement Chemistry at the participating institution, the sample represented a group of advanced students, who were exposed to a complex knowledge domain.

Protection of Human Subjects

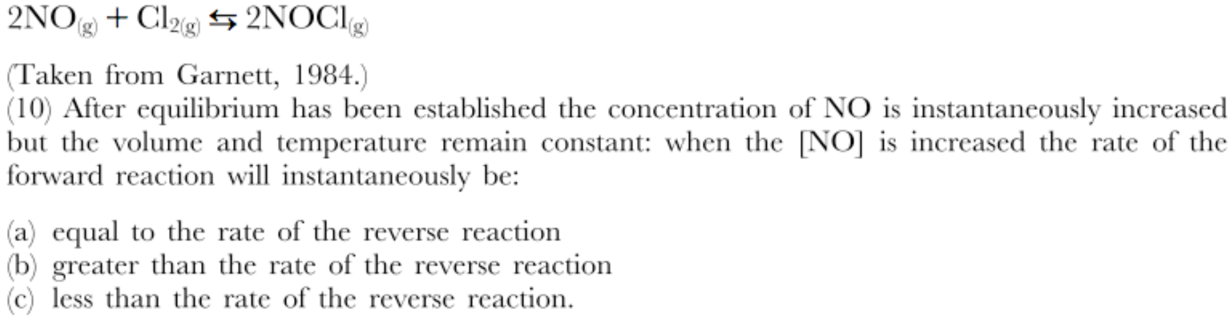
Approval for this study was given by the University of San Francisco's Internal Review Board for Protection of Human Subjects (IRBPHS). A permission letter (Appendix A) was obtained from the participating academic institution, and informed consent was requested from each participant (Appendix B). Given the age of the participants, parental consent for research participation was also obtained. Along with the informed consent letter, a cover letter describing the study, the instruments, and explaining the confidentiality terms of the study was distributed to each participant (Appendix C).

Instrumentation

The first dependent variable studied was intrinsic cognitive load, as measured by ratings of mental effort. Specifically, this study analyzed levels of intrinsic cognitive load associated with a lesson on the basic concepts of chemical equilibrium after a group of students received either pre-training or no pre-training. According to Sweller et al. (1998), levels of intrinsic cognitive load are highly affected by prior-knowledge, therefore the researcher designed a Chemical Equilibrium Concept Assessment to be used as both a pre-test and post-test (Appendix D). To measure intrinsic cognitive load, each equilibrium content item was followed by a subjective Mental Effort Rating Scale originally designed by Paas and Van Merriënboer (1993) and modified for a chemistry learning environment by Knause, et al. (2009). The second dependent variable was performance on the items of the Chemical Equilibrium Concept Assessment.

Chemical Equilibrium Concept Assessment

The Chemical Equilibrium Concept Assessment (used as both a pre and post-test) was developed by the researcher, and represents a merger of two previously used equilibrium concept assessments noted in the literature (Banerjee, 1991; Hackling & Garnett, 1985). The instrument consisted of 4 multiple-choice items, and 3 multi-part questions. The instrument included 14 total items. All 14 items on the pre and post-test included an associated mental effort rating scale. Only one correct answer existed for each item. Figure 3 below shows a screenshot of a multiple-choice item from the Hackling and Garnett (1985) assessment. Figure 4 shows a screen shot of a multi-part question from the Banerjee (1991) assessment. Both items were included on the assessment.

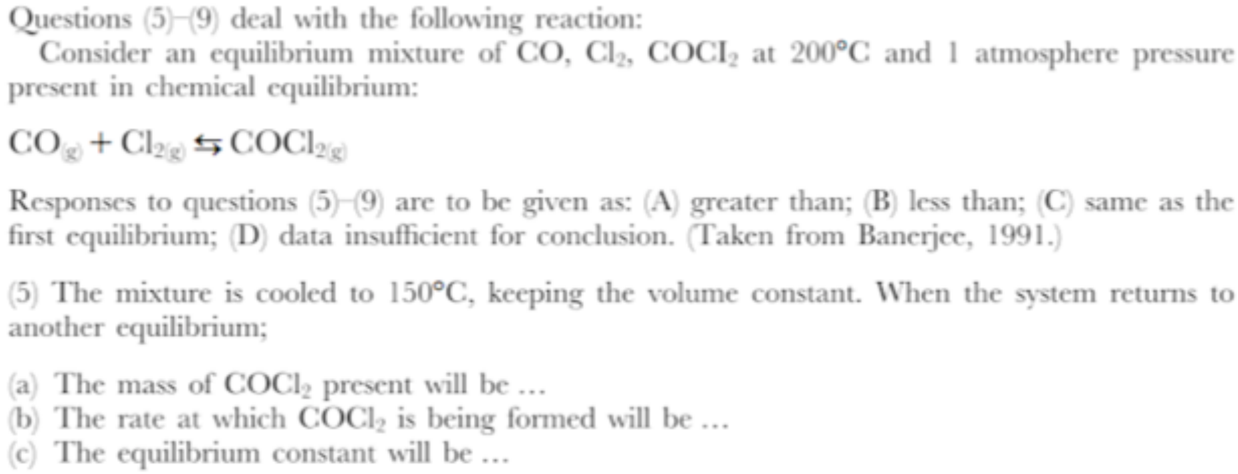


$2NO_{(g)} + Cl_{2(g)} \leftrightarrows 2NOCl_{(g)}$

(Taken from Garnett, 1984.)
(10) After equilibrium has been established the concentration of NO is instantaneously increased but the volume and temperature remain constant: when the [NO] is increased the rate of the forward reaction will instantaneously be:

(a) equal to the rate of the reverse reaction
(b) greater than the rate of the reverse reaction
(c) less than the rate of the reverse reaction.

Figure 3. Multiple-choice item used in Chemical Equilibrium Pre and Post-Test (Hackling & Garnett, 1985).



Questions (5)–(9) deal with the following reaction:
Consider an equilibrium mixture of CO, Cl_2, $COCI_2$ at 200°C and 1 atmosphere pressure present in chemical equilibrium:

$CO_{(g)} + Cl_{2(g)} \leftrightarrows COCl_{2(g)}$

Responses to questions (5)–(9) are to be given as: (A) greater than; (B) less than; (C) same as the first equilibrium; (D) data insufficient for conclusion. (Taken from Banerjee, 1991.)

(5) The mixture is cooled to 150°C, keeping the volume constant. When the system returns to another equilibrium;

(a) The mass of $COCl_2$ present will be …
(b) The rate at which $COCl_2$ is being formed will be …
(c) The equilibrium constant will be …

Figure 4. Multiple-part item used in Chemical Equilibrium Pre and Post-Test (Banerjee, 1991).

Given that intrinsic cognitive load is estimated by the element interactivity of a particular learning task, only items containing a significant number of interacting elements were included in the instrument (Paas et al., 2003; Sweller & Chandler, 1994). Chandler and Sweller (1994) developed a method for estimating the level of element interactivity that accompanies a learning task. Assuming prior knowledge is controlled, and each element is relevant to the participants in the study, one can arrive at the element interactivity by counting the number of elements that must be simultaneously considered

(Sweller, 2003). Using the method outlined by Chandler and Sweller (1994), a validity panel, made up of three chemistry instructors from the participating institution, individually and collectively counted interacting elements on all 14 items of the Chemical Equilibrium Concept Assessment. It was determined by the validity panel that each item had an element interactivity of 6.

To provide a specific example of how an element interactivity level of 6 was determined by the validity panel, the item in figure 3 will be referenced. First, the student must identify *NO* as being a gas, and because of its state, understand that it does affect the equilibrium position of the reaction. Second, the reaction must be identified as being correctly balanced. Third, the equilibrium and non-equilibrium constant expressions (K and Q) must be defined. Fourth, the student must know that when the concentration of *NO* is increased, Q is less than K. Fifth, when Q is less than K, it must be understood that the reaction will shift to the product side. Finally, in order for the reaction to shift to the product side, the rate of the forward reaction will be instantaneously greater than the reverse reaction. By these criteria, the items on the Chemical Equilibrium Concept Assessment are similar in complexity to those coded as having high element interactivity in the CLT literature (Ginns, 2005).

Mental Effort Rating Scale

Subjective measures of mental effort were initially collected on scales developed by Paas and Van Merriënboer (1993) as a way for learners to assign a number to the level of mental load. The efficacy of using subjective measures to predict mental load is widely supported in the CLT research literature (Ayres, 2006; Paas & Van Merriënboer, 1993, 1994). As noted earlier, because the research design assessed for differences in prior knowledge, extraneous cognitive load and germane cognitive load across each group, it can be assumed that subjective measures of mental load approximate intrinsic cognitive load (Sweller, 2006).

The study used a variation of Pass and Van Merriënboer's scale developed by Knaus, Murphy, and Holme (2009). The scales five descriptors (very little, little, moderate amounts, large amounts, very large amounts) are designed to assess how much mental effort was expended on each item of the Chemical Equilibrium Concept Assessment Pre and Post-test described above. After each item in the instrument, a mental effort scale was inserted (Appendix D).

As previously mentioned, to assess the validity of Chemical Equilibrium Concept Assessment, three chemistry instructors at the participating institution comprised a group of *equilibrium experts*. Each instructor analyzed all items for content and element interactivity. Each instructor assessed the items of the instrument individually, and then shared their observations with one another as a group. In collaboration, the validity panel agreed that all items tested the knowledge domain of Chemical Equilibrium, specifically Le Chatelier's Principle, and all items contained 6 interacting elements. No items were altered or deleted as a result of the validity panel analysis.

Additional Instrumentation

De Leeuw and Mayer (2008) note a strong connection between difficulty ratings and germane cognitive load. Keeping this in mind, students were asked the following question to monitor germane cognitive load at the end of the pre and post-test: *How easy or difficult is it for you to understand chemical equilibrium at this moment?* Students reported their difficulty rating on a 9-point scale from ranging from *very easy* to very *difficult*. To monitor extraneous cognitive load, the following question, derived from the *SOS scale*, a cognitive load measure suggested by Swaak and De Jong (2001), was used at the end of the pre and post-test: *How easy or difficult is it for you to work in this learning environment at the moment?* Like the germane measure, students reported their difficulty rating on a 9-point scale from ranging from *very easy* to very *difficult.*

Procedures and Treatment

The researcher was also the lead teacher in the participating advanced placement chemistry classrooms. The purpose of the study was outlined by the researcher one week prior to pre-test distribution. After a short verbal summary, the researcher asked for student participation in the study. A cover letter, informed consent form, and a parental consent form were distributed to each student. All students were asked to return the informed consent forms in an envelope provided by the researcher at least one day before the treatment date. Students who choose to participate in the study were randomly assigned a number beginning with 1 to 62 to ensure confidentiality. Participating students received a copy of the informed consent form and a copy of the Research Subject's Bill of Rights.

The treatment for the study was divided into four phases. First, prior knowledge of chemical equilibrium concepts was assessed via a pre-test. Second, students were randomly assigned to one of two different groups where pre-training was or was not implemented. Third, all students gathered for in-depth instruction on the basic concepts of chemical equilibrium. Last, students completed a concept assessment with an associated mental effort measure to identify any differences in intrinsic cognitive load across each group. Throughout the first (pre-test administration) and fourth (post-test administration) phase, students were surveyed to assess changes in extraneous and germane cognitive load during the duration of the study.

Prior Knowledge Phase

Assessment of learner prior knowledge is crucial when attempting to determine differences in intrinsic cognitive load across a group of students (Sweller et al., 1998). In order to assess learners' prior knowledge of equilibrium concepts, the researcher administered the 14-item multiple Chemical Equilibrium Concept Assessment pre-test (see Appendix D). All participants gathered together in the same room for the pre-test, two weeks prior to treatment. When participants were present, the researcher distributed hard copies of each instrument face down on the desk of each participant. The researcher reminded students of the confidentiality terms of the study, and fielded any remaining questions from participants.

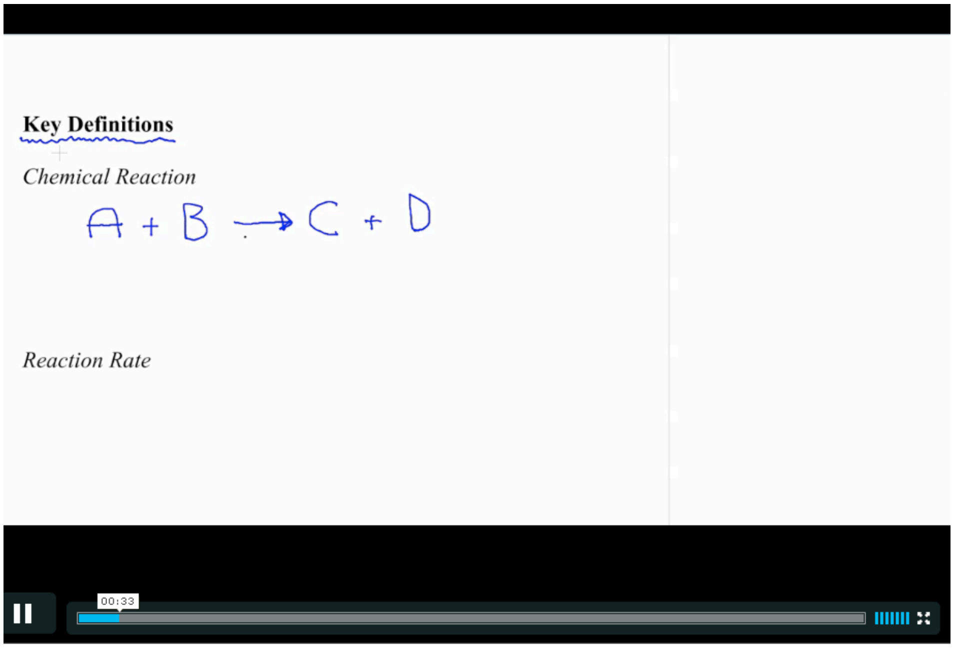
Students were asked to place all calculators under their desk for the duration of the assessment. The researcher read a script that outlined the purpose of the pre-test and information specific to interpreting the chemistry content of the instrument (Appendix E). Upon conclusion of the script, the researcher set a timer for 30 minutes, and instructed students to begin. When finished, students remained seated, and the researcher collected each completed instrument.

Pre-Training Phase

The pre-training phase consisted of two separate groups that represented the two levels of the independent variable: screencast pre-training and no-pre-training. Students who were randomly assigned to the screencast pre-training group reported to the researcher's classroom 15 minutes prior to the beginning of the instructional phase.

Twenty laptop computers, including audio headsets, were present in the room for students to view the pre-training screencasts. Although there were no more than 11 students assigned to any one of the three pre-training sessions, additional computers were provided in case technical difficulties occurred during pre-training. Because the two research groups represented students randomly assigned from three different advanced placement chemistry classes, the pre-training phase was repeated by the researcher three times.

The lead researcher instructed students to open the movie file on the desktop of the computer titled *Pre-training Screencast.* The researcher read the screencast pre-training script to students (Appendix E). The script contained specific instructions about navigating the screencast, and rules regarding accessing the Internet and other computer files during the treatment phase. Students were allowed 10 minutes and 52 seconds to interact with the screencast (total length of screencast). During the course of the screencast pre-training, students were exposed to the basic definitions and key characteristics of chemical equilibrium, along with a general introduction to the overarching concepts and problem solving strategies that relate Le Chatelier's Principle of chemical equilibrium. Instruction included on the screencast consisted of digital pen annotations and narrations all created by the lead researcher. Students randomly assigned to the no pre-training group were instructed to report to class at the normally scheduled time. Figure 5 shows a screen shot of the screencast pre-training video taken at the 33-second mark in the video.



Key Definitions

Chemical Reaction

$A + B \rightarrow C + D$

Reaction Rate

Figure 5. Screencast pre-training video. 33-second mark.

With respect to screencast design, the researcher created a pre-training template document, and using a mobile tablet, screen recording software and a microphone, recorded digital annotations and audio narration of the basic definitions and key concepts associated with chemical equilibrium. The pre-training screencast was designed according to the pre-training principles described by Mayer (2005a) and the whole-task sequencing procedures outlined by van Merriënboer et al. (2003, 2006). The screencast included the basic definitions and key terms essential to Mayer's definition of pre-training, and also exposed to students to the holistic, and over arching concepts necessary for complete schema formation described by van Merriënboer's whole-task sequencing approach.

The screencast began with an introduction to the basic definitions, key terms and concepts in chemistry that provide an infrastructure for chemical equilibrium. Following basic definitions, terms and concepts, the pre-training screencast outlined and briefly explained the factors that, according to Le Chatelier's Principle, are capable of shifting a reaction at chemical equilibrium. See Appendix F for all screencast pre-training materials including the document template, screenshots of the pre-training video, and a link to view the pre-training video online.

Instructional Phase

Upon conclusion of the pre-training phase, the researcher and students reported to their respective classrooms for the school day. At the beginning of each of the researcher's three Advanced Placement Chemistry classes, a script was read that described the purpose of the instructional phase and any questions students had were answered (Appendix E). Handouts of slides used by the instructor during the instructional phase were distributed to students for optional note taking (Appendix G). The researcher then set a timer for 50 minutes, and began the instruction on the basic concepts of chemical equilibrium.

Assessment Phase

Assessment of learner intrinsic cognitive load was accomplished by use of the Chemical Equilibrium Concept Assessment along with associated ratings of mental effort for each item (see Knaus et al., 2009; Paas & Van Merriënboer, 1993). The assessment was identical in structure and content to the pre-test all students completed two weeks prior to treatment. The assessment phase took place directly after the instructional phase, in the same classroom. The researcher distributed the assessment face down on the desk of each participant. The researcher reminded students of the confidentiality terms of the study, and fielded any remaining questions from participants.

Students were asked to place all calculators and notes under their desk for the entire duration of the assessment. The researcher read a script to students that outlined the purpose of the assessment and any information specific to interpreting the chemistry content of the instrument (see Appendix E). Upon conclusion of the script, the researcher set a timer for 30 minutes, and instructed students to begin. When finished, students remained seated, and the researcher collected each instrument, and the corresponding score sheet from each student.

Data Analysis

Prior Knowledge Assessment

Because intrinsic cognitive load is a function of learner prior knowledge, all students took the Equilibrium Concept Assessment as a pre-test to see if significant differences in both mental effort, and content knowledge, existed between each group (Sweller et al., 1998). The mental effort descriptors (very little, little, moderate amounts, large amounts, very large amounts) were coded from 1 to 5 respectively. In order to maintain the 1-5 scale for mental effort, student responses were first averaged, then group averages were obtained for comparison. Scores on the content items were coded with a 1 for a correct response and 0 for an incorrect response. Raw scores for each student were summed, and then a group average was obtained for comparison.

Research Question 1

To answer research question 1, an independent samples t test was conducted to evaluate the effect of pre-training on intrinsic cognitive load. The independent variable, pre-training, includes two levels: screencast and no pre-training. The dependent variable is the intrinsic cognitive load of chemical instruction, as measured by ratings of mental effort. Between group comparisons were conducted for mental effort rating averages on the instrument as a whole. As an added analysis, a paired t test was conducted to see if significant differences in mental effort existed in pre and post-test scores within groups.

Research Question 2

To answer research question 2, an independent samples t test was conducted to evaluate the effect of pre-training on performance. The independent variable, pre-training, includes two levels: screencast and no pre-training. The dependent variable is performance, as measured by score on equilibrium concept items. Between group comparisons were conducted for total raw score averages. As an added analysis, a paired t test was conducted to see if significant differences in performance existed in pre and post-test scores within groups.

Additional Data Analysis

In order to more accurately relate mental effort and performance to changes intrinsic cognitive load, two survey questions were asked at the conclusion of the pre and post-test to monitor differences in germane and extraneous cognitive load between groups. An independent samples t test was conducted to see if significant differences between the pre-training and no-pre-training groups exist.

Research Question 3

To answer research question 3, a correlation analysis was conducted to examine the relationship between performance on the chemical equilibrium assessment and intrinsic cognitive load, as measured by ratings of mental effort. Correlations coefficients were calculated between mental effort and performance in the no pre-training and pre-training groups individually and across both groups together on the Chemical Equilibrium Concept Assessment post-test.

Summary

This study investigated the effects of pre-training to manage the intrinsic cognitive load of chemistry instruction for high school chemistry students. Students from an intact sample of three advanced placement chemistry classes were randomly assigned to one of two treatment groups: screencast pre-training or no pre-training. Prior to treatment, students in each group were administered the Chemical Equilibrium Concept Assessment as a pre-test to assess for any between group differences in prior knowledge regarding chemical equilibrium. An independent samples t test was conducted to see if any significant differences exist in both the mental effort invested, and performance on the assessment. Survey questions designed to evaluate germane and extraneous cognitive load were administered upon conclusion of the pre-test and t tests were also conducted to evaluate between group differences.

After prior knowledge assessment, students in the pre-training treatment group were exposed to a 10 minute and 52 second screencast where the basic definitions, terms and key concepts of chemical equilibrium were outlined. Upon conclusion of pre-training, all students received an in-depth lecture on chemical equilibrium. The Chemical Equilibrium Concept Assessment, along with the associated germane and extraneous cognitive load survey items, was administered directly after the lecture. An independent samples t tests was conducted to evaluate differences in intrinsic cognitive load, performance, and to assess any differences in germane or extraneous cognitive load between groups. Scores on all variables of the pre and post-test were then correlated.

Specifically, relationships between the two dependent variables, intrinsic cognitive load, and performance, were assessed.

CHAPTER IV

RESULTS

The purpose of the study was to investigate the use of screencasts as a pre-training tool to manage the intrinsic cognitive load of chemistry instruction at the high school level. This study examined differences in performance and mental effort on an equilibrium concept assessment between two groups of chemistry students. One group of students received pre-training and one group did not. The independent variable for each of the two research questions was pre-training (screencast or no pre-training). The dependent variables were intrinsic cognitive load as measured by mental effort and performance, as measured by score on an equilibrium concept assessment. A rationale for the cognitive load measures used and the results of the inferential statistics reported for each research question are included in the following sections. If significant differences do not exist, p values are not reported, and data is displayed in an associated table. If significant differences do exist, p values are reported and the data is also displayed in a table. For all comparisons, the alpha level was set at .05. For the first two research questions, effect sizes as measured by *Cohen's d* are reported for all statistically significant differences for between group comparisons. Estimated effect sizes are reported for within group comparisons.

Cognitive Load Measures

According to Brunken et al. (2003) mental effort ratings, as indirect subjective assessments, are reliable indicators of intrinsic cognitive load. The efficacy of using ratings of mental effort to predict intrinsic cognitive load is widely noted in the CLT literature (Ayres, 2006; Paas & Van Merriënboer, 1993, 1994). Each content item on the

Chemical Equilibrium Concept Assessment was followed by a mental effort rating scale. The scales five descriptors (very little, little, moderate amounts, large amounts, very large amounts), were coded 1-5, with 1 being *very little* mental effort, and 5 being *very large amounts* of mental effort. The mental effort scale used on the instrument was originally designed by Paas and Van Merriënboer (1993) and modified by Knause et al. (2009).

In addition to ratings of mental effort, performance on each item of the Chemical Equilibrium Concept Assessment was measured. In this study, a correct answer was coded with a 1 and an incorrect answer with a 0*,* giving a maximum raw performance score of 14 on the instrument. Research into the efficacy of using performance measures, and other indirect, objective measures such as reaction time, accuracy and error rate, to measure cognitive load, are noted in the CLT literature (Brunken, et al., 2003; Chandler & Sweller, 1996; Paas, et al., 2003). Because the CLT literature does not indicate a direct relationship between performance and intrinsic cognitive load specifically, ratings of mental effort and performance measures were correlated to evaluate any significant relationship between the variables.

Because the design and organization of the learning environment, and the instructional methodologies used across each group were identical, it was assumed that extraneous and germane cognitive load were limited. Under such conditions significant differences in performance between groups is assumed to be due to changes in intrinsic cognitive load. The lower the intrinsic load for a group, the more partial schema formation occurred as a result of pre-training (Ayres, 2006).

Given the additive nature of the three sources of cognitive load (intrinsic, extraneous and germane), an attempt to verify the assumption that extraneous and germane load were neutralized across both groups was conducted. To monitor germane load, students were asked the following question at the conclusion of the pre and post-test: *How easy or difficult is it for you to understand chemical equilibrium at this moment?* Students reported their difficulty rating on a 9-point scale ranging from *very easy* to very *difficult*, with 1 being *very easy* and 9 being very *difficult.* To monitor extraneous cognitive load, students were asked the following question at the conclusion of the pre and post-test: *How easy or difficult is it for you to work in this learning environment at the moment?* The question was derived from the *SOS scale*, a cognitive load measure suggested by Swaak and De Jong (2001). The question was reported using the same 9-point scale used with the germane load measure.

Research Question 1

What are the effects of pre-training on the intrinsic cognitive load of chemical equilibrium instruction for advanced high school students as measured by ratings of mental effort?

The first research question investigated whether or not there is a statistically significant difference in average mental effort ratings between the pre-training group and no pre-training group. As described above, directly following each of the 14 items on the Chemical Equilibrium Concept Assessment, students responded to an associated mental effort rating scale with five descriptors (very little, little, moderate amounts, large amounts, very large amounts), coded 1-5 respectively. An independent sample t test was used to assess differences between each group on their average ratings of mental effort. Given that students were randomly assigned to each group, and groups were independent of one another, it can be assumed that all assumptions associated with conducting the t test were met.

To get a baseline measure of the intrinsic cognitive load of the chemical equilibrium concepts, students were given the Chemical Equilibrium Concept Assessment as a pre-test wherein they were asked to rank their mental effort directly following completion of each item. As expected, on all chemical equilibrium content items, there was no significant difference between both groups in mental effort prior to treatment, *t*(60) = 1.83, *ns.* Thus, it can be assumed from these results, both groups entered the treatment with the same intrinsic cognitive load baseline. See Table 1 for the mean mental effort for students in the pre-training and no pre-training groups on the pre-test.

Table 1

Means, Standard Deviations, and Independent t-test Results for Mental Effort Ratings on the Chemical Equilibrium Concept Assessment Pre-Test

Intrinsic Load Measure	Statistic	Pre-Training (n=31)	No Pre-Training (n=31)	t
Mental Effort	Mean	3.80	4.14	1.83
	SD	.76	.70	

Following the treatment (pre-training or no pre-training) and instructional phases of the study, students were once again given the Chemical Equilibrium Concept Assessment and asked to rate their mental effort. There was a significant difference in the mental effort ratings of the pre-training group and the no pre-training group, *t*(60) = 5.34, *p* = .0001. The results were as expected in that students in the pre-training group (*M* = 2.52, *SD* = .64) on average invested less mental effort, and thus experienced less intrinsic cognitive load, than students in the no pre-training group (*M* = 3.43, *SD* = .70). All statistics used to assess between group differences in average mental effort for the post-test are displayed in Table 2.

Table 2

Means, Standard Deviations, and Independent t-test Results for Mental Effort Ratings on the Chemical Equilibrium Concept Assessment Post-Test

Intrinsic Load Measure	Statistic	Pre-Training (n=31)	No Pre-Training (n=31)	t	d
Mental Effort	Mean	2.52	3.43	5.34*	1.36
	SD	.64	.70		

*Statistically significant at the .05 level

Additionally, because both the pre-training and no pre-training groups showed a decrease in mean mental effort from pre to post-test, a paired t test was conducted to assess significant differences in mental effort within groups. There was a significant difference in mental effort ratings within the pre-training group, *t*(60) = 7.17, *p* = .0001. A significant difference in mental effort rating within the no pre-training group also existed, *t*(60), = 3.04, *p* = .0002. All statistics used to assess within group differences in mental effort for the pre and post-test are displayed in Table 3.

Table 3

Means, Standard Deviations, and Paired t-test Results for Mental Effort Ratings on the Chemical Equilibrium Concept Assessment Pre and Post-Test

Group	Statistic	Pre-Test	Post-Test	t	d
Pre-Training (n= 31)	Mean SD	3.80 0.76	2.52 .64	7.17*	1.56
No Pre-Training (n=31)	Mean SD	4.14 .70	3.43 .70	3.04*	1.12

*Statistically significant at the .05 level

Research Question 2

What are the effects of pre-training on advanced high school chemistry students' performance on an equilibrium concept assessment?

The second research question investigated whether or not there is a statistically significant difference in performance on equilibrium content items between the pre-training group and no pre-training group. As described above, each of the 14 items were coded 1 for correct and 0 for incorrect with a maximum raw performance score of 14 on the instrument. An independent samples t test was used to assess difference in total raw score averages between each group. Given that students were randomly assigned to each group, and groups were independent of one another, it can be assumed that all assumptions associated with conducting the t test were met.

To get a baseline measure for performance on chemical equilibrium content items, students were given the Chemical Equilibrium Concept Assessment as a pre-test. As expected, on all chemical equilibrium content items, there was no significant difference between both groups in performance, $t(60) = .28$, *ns.* Thus, it can be assumed from these results, both groups entered the treatment with the same level of understanding of how to solve basic problems of chemical equilibrium. See Table 4 for the mean performance for students in the pre-training and no pre-training groups on the pre-test.

Table 4

Means, Standard Deviations, and Independent t-test Results for Performance Raw Scores on the Chemical Equilibrium Concept Assessment Pre-Test

Intrinsic Load Measure	Statistic	Pre-Training (n=31)	No Pre-Training (n=31)	t
Performance	Mean	3.16	3.10	.28
	SD	2.20	2.29	

Following the treatment (pre-training or no pre-training) and instructional phases of the study, students were once again given the Chemical Equilibrium Concept Assessment. There was a significant difference in performance for the pre-training group and the no pre-training group, *t*(60) = 3.70, *p* = .0005. The results were as expected in that students in the pre-training group (*M* = 8.14, *SD* = 3.16) on average scored higher, than students in the no pre-training group (*M* = 5.25, *SD* = 2.98). All statistics used to assess differences in performance are displayed in Table 5.

Table 5

Means, Standard Deviations, and Independent t-test Results for Performance Raw Scores on the Chemical Equilibrium Concept Assessment Post-Test

Intrinsic Load Measure	Statistic	Pre-Training (n=31)	No Pre-Training (n=31)	t	d
Performance	Mean	8.14	5.25	3.70*	.94
	SD	3.16	2.98		

* Statistically significant at the .05 level

Additionally, because both the pre-training and no pre-training groups showed an increase in performance from pre to post-test, a paired t test was conducted to assess significant differences within groups. There was a significant difference in performance within the pre-training group, *t*(60) = 7.20, *p* = .0001. A significant difference in performance within the no pre-training group also existed, *t*(60), = 3.14, *p* = .002. All statistics used to assess within group differences in performance for the pre and post-test are displayed in Table 6.

Table 6

Means, Standard Deviations, and Paired t-test Results for Performance Raw Scores on the Chemical Equilibrium Concept Assessment Pre and Post-Test

Group	Statistic	Pre-Test	Post-Test	t	d
Pre-Training	Mean	3.16	8.14	7.20*	1.67
(n= 31)	SD	2.20	3.16		
No Pre-Training	Mean	3.10	5.25	3.14*	.71
(n=31)	SD	2.24	2.98		

*Statistically significant at the .05 level

Additional Data Analysis

Additional data analysis was conducted to see if a statistically significant difference in either germane or extraneous cognitive load existed between the pre-training and no pre-training group during pre-test or post-test administration. While the dependent variable, intrinsic cognitive load, assesses complexity in the form of the element interactivity, extraneous cognitive load relates to the manner in which information is presented, and germane cognitive load is the load induced via the learners processing efforts (Pollock, et al., 2002; Renkl & Atkinson, 2003). An independent samples t test was used to assess difference in total raw score averages on each of the two cognitive load survey items outlined previously in this chapter designed to assess for changes in extraneous and germane cognitive load. Given that students were randomly assigned to each group, and groups were independent of one another, it can be assumed that all assumptions associated with conducting the t test were met.

With respect to pre-test administration, there was no significant difference between both groups on either cognitive load measure. All statistics used to assess differences in germane and extraneous cognitive load during the pre-test are displayed in Table 7.

Table 7

Means, Standard Deviations, and Independent t-test Results for Germane and Extraneous Cognitive Load Ratings During Pre-Test Administration

Measure	Statistic	Pre-Training (n=31)	No Pre-Training (n=31)	t
Germane Load	Mean	8.03	8.29	.90
	SD	1.05	1.22	
Extraneous Load	Mean	2.39	2.13	.46
	SD	1.74	1.67	

With respect to post-test administration, the results were as expected in that there was no significant difference between both groups in extraneous cognitive load. An unexpected significant difference in germane cognitive load was detected, *t*(60) = 2.79, *p* = .007. Students in the pre-training (*M* = 5.10, *SD* = 1.77) on the average reported to have less *difficulty* in understanding chemical equilibrium during post-test administration than the no pre-training group (*M* = 6.31, *SD* = 1.64). All statistics used to assess differences in germane and extraneous cognitive load during the post-test administration are displayed in Table 8

Table 8

Means, Standard Deviations, and Independent t-test Results for Germane and Extraneous Cognitive Load Ratings During Post-Test Administration

Measure	Statistic	Pre-Training (n=31)	No Pre-Training (n=31)	t	d
Germane Load*	Mean	5.10	6.31	2.79	.71
	SD	1.77	1.64		
Extraneous Load	Mean	3.61	3.34	.47	
	SD	2.31	2.24		

* Statistically significant at the .05 level

Research Question 3

What is the relationship between intrinsic cognitive load, as measured by ratings of mental effort and advanced high school chemistry students' performance on an equilibrium concept assessment?

The third research question investigated whether or not there is a statistically significant relationship between intrinsic cognitive load, as measured by ratings of mental effort, and performance as measured by score on an equilibrium concept assessment. Correlations between intrinsic cognitive load and performance were conducted using scores from the post-test for the pre-training and no pre-training groups independently, and together as a whole.

On the post-test, there was small, but not significant correlation between intrinsic load and performance for the no pre-training group. Likewise, there was a small, but not significant correlation between intrinsic load and performance for the pre-training group.

However, across the entire data set (pre-training and no pre-training) there was a significant and moderate negative, correlation between performance and intrinsic load, *r* (60) = -0.44, *p* = .0003. Correlations between intrinsic load and performance are displayed in Table 9.

Table 9

Correlations Between Intrinsic Cognitive Load and Performance on the Chemical Equilibrium Concept Assessment Post-Test

No Pre-Training Group	Pre-Training Group	Both Groups
-.24	-.21	-.44*

* Statistically significant at the .05 level

Summary of Results

The purpose of this study was to investigate the effects of using screencasts as a pre-training tool to manage the intrinsic cognitive load of a lesson on chemical equilibrium delivered to advanced high school chemistry students. To accurately relate changes in the dependent variable, intrinsic cognitive load, to the independent variable, pre-training, a pre-test on chemical equilibrium was given to both groups. No statistically significant difference in performance, or mental effort existed between each group prior to treatment.

Upon conclusion of pre-training and instruction, a statistically significant difference in mental effort on the post-test did exist between groups. Students in the pre-training group on average invested less mental effort than students in the no pre-training group. Additionally, a statistically significant difference in performance on equilibrium content items on the post-test did exist between groups. Students in the pre-training group on average scored higher than students in the no pre-training group. Paired t tests were also conducted, and both groups showed significant increases in performance, and decreases in mental effort from pre-test to post-test.

Ayres (2006) argues that the three sources of cognitive load are additive. That is, if the sum of extraneous and intrinsic load is reduced, more germane load can be directed towards active processing in the working memory. Keeping this in mind, in order to accurately attribute changes in intrinsic cognitive load to the dependent variable, pre-training, germane and extraneous load were monitored during pre-test and post-test administration. No significant difference in germane or extraneous load was observed during pre-test administration. Likewise, no significant difference in extraneous cognitive load was noted during post-test administration. However, a statistically significant difference in germane cognitive load was observed. Students in the pre-training on the average reported to have less difficulty in understanding chemical equilibrium during post-test administration than the no pre-training group.

Unlike ratings of mental effort, a direct connection between performance measures and intrinsic cognitive load is not noted in the CLT literature. (Brunken, et al., 2003). In order to relate changes in performance to changes in intrinsic cognitive load, ratings of mental effort and performance measures were correlated on the post-test. A statistically significant relationship between performance and intrinsic cognitive load was observed on the post-test when ratings of mental effort and performance were combined across both groups.

CHAPTER V

DISCUSSION OF RESULTS

The purpose of the study was to investigate the efficacy of using screencasting as a multimedia pre-training tool to manage the intrinsic cognitive load of chemistry instruction. First, the study is summarized, including a restatement of the research problem. Limitations of the study are then outlined, findings are discussed and research conclusions are made. Finally, implications for research and instructional design are identified.

Summary of the Study

The complexity associated with learning chemistry, and the negative side effects of student and instructor misconceptions that result, are consistent themes throughout the research literature (Banerjee, 1991; Hackling and Garnett, 1985; Tai, et al., 2005; Tyson & Treagust, 1999). Defined as *intrinsic cognitive load*, research aimed at managing the complexity of difficult to learn subjects such as chemistry is limited (Ayres, 2006; Gerjets, et al., 2004, 2006; Kirschner, et al., 2009). Moreover, studies that intentionally investigate the use of technology such as *screencasts*, which could empower instructors to facilitate online intrinsic cognitive load management via pre-training, are non-existent (Mayer, 2005a). Given the high intrinsic cognitive load of learning chemistry, and the lack of efficacy research noted above, this study was conducted.

A sample of 62 advanced placement chemistry students at a co-ed Catholic high school in downtown San Francisco participated in the study. Students were randomly assigned to one of two groups representing the two levels of the independent variable: pre-training or no pre-training. Prior to treatment, students took the Chemical

Equilibrium Content Assessment as a pre-test to detect any between group differences in prior knowledge. Data analysis using an independent samples t test indicated that there was no statistically significant difference in performance, or mental effort across both groups.

Students assigned to the pre-training group viewed a 10-minute screencast that included the basic definitions, diagrams and a simple summary of chemical equilibrium. Upon conclusion of pre-training, students in both groups received a 50-minute, in depth lecture, on the basic concepts of chemical equilibrium. Specifically, the lecture proceeded through a series of explanations and examples of *Le Chatelier's Principle*. Le Chatelier's Principle was chosen due to the high level of student misconception and instructional complexity noted in the literature (Banerjee, 1996; Tyson et al.,1999).

After treatment, all students took the Chemical Equilibrium Concept Assessment again, as a post-test. An independent samples t test indicated that there was a statistically significant difference in both performance and mental effort between groups on the post-test. On average, the pre-training group invested less mental effort and generated more correct answers to items on the assessment than did the no pre-training group. A paired t test was also conducted to see if significant within group differences existed from pre to post-test. On average, both groups invested less mental effort and reported more correct answers on the post-test than they did on the pre-test.

Given the additive nature of cognitive load, extraneous and germane cognitive load were monitored during pre and post-test administration (Ayres, 2006). Because an independent samples t test did not identify a significant difference in germane or extraneous cognitive load on the pre-test, and only an increase in germane load for the treatment group on the post test, differences in performance and mental effort can, to a degree, be extrapolated to changes intrinsic cognitive load. According to Pollock et al. (2002) and van Merriënboer et al. (2003, 2006), this result is due to partial schema formation and a decrease in overall element interactivity for the learner.

Because a direct link between performance and intrinsic cognitive load is not noted in the research literature, a correlation analysis between intrinsic load, as measured by ratings of mental effort, and performance was conducted (Brunken, et al., 2003). A significant relationship between performance and intrinsic cognitive load was observed across all students on the post-test.

Limitations

This study was limited by factors related to the sample and the methodology. The use of a convenience sample brings into question the ability to generalize results to the larger *advanced* high school chemistry student population. Additionally, there is no literature that clearly outlines the difference between an advanced and non-advanced high school chemistry student at large. At best, the use of advanced placement chemistry students only approximates the desired sample of students.

With respect to the methodology, the lack of a pilot study used to assess the reliability of the Chemical Equilibrium Concept Assessment prior to treatment is a limitation of this study. Although a validity panel of experts was conducted, and the instrument represents a hybrid of two previously used assessments, reliability and validity information regarding its past use was not available (Banerjee, 1991; Hackling & Garnett, 1985).

With respect to the dependent variables, although indirect subjective mental effort ratings are frequently used in current CLT research, questions still exist as to the exact connection between mental effort ratings and intrinsic cognitive load (Brunken & Leutner, 2003). In addition to mental effort ratings, performance on the Chemical Equilibrium Concept Assessment was also included as a dependent variable. Given the additive nature of intrinsic, extraneous and germane cognitive load, using mental effort ratings and performance to assess intrinsic cognitive load relies heavily on the control of the extraneous and germane load (Ayres, 2006). Additionally, because the CLT research does not indicate a direct link between performance measures and intrinsic cognitive load, a correlation analysis between ratings of mental effort and performance was conducted in order to extrapolate a link between performance and intrinsic cognitive load (Brunken & Leutner, 2003).

Although survey items were used to monitor changes in extraneous and germane cognitive load between groups on the pre and post-test, reliability and validity of the survey item was not assessed. Moreover, because extraneous and germane load were only monitored at the pre and post-test level, subsequent alterations in extraneous and germane load during the treatment and instruction could have impacted subjective mental effort and performance.

Discussion of Research Questions

The first research question regarding the effect of pre-training on intrinsic cognitive load was measured using ratings of mental effort on the items of the Chemical Equilibrium Concept Assessment. As expected, students randomly assigned to the pre-training group reported a statistically significant decrease in mental effort on the

Chemical Equilibrium Concept Assessment after instruction than did the students that did not receive pre-training. The effect size for this comparison was 1.36. An additional analysis of within group differences between the pre and post-test was conducted. Although the between group comparison showed that the pre-training group reported less perceived mental effort, both groups invested a statistically significant decrease in mental effort from the pre to post-test. The estimated effect sizes for the pre-training and no pre-training groups were 1.51 and 1.12 respectively.

The second research question regarding the effect of pre-training on performance was measured using student score on the items of the Chemical Equilibrium Concept Assessment. As expected, students randomly assigned to the pre-training group demonstrated a statistically significant increase in performance on the Chemical Equilibrium Concept Assessment after instruction than did the students that did not receive pre-training. The effect size for this comparison was .94. An additional analysis of within group differences between the pre and post-test was conducted. Although the between group comparison showed that the pre-training group demonstrated increased performance, both groups improved significantly in performance from pre to post-test. The estimated effect sizes for the pre-training and no pre-training groups were 1.67 and .71 respectively.

The third research question regarding the relationship between performance and intrinsic cognitive load was measured by calculating correlations between performance and mental effort variables on the post-test. A significant relationship between performance and mental effort was observed across all student scores on the post-test.

The significant correlation coefficient between performance and intrinsic cognitive load on the post-test was measured to be -.44.

Conclusions

A key finding in this study was the effect that a short pre-training intervention delivered via a screencast had on both performance and subjective ratings of mental effort on chemical equilibrium content items. Students who received pre-training prior to instruction reported a statistically significant decrease in perceived mental effort, and increase in performance as compared to students who did not receive pre-training.

Because recent CLT research strongly supports the use of ratings of mental effort as subjective measures of intrinsic cognitive load, and performance as objective measures of overall cognitive load, pre-training appeared to successfully manage the intrinsic cognitive load of students in the pre-training group (Ayres, 2006; Paas & Van Merriënboer, 1993, 1994). However, because Sweller (2005) notes that the three facets of cognitive load (extraneous, germane and intrinsic) are additive, extrapolating changes in mental effort and performance to changes in intrinsic cognitive load requires successful control of extraneous and germane load.

Although survey item response on the pre and post-test showed no significant difference in extraneous cognitive load between groups, using difficulty ratings developed by DeLeeuw and Mayer (2008) to assess germane cognitive load, showed a statistically significant decrease in difficulty for the pre-training group. Despite control of the learning environment and materials by the researcher, this result, in the context of the additive nature of cognitive load, brings the direct connection between pre-training and intrinsic cognitive load into question.

As expected, it was found that despite between group differences, both groups had statistically significant within group changes in mental effort and performance from pre to post-test. None of the students in either the pre-training or the no pre-training group had received any instruction in chemical equilibrium prior to the study. Additionally, no significant differences in between group chemical equilibrium prior knowledge at the onset of the study were observed. Thus, it can be concluded that through a CLT lens, even without pre-training, after instruction, both groups formed enough partial schema to successfully negotiate the complexity of chemical equilibrium and demonstrate improved performance and decreased mental effort.

Another key finding of this study was a statistically significant negative correlation between intrinsic cognitive load and performance, as measured by ratings of mental effort, across all students on the Chemical Equilibrium Concept Assessment post-test. Because only mental effort is directly linked to intrinsic cognitive load in the CLT literature, objective performance measures only approximate, at best, intrinsic cognitive load when extraneous and germane cognitive load are controlled. A significant negative correlation between ratings of mental effort and performance strengthens the argument that changes in performance are a result of the pre-training intervention.

Implications

The implications of the current study are discussed in two parts. First, research implications, specifically in the field of intrinsic cognitive load management, are discussed. Second, educational implications regarding pre-training as an intrinsic cognitive load management technique, and screencasting as a multimedia learning intervention, are outlined.

Research Implications

The current study suggests that there is a relationship between pre-training and intrinsic cognitive load. This observation supports conclusions in the CLT research that pre-training helps learners *chunk* multiple interacting elements into smaller units, thus decreasing the overall intrinsic cognitive load of the material (Ayres, 2006). Moreover, results from this study support literature collected by Pollock et al. (2002), van Merriënboer et al. (2003), Gerjets et al. (2004), and Ayres (2006), that pre-training is an effective intrinsic cognitive load management technique. With respect to method of pre-training used in the current study, results corroborate additional conclusions made by van Merriënboer et al. (2003) and Gerjets et al. (2004) that whole-task sequencing*,* a form of pre-training where learners are exposed to a simplified, but holistic pre-training experience, is beneficial in complex learning environments such as the chemistry classroom (Ginns, 2005).

Given the complexity of learning chemistry noted in the literature, specifically chemical equilibrium, further efficacy research is needed that assesses the potential benefits of pre-training as a tool to help students negotiate the high intrinsic cognitive load the topic presents (Banerjee, 1995; Hackling and Garnett, 1985). Specifically, given the significant change in germane cognitive load observed in the pre-raining group, there is a need for research that intentionally, and systematically, monitors intrinsic cognitive load in the context of extraneous and germane load. Given the additive nature of extraneous, intrinsic and germane cognitive load, the measurement of intrinsic load relies heavily on controlling the other two cognitive load variables (Sweller, 2005). Further research must emphasize the need to intentionally see cognitive load management as a sum of its parts in order for results, such as those observed in the current study, to accurately challenge the assumption that intrinsic cognitive load can not be altered by the instructor.

The methodology of the current study involved one group receiving a short multi-media pre-training intervention prior to a lecture of the basic concepts of chemical equilibrium. The pre-training protocol adopted in the current study represents a merger between Mayer's (2005a) approach and the van Merriënboer et al. (2003) method of pre-raining. Mayer's pre-training involves short instructional sequences where learners are exposed to the names and basic characteristics of a specific instructional topic. Although similar in function, the van Merriënboer et al. approach relies heavily on schema formation via exposing students to the overarching principles and concepts of a lesson, rather than simply the names and basic characteristics intrinsic to Mayer's format. Given their similarities and differences, research is needed that intentionally compares the efficacy of both approaches to pre-training in complex learning environments such as chemistry.

Although the CLT literature notes a strong connection between pre-training and intrinsic cognitive load management via schema formation, an alternative explanation for decreased mental effort and increased performance is increased instructional time. From strictly a time perspective, the pre-training group received a 10 minute and 52 second pre-training phase along with a 50 minute instructional phase, yielding 60 minutes and 42 seconds of overall instruction. The no pre-training group received only 50 minutes of instruction. Further research is needed to more critically analyze pre-training in the context of instructional time. For example, instructional time could be controlled by offering the no pre-training group a chance to review the material for 10 minutes and 52 seconds after the lecture and prior to the post-test. This intervention could lend insight into whether or not building prior-knowledge, and schema before a lesson is more effective at managing overall element interactivity than simply increasing overall instructional time.

Although not directly connected to pre-training, a further research implication involves the general use of screencasting as multimedia learning tool. Given the lack of multimedia learning literature, more research is needed that examines potential benefits and various applications of screencasts in education, specifically chemistry. Moreover, the ability to record instructor audio narrations and any on-screen visual activity aligns well with past research into other intrinsic cognitive load management techniques such as managing modality, user control, personalization and voice (Mayer, 2005a). Specific to the current study, the above implication is directly tied to Mayer's (2005c) call for more research on the effects of using multimedia in a chemistry learning environment.

Educational Implications

Instructional methods to help students learn complex subjects are suggested as a result of this study. Because chemistry, specifically chemical equilibrium, is identified as being highly complex, the results of this study are very applicable to chemistry instructors whose curriculum includes coverage of chemical equilibrium (Banerjee, 1995; Ginns, 2005; Tai, et al., 2006; Wandersee et al., 1994). Given the population of the current study, implications are appropriate for teachers of advanced secondary school chemistry instructors. Two instructional strategies that show particular promise are discussed in this section.

The first strategy is the form of pre-training discussed in the current study that incorporates Mayer's (2005a) definition of pre-training where students receive exposure to the basic definitions and key terms prior to instruction, and the van Merriënboer et al. (2003, 2006) holistic *whole-task sequencing* instructional sequencing approach. In simpler learning environments, an isolated-elements approach suggested by Pollock et al. (2002), where elements are independently assimilated prior to discussing their interactions, is effective. However, van Merriënboer et al. (2003, 2006), argues that, while an isolated-elements approach might be successful in some knowledge domains, the integrated nature of complex learning tasks, such as with chemical equilibrium problems, requires an incorporated rather than fragmented approach. Results from the current study suggest that using a brief, whole-task pre-training method, where students are exposed to the basic definitions and key concepts, significantly impacts student performance and mental effort.

The second strategy is the use of screencasting. Screencasts, video recordings of all on-screen computer activity, were used as the medium for pre-training in the current study (Richardson, 2009). Screncasts can be distributed and cataloged online, and reviewed any number of times by students. Given the efficient means of sharing screencasts, pre-training can take place in variety of settings, in-line with current movements in technology, society and education (Richardson, 2009). Moreover, the ability to continuously revisit topics that require a high level of algorithmic problem solving is a major educational benefit (Franciszkowicz, 2009; Richardson, 2009). Cognitive benefits of screencasting that transcend pre-training include the inclusion of native instructor voice and hand writing (if digital annotation is incorporated), both proven to be sensitive to the working memory architecture described by Mayer's (2001) CTML.

Summary

The purpose of this study was to examine the effects of pre-training on the intrinsic cognitive load of chemical equilibrium instruction on advanced high school chemistry students. To measure the dependent variable, intrinsic cognitive load, mental effort and performance were measured in the context of extraneous and germane cognitive load, to assess a causal relationship with pre-training, the independent variable.

The current study showed that there was a significant relationship between pre-training and intrinsic cognitive load. With respect to the two measures of the dependent variable, the most statistically significant relationship was between pre-training and mental effort. The effect size for the relationship between pre-training and mental effort, as measured by Cohen's d, was 1.36.

The current study confirmed recent movements in CLT research that identify pre-training as an effective intrinsic cognitive load management method (Ayres, 2006). This study adds to the current research by extending the analysis to the field of chemistry, a subject noted in both the CLT, and chemistry education literature, as having particularly high intrinsic cognitive load (Ginns, 2005; Tai, et al., 2006). Moreover, the current study adds to the multimedia learning research by assessing the efficacy of using screencasts as multimedia tools in the classroom (Mayer, 2005c).

The implications of this study are related to research and classroom instruction. Additional research that continues to challenge the assumption that intrinsic cognitive load is a static component of overall cognitive load, should be conducted. Specifically, research must take into account the additive nature of cognitive load, assuring that measurement techniques used to monitor intrinsic cognitive load management are accurate and causal (Sweller, 2005).

With respect to the method of pre-training, added research is needed that more intentionally examines the difference between Mayer's (2005a) more general approach of providing learners with only names and characteristics, and the van Merriënboer et al. (2003, 2006) over-arching, more holistic, approach to pre-training. Moreover, efficacy research that critically assess the effects of pre-training in the context of instructional time is needed to strengthen the argument that pre-training is indeed responsible for the significant decrease in mental effort and increase in performance observed. Finally, chemistry educators are encouraged to use screencasting as an instructional technique to help students interact with, and negotiate through, the complexities innate to the subject.

References

Akkus, H., Kadayifci, H., & Atasoy, B. (2003). Effectiveness of Instruction based on the constructivist approach on understanding chemical equilibrium. *Research in Science and Technology Education, 21*, 209-227.

Agapova, O., Jones, L., Ushakov, A., Ratcliffe, A., and Varanka Martin, M. (2002). Encouraging independent chemistry learning through multimedia design experiences, *Chemistry Education International*, *3,* 3-7.

Ardac, D., & Akaygun, S. (2004). Effectiveness of multimedia-based instruction that emphasizes molecular representations on students' understanding of chemical change. *Journal of Research in Science Teaching, 41*, 317-337.

Astleitner, H., & Leutner, D. (1996). Applying standard network analysis to hypermedia systems: Implications for learning. *Journal of Educational Computing Research, 14,* 285-303.

Ayres, P. (2006). Impact of reducing intrinsic cognitive load on learning in a mathematical domain. *Applied Cognitive Psychology, 20*, 287-298.

Ayres, P. (2006). Impact of reducing intrinsic cognitive load on learning in a mathematical domain. *Applied Cognitive Psychology, 20*, 287-298.

Ayres, P. & Sweller, J. (2005). The split-attention principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning*. (pp. 135-146). New York: Cambridge University Press.

Baddeley, A.D. (1986). *Working memory*. Oxford, England: Oxford University Press.

Baddeley, A.D., & Hitch, G.J.L (1974). Working memory, In G.a. Bower (Ed.), The psychology of learning and motivation: Advances in research and theory (pp. (47-89). New York: Academic Press.

Banerjee, A.C. (1991). Misconceptions of students and teachers in chemical equilibrium. *International Journal of Science Education, 13*, 487-494.

Banerjee, A.C. (1995). Teaching chemical equilibrium and thermodynamics in undergraduate general chemistry classes, *Journal of Chemical Education, 72,* 879-881.

Banerjee, A. C. (1996). Letter to the editor on chemical equilibrium. *Journal of Chemical Education*, 73, 261-62.

Bergman, J., & Sams, A. (2008). Remixing the chemistry class. *Learning and Leading with Technology, 1*, 22-27.

Birk, J. P., and J. Foster. (1993). The importance of lecture in general chemistry course performance. *Journal of Chemical Education, 70*, 180-182.

Borg, G., Bratfisch, O., & Dornic, S. (1971). On the problem of perceived difficulty. *Scandinavian Journal of Psychology, 12*, 249-260.

Breuer, S. (2002). Does chemistry have a future? *The Royal Chemistry Society, 6,* 13-16.

Brunken, R., Plaas, J.L, Leutner, D. (2003) Direct measurement of cognitive load in multimedia learning. *Educational Psychologist, 38*, 53-61.

Brunken, R., Plass, J.L. & Leutner, D. (2004). Assessment of Cognitive Load in Multimedia Learning with Dual-Task Methodology: Auditory Load and Modality Effects. *Instructional Science*, *32* , 115-132.

Cooper, G., Tindall-Ford, S., Chandler, P., & Sweller, J. (2001). Learning by imagining. *Journal of Experimental Psychology: Applied, 7*, 68-82.

Carlson, R., Chandler, P. & Sweller, J. (2003). Learning and understanding science instructional material. *Journal of Educational Psychology, 95* (3), 629-640.

Chandler, P. & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction, 8,* 293-332.

Chandler, P. & Sweller, J. (1992). The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology, 62,* 233-246.

Colburn, A. (2009). The prepared practitioner. *The Science Teacher, 76*, 10.

College Board (2008). *Chemistry released exam*. New York: College Entrance Exam Board.

De Jong, O. (2000). The teacher trainer as researcher: Exploring the initial pedagogical content concerns of prospective science teachers. *European Journal of Teacher Education*, 23, 127-137.

DeLeeuw, K. E., & Mayer, R. E. (2008). A comparison of three measures of cognitive load: Evidence for separable measures of intrinsic, extraneous, and germane load. *Journal of Educational Psychology, 100*, 223-234.

de Vos, W., van Berkel, B., & Verdonk, A.H. (1994). Coherent Conceptual Structure of the Chemistry Curriculum. *Journal of Chemical Education, 71,* 734-746.

Dori, Y., & Barak, M. (2001). Virtual and physical molecular modeling: Fostering model perceptions and spatial understanding. *Educational Technology and Society, 4,* 61-73.

Erdemir, A., Geban, O., & Uzuntirayaki, E. (2000). Freshman students' misconceptions in chemical equilibrium. *Hacettepe Universitesi Egitim Fakultesi Dergisi, 18*, 79-84.

Francisco J. S., Nicoll, G., Trautmann, M. (1998). Integrating multiple teaching methods into a general chemistry classroom. *Journal of Chemical Education, 75*, 210-213.

Franciszkowicz, M. (2008). Video-based instruction. *Journal of Research Center for Educational Technology, 4*, 5-14.

Gable, D., & Bunce, D.M. (1994). *Handbook of research on science teaching and learning* (pp. 301-326). New York: Macmillian Press.

Gerjets, P., Scheiter, K., & Catrambone, R. (2004). Designing instructional examples to reduce intrinsic cognitive load: Molar versus modular presentation of solution procedures. *Instructional Science, 32*, 33-58.

Gerjets, P., Scheiter, K., & Catrambone, R. (2006). Can learning from molar and modular worked examples be enhanced by providing instructional explanations and prompting self-explanations? *Learning and Instruction, 16*, 104-121.

Ginns, P. (2005). Meta-analysis of the modality effect. *Learning and Instruction, 15,* 313-331.

Habraken, C.L. (1996). Perceptions of chemistry: Why is the common perception of chemistry, the most visual of sciences, so distorted? *Journal of Science Education and Technology, 5*, 193-201.

Hackling, M.W., & Garnett, P.J. (1985) Misconceptions of chemical equilibrium " the associated framework". *European Journal of Science Education, 7*, 205-211.

Harrison, A.G., & De Jong, O. (2005). Exploring the use of multiple analogical models when teaching and learning chemical equilibrium. *Journal of Research in Science Teaching, 42*, 1135-1159.

Herron, J., & Nurrenbern, S. C. (1999). Chemical education research: Improving chemistry learning. *Journal of Chemical Education, 76*, 1353-1360.

Huddle, P.A., & Pillay, A.E. (1996). An in-depth study of misconceptions in stoichiometry and chemical equilibrium at a south African university. *Journal of Research in Science Teaching, 33*, 65-77.

Johnstone, A.H. (2000). Chemistry teaching: logical or psychological. *Chemistry Education: Research and Practice in Eutope, 1*, 9-15.

Kalyuga, S. (2005). Prior knowledge principle in multimedia learning. In R.E. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning* (pp. 325-338). New York: Cambridge University Press.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*(1), 23-31.

Kalyuga, S., Chandler, Pl, Touvinene, J., & Sweller, J. (2001). When problem solving is superior to studying worked examples. *Journal of Educational Psychology, 93*, 579-588.

Kempa, R.F. (1991). Students' learning difficulties in science: Causes and possible reasons. *Ensenanza de la Ciencias, 9*, 119-128.

Knaus, J.K., Muprhy, K.L., & Holme, T.A. (2009). Designing chemistry pratice exams for enhanced benefits. *Journal of Chemical Education, 86*, 827-830.

Krajicik, J.S. (1991). *The psychology of learning science* (pp. 117-147). Hillsdale, NJ: Lawrence Erlbaum Press.

Kester, L., Lehnen, C., Van, G., Pascal W. M., & Kirschner, P., A. (2006). Just-in-time, schematic supportive information presentation during cognitive skill acquisition. *Computers in Human Behavior*, *22*(1), 93-112.

Kirshner, F., Paas, F., & Kirschner, P.A. (2009). Individual and group-based learning from complex cognitive tasks: Effects on retention and transfer efficiency. *Computers in Human Behavior, 25*, 306-314.

Knaus, K., Murphy, K., & Holme, T. (2009). Designing chemistry practice exams for enhanced benefits: An Instrument for comparing performance and mental effort eeasures. *Journal of Chemical Education, 86*, 827-834.

Kousathana, M., & Tsaparlis, G. (2002). Students' errors in solving numerical chemical-equilibrium problems. Chemistry Education: *Research and Practice in Europe, 3*, 5-17.

Kozma, R.B. (2000). The use of multiple representations and the social construction of understanding chemistry. In M. Jacobson & R. Kozma (Eds.) Innovations in science and mathematics' education: Advance designs for technologies of learning (pp. 11-46. Mahwah, NJ: Lawrence Erlbaum Associates.

Kozma, R.B, Russell, J., Jones, T., Marx, N., & Davis, J. (1996). The use of multiple, linked representations to facilitate science understanding. In S. Vonsniadou, R. Glasser, E. DeCorte, & H. Mandel (Eds.), *International perspective on psychological foundations of technology-based learning environments* (pp. 41-60) Hillsdale, NJ: Lawrence Erlbaum Associates.

Lee, H., Plaas, J.L., & Homer, B.D. (2006). Cognitive load for learning from computer-based science simulations. *Journal of Educational Psychology, 98*, 902-913.

Linn, M. (1987). Establishing a research base for science education challenges; Trends and recommendations. *Journal of Research in Science Teaching, 24*, 191-216.

Low, R. & Sweller, J. (2005). The modality principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning*. (pp. 147-158). New York: Cambridge University Press.

Lowe, J.N. (1968). Who will our teachers be? *Journal of Chemical Education, 45*, 649-650.

Mayer, R.E. (1997). Multimedia learning: Are we asking the right questions. *Educational Psychologist*, 32, 1-19.

Mayer, R.E. (2001). *Multimedia learning*. New York Cambridge University Press

Mayer, R. E. (2005a). Principles for managing essential processing in multimedia learning: Segmenting, pre-training, and modality principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning*. (pp. 169-182). New York: Cambridge University Press.

Mayer, R. E. (2005b). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning*. (pp. 183-200). New York: Cambridge University Press.

Mayer, R.E. (2005c). Cognitive theory of multimedia learning. In R.E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31-48). New York: Cambridge University Press.

Mayer, R.E., & Chandler, P. (2001). When learning is just a click away: Does simple user interaction foster deeper understanding of multimedia messages? *Journal of Educational Psychology, 95*, 390-397.

Mayer, R.E., Dow, G., & Mayer, S. (2003). Multimedia learning in an interactive self-explaining environment: What works in the design of agent-based microworlds? *Journal of Educational Psychology, 95*, 806-813.

Mayer, R.E., Mathias, A., & Wetzell, K. (2002). Fostering understanding of multimedia messages through pre-training: Evidence for a two-stage theory of mental model construction. *Journal of Experimental Psychology: Applied, 8,* 147-154.

Mayer, R.E., Mautone, P., & Prothero, W. (2002). Pictorial aids for learning by doing in a multimedia geology simulation game. *Journal of Educational Psychology, 94*, 171-185.

Mayer, R.E. & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Journal of Educational Psychology, 38* (1), 43-52.

Mayer, R. E., Sobko, K., & Mautone, P. D. (2003). Social cues in multimedia learning: Role of speaker's voice. *Journal of Educational Psychology, 95*, 419-425.

Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81-87.

Mills, P., & Sweeney, W. (2009). Using the first exam for student placement in beginning chemistry courses. *Journal of Chemical Education, 86,* 738-744.

Montgomery, C. (2001). Integrating molecular modeling into the inorganic chemistry laboratory. *Journal of Chemical Education, 78*, 840-844.

Moreno, R., & Mayer, R. E. (2004). Personalized messages that promote science learning in virtual environments. *Journal of Educational Psychology, 96*,165-173.

Myiake, A., & Shah, P. (1999). *Models of working memory: Mechanisms of active maintenance of executive control*. Cambridge, England: Cambridge University Press.

National Educational Technology Plan. (2005). Retrieved September 25, 2005, from http:///www.ed.gove/about/officeds/list/os/technology/plan/2004/site/edlite-default.html.

Nakhleh, M. B. (1992). Why some students don't learn chemistry: Chemical Misconceptions. *Journal of Chemical Education, 69,* 191-196.

Niaz, M. (1995). Relationship between student performance on conceptual and computational problems of chemical equilibrium. *International Journal of Science Education, 17,* 343-355.

Notess, G.R. (2005). Cating the net: Podcasting and screencasting. *Online, 29,* 43-45.

Ozedemir, A.I.B., & Ardac, D. (2009). Visualization in learning about chemical equilibrium. *European Science Research, 3,* 3-12.

Paas, F. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology*, 84, 429–434.

Paas, F., & van Merriënboer. (1993). The efficiency of instructional conditions: An approach to combine mental effort and performance measures. *Human Factors, 35*, 737-743.

Paas, F. & van Merriënboer, J.J.G. (1994). Variability of worked examples and transfer of geometrical problem solving skills: A cognitive load approach. *Journal of Educational Psychology, 86,* 122-133.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. Educational Psychologist, 38, 43-52.

Paas, F.,van Merriënboer, J.J.G., & Adam, J.J. (1994). Measuring cognitive load in instructional research. *Perceptual and Motor Skills, 79*, 419-430.

Paas, F.,Touvinen, J.E., Tabbers, H., & van Gerven, P.W.M. (2003). Cognitive load measures as a means to advance cognitive load theory. *Educational Psychologist, 38*, 63-712.

Paivio*,* A. (1986). Mental representations: a dual coding approach. Oxford, England: Oxford University Press.

Pardo, J.Q., & Portoles, J.J.S. (1995). Students' and teachers' misapplication of Le Chatelier's principle: Implications for Teaching of Chemical Equilibrium. Journal of *Research in Science Teaching, 32,* 939-957.

Peterson, E. (2007). Incorporating screencasts into online teaching. *The International Review of Research in Open and Distance Learning, 8*, 1-4.

Pew, (2009). Mobile internet use increases sharply in 2009 as more than half of all Americans have gotten online by some wireless means. *Pew Internet and American Life Project*. Retrieved from http://www.pewinternet.org/Press-Releases/2009/Mobile-internet-use.aspx

Plass, J.L., Chun, D.M.; Mayer, R.E.; & Leutner, D. (1998). Supporting Visual and Verbal Learning Preferences in a Second Language Multimedia Learning Environment. *Journal of Educational Psychology, 90*, 25-36.

Plass, J.L., Chun, D.M., Mayer, R.E., & Leutner, D. (2003). Cognitive load in reading a foreign language text with multimedia aids and the influence of verbal and spatial abilities. *Computers in Human Behavior, 19*, 221-243.

Pollock, E., Chandler, P., & Sweller, J. (2002). Assimilating complex information. *Learning and Instruction, 12,* 61-86.

Prensky, M. (2001). Digital natives, digital immigrants. *On the Horizon, 9*, 1-6.

Richardson, W. (2009). *Blogs, wikis, podcasts.* Thousand Oaks, CA: Corwin Press.

Renkl, A. & Atkinson, R. K. (2003). Structuring the transition from example study to problem solving in cognitive skill acquisition: A cognitive load perspective. *Educational Psychologist, 38*, 15-22.

Roberts, G. (2005). Instructional technology that's hip high-tech. *Computers in Libraries, 25*, 26-28.

Russell, J. (2004). Enhancing chemical understanding and visualization skills with SMV: Chem – synchroinized multiple visualizations of chemistry. Manuscript submitted for publication.

Russell, J., Koazma, R., Becker, D., & Susskind, T. (2000). *SMV: Chem – Synchronized Multiple Visualizations in Chemistry [Computer software].* New York: John Wiley.

Roberts, K. (1995). Cultivating chemical awareness. *Education in Chemistry, 32,* 58.

Sacred Heart Cathedral Preparatory (2010). *Yearbook*. San Francisco: Shamrock Brand Notebooks.

Sanger, M., & Badger, S. (2001). Using computer-based visualization strategies to improve students' understanding of molecular polarity and miscibility. *Journal of Chemical Education, 78*, 1412-1416.

Sanger, M., Phelps, A., & Fienhold, J. (2000). Using a computer animation to improve students' conceptual understanding of a can-crushing demonstration. *Journal of Chemical Education, 77*, 1517-1520.

Saricayir, H., Sahin, M., & Uce, M. (2006). Dynamic equilibrium explained using the computer. Eurasia Journal of Mathematics. *Science and Technology Education, 2*, 130-137.

Schaffhauser, D. (2009). The vod couple. Retrieved August 19, 2009 from: http://www.thejournal.com

Schank, P., & Kozma, R. (2002). Learning chemistry through the use of representations-based knowledge-building environment. *Journal of Computers in Mathematics and Science Teaching, 21*, 253-279.

Seufert, T., & Brunken, R. (2006). Cognitive load and the format of instructional aids for coherence formation. *Applied Cognitive Psychology, 20,* 321-331.

Smith, E.E., & Jonides, J. (1997). Working memory: A view from neuroimaging. *Cognitive Psychology, 33*, 15-22.

Stavy, R. (1995). Learning science in the schools: Research informing practice (pp. 131-154). Hillsdale, NJ: Lawrence Erlbaum Press.

Stieff, M., & Wilensky, U. (2003). Connected Chemistry: Incorporating interactive simulations into the chemistry curriculum. *Journal of Science Education and Technology, 12*, 285-302.

Stevenson, R. (1994). Will chemistry survive? *Education in Chemistry, 32,* 59.

Swaak, J & de Jong ,T (2001). Discovery simulations and the assessment of intuitive knowledge. *Journal of Computer Assisted Learning*, *17*, 284-295.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12,* 257-285.

Sweller, J. (1999). Instructional design in technical areas. Melbourne: ACER.

Sweller, J. (2003). Evolution of Human Cognitive Architecture, In B.Ross (Ed), *The Psychology of Learning and Motivation*. San Diego: Academic Press.

Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. In R.E. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning* (pp. 19-30). New York: Cambridge University Press.

Sweller, J. & Chandler, P. (1991). Evidence for cognitive load theory. *Cognition and Instruction, 8,* 351-362.

Sweller, J. & Chandler, P. (1994). Why some material is difficult to learn. *Cognition and Instruction, 12*, 185-233.

Sweller, J., van Merriënboer, J., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*, 251-296.

Tai, R.H., Sadler, P.M., & Loehr, J.F. (2005). Factors influencing success in introductory college chemistry *Journal of Research in Science Teaching*, *42*, 987-1012.

Tai, R. H., Sadler, P.M., & Mintzes, J. J. (2006). Factors influencing college science success. *Journal of College Science Teaching, 35*, 56-60.

Tindall-Ford, S., Chandler, P., & Sweller, J. (1997). When two sensory models are better than one. *Journal of Experimental Psychology: Applied, 3,* 257-287.

Tobin, K., & Espinet, M. (1989). Impediments to change applications of coaching in high school science teaching. *Journal of Research in Science Teaching, 31*, 227-242.

Tsaparlist, G., Kousathana, M., & Niaz, M. (1998). Molecular-equilibrium problems: Manipulation of the logical structure of the M-demand, and their effect on student performance. *Science Education, 82*, 437-454.

Tyson, L., & Treagust, D.F. (1999) The complexity of teaching and learning chemical equlibrium. *Journal of Chemical Education, 7,* 554-558.

van Merriënboer, J.J. (1997). *Training complex cognitive skills*. Englewood Cliffs, NJ: Educational Technology Publications

van Merriënboer, J.J.G, & Ayres, P. (2005). Research on cognitive load theory and its design implications for e-learning. *Educational Technology, Research and Development, 53*, 5-13.

van Merriënboer, J.J.G., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review, 17*, 147-177.

van Merriënboer, J.J.G., Kester, L., & Paas, F. (2006). Teaching complex rather than simple tasks: Balancing intrinsic and germane load to enhance transfer of learning. *Applied Cognitive Psychology*, *20*, 343-352.van Merriënboer, J.J.G., Kirschner, P.A. & Kester, L. (2003). Taking the load off a learner's mind: Instructional design for complex learning. *Educational Psychologist, 38*, 5-13.

van Merriënboer, J.G. Schuurman, M.B.M. de Croock, & F. Paas. (2002). Redirecting learners' attention during training: Effects on cognitive load, transfer test performance, and training efficiency, *Learning and Instruction*, *12,* 11–37.

Voska, K.W., & Heikkinen, H.W. (2000). Identification and analysis of student conceptios used to solve chemical equilibrium problems. *Journal of Research in Science Teaching, 37*, 160-176.

Wandersee, J.H., Mintzes, J.J., & Novak. (1994). Handbook of research on science teaching and learning (pp. 177-210). New York: Macmillian Press.

Webster, G.H. (2009). Attitude counts: *Self-concept and success in general chemistry. Journal of Chemical Education, 86*, 744-749.

Xie, Q., & Tinker, R. (2005). Molecular dynamics simulations of chemical reactions for use in education. *Journal of Chemical Education.*

Yang, E.M., Andre, T., & Greenbowe, T. (2003). Spatial ability and the impact of visualization/animation on learning electrochemistry. *International Journal of Science Education, 25*, 329-249.

Zumndahl, S.S. (2007). *World of chemistry*. Evanston, Illinois: McDougal Littell.

Appendix A

Permission Letter

February 1, 2010

Institutional Review Board for the Protection of Human Subjects
University of San Francisco
2130 Fulton Street
San Francisco, CA 94117

Dear Members of the Committee:

On behalf of the Sacred Heart Cathedral Preparatory, I am writing to formally indicate our awareness of the research proposed by Mr. Ramsey Musallam, a student at USF. We are aware that Mr. Musallam intends to conduct his research by administering two total assessments to our students. The assessments will be administered to a group of 60 Advanced Placement Chemistry students.

I am responsible for all students at Sacred Heart Cathedral Preparatory and am the Principal of the institution. I give Mr. Musallam permission to conduct his research at our academic institution.

If you have any questions or concerns, please feel free to contact my office at (415) 775-6626.

Sincerely,

Ken Hogarty
Principal, Sacred Heart Cathedral Preparatory

Appendix B

Informed Consent

INFORMED CONSENT FORM

UNIVERSITY OF SAN FRANCISCO

CONSENT TO BE A RESEARCH SUBJECT

Purpose and Background

Ramsey Musallam, a doctoral student, in the School of Education at the University of San Francisco is doing a study on Cognitive Load Theory in high school chemistry. The chemistry education literature indicates that the subject is complex for students and that performance and interest in chemistry are low. I am being asked to participate because I am an Advanced Placement high school chemistry student.

Procedures

If I agree to be a participant in this study, the following will happen:

1. I will complete a 10-question multiple-choice pre-test

2. I will participate in one of two 10-minute research groups

3. I will participate in a 45-minute chemistry lecture

4. I will complete a 10-question multiple-choice post test.

5. After procedural steps 1, 2, 3 and 4, I will answer a 3 survey Cognitive Load survey questions.

Risks and/or Discomforts

1. It is possible that some of the questions on the pre and post-test will appear beyond my abilities in the subject of chemistry and could impact my perceived sense of confidence and self-worth in the class. I am free to decline to answer any questions I do not wish to answer or to stop participation at any time.

2. Participation in research may mean a loss of confidentiality. Student records will be kept confidential. No individual identities will be used in any reports or publications resulting from the study. Study information will be coded and kept in locked files at all times. Only study personnel will have access to the files.

Benefits

There will be no direct benefit to me for participating in this study. The anticipated benefit of this study is a better understanding of how to manage Cognitive Load in chemistry education.

Costs/Financial Considerations

There will be no financial costs to me as a result of taking part in this study.

Payment/Reimbursement

There will be no payment or reimbursement for me as a result of taking part in this study.

Questions

I have talked to Mr. Musallam about this study and have had my questions answered. If I have further questions about the study, I may call him at (415) 775-6626 x 808. If I have any more questions or comments about participation in this study, I should first talk with the researcher, Mr. Musallam. If for some reason I do not wish to do this, I may contact the IRBPHS, which is concerned with protection of volunteers in research projects. I may reach the IRBPHS office by calling (415) 422-6091 and leaving a voicemail message, by e-mailing IRBPHS@usfca.edu, or by writing to the IRBPHS, Department of Psychology, University of San Francisco, 2130 Fulton Street, San Francisco, CA 94117-1080.

Consent

I have been given a copy of the "Research Subject's Bill of Rights" and I have been given a copy of this consent form to keep. PARTICIPATION IN RESEARCH IS VOLUNTARY. I am free to decline to be in this study, or to withdraw from it at any point. My decision as to whether or not to participate in this study will have no influence on my present or future status as a student at Sacred Heart Cathedral Preparatory

My signature below indicates that I agree to participate in this study.

Subject's Signature Date of Signature

Signature of Person Obtaining Consent Date of Signature

PARENTAL CONSENT FOR RESEARCH PARTICIPATION

Purpose and Background

Ramsey Musallam, a doctoral student, in the School of Education at the University of San Francisco is doing a study on Cognitive Load Theory in high school chemistry. The chemistry education literature indicates that the subject is complex for students and that performance and interest in chemistry are low. My child is being asked to participate because he/she is an Advanced Placement high school chemistry student.

Procedures

If my child agrees to be a participant in this study, the following will happen:

1. My child will complete a 10-question multiple-choice pre-test

2. My child will participate in one of two 10-minute research groups

3. My child will participate in a 45-minute chemistry lecture

4. My child will complete a 10-question multiple-choice post test.

5. After procedural steps 1, 2, 3 and 4, my child will answer a 3 survey Cognitive Load survey questions.

Risks and/or Discomforts

1. It is possible that some of the questions on the pre and post-test will appear beyond my child's abilities in the subject of chemistry and could impact my child's perceived sense of confidence and self-worth in the class. My child is free to decline to answer any questions he/she does not wish to answer or to stop participation at any time.

2. Participation in research may mean a loss of confidentiality. Student records will be kept confidential. No individual identities will be used in any reports or publications resulting from the study. Study information will be coded and kept in locked files at all times. Only study personnel will have access to the files.

Benefits

There will be no direct benefit to my child for participating in this study. The anticipated benefit of this study is a better understanding of how to manage Cognitive Load in chemistry education.

Costs/Financial Considerations

There will be no financial costs to my child as a result of taking part in this study.

Payment/Reimbursement

There will be no payment or reimbursement for my child as a result of taking part in this study.

Questions

If I have further questions about the study, I may call him at (415) 775-6626 x 808. If I have any more questions or comments about participation in this study, I should first talk with the researcher, Mr. Musallam. If for some reason I do not wish to do this, I may contact the IRBPHS, which is concerned with protection of volunteers in research projects. I may reach the IRBPHS office by calling (415) 422-6091 and leaving a voicemail message, by e-mailing IRBPHS@usfca.edu, or by writing to the IRBPHS, Department of Psychology, University of San Francisco, 2130 Fulton Street, San Francisco, CA 94117-1080.

Consent

My child has been given a copy of the "Research Subject's Bill of Rights" and has also been given a copy of this consent form to keep. PARTICIPATION IN RESEARCH IS VOLUNTARY. My child is free to decline to be in this study, or to withdraw from it at any point. My child’s decision as to whether or not to participate in this study will have no influence on his/her present or future status as a student at Sacred Heart Cathedral Preparatory

My signature below indicates that I agree to allow my child to participate in this study.

Parent/Guardian’s Signature Date of Signature

Signature of Person Obtaining Consent Date of Signature

Appendix C

Cover Letter

Dear Advanced Placement Chemistry Student:

My name is Ramsey Musallam and I am a doctoral student in the School of Education at the University of San Francisco. I am doing a study on Cognitive Load Theory in Advanced Placement chemistry. I am interested in learning how to decrease the complexity of chemistry education using multimedia. The principal of Sacred Heart Cathedral Preparatory has given me permission to conduct this study.

You are being asked to participate in this research study because your presence in Advanced Placement means that you are an *advanced* chemistry student. If you agree to participate in this study, you will complete a 14 question pre-test. You will then be randomly assigned to one of two research groups and then you will report to a classroom, where I will deliver a 50-minute in-depth chemistry. After the lecture, you will complete a 14 question post-test. After the pre/post tests, research treatment and lecture, you will answer the 3 survey questions about Cognitive Load.

It is possible that some of the questions on the pre/post tests will appear beyond your abilities in the subject of chemistry and could impact your perceived sense of confidence and self-worth in the class. You are free to decline to answer any questions you do not wish to answer or to stop participation at any time. Participation in research may mean a loss of confidentiality. Student records will be kept as confidential as possible. No individual identities will be used in any reports or publications resulting from the study. Study information will be coded and kept in locked files at all times. Only the lead researcher (myself) will have access to the files. Individual results will not be shared with any other students, faculty or staff at Sacred Heart Cathedral Preparatory.

While there are no direct benefits to you for participating in this study, the anticipated benefit of this study is a better understanding of how to manage the Cognitive Load of chemistry education. There will be no costs to you as a result of taking part in this study.

If you have questions about the research, you may contact me at (415) 775-6626 x808. If you have further questions about the study, you may contact the IRBPHS at the University of San Francisco, which is concerned with protection of volunteers in research projects. You may reach the IRBPHS office by calling (415) 422-6091 and leaving a voicemail message, by e-mailing IRBPHS@usfca.edu, or by writing to the IRBPHS, Department of Psychology, University of San Francisco, 2130 Fulton Street, San Francisco, CA 94117-1080.

PARTICIPATION IN RESEARCH IS VOLUNTARY. You are free to decline to be in this study, or to withdraw from it at any point. Sacred Heart Cathedral Preparatory is aware of this study but does not require that you participate in this research and your decision as to whether or not to participate will have no influence on your present or future status as an Honors Chemistry student at Sacred Heart Cathedral Preparatory

Thank you for your attention. If you agree to participate, please complete the attached consent form, ask a parent or guardian to complete the attached consent form, and return both to me in the envelope provided.

Sincerely,

Ramsey Musallam
Learning and Instruction Doctoral Student
University of San Francisco

Appendix D

Chemical Equilibrium Concept Assessment
(Pre and Post-Test)

Number______

Chemical Equilibrium Concept Assessment
(Banerjee, 1991; Hackling & Garnett, 1985)

Questions 1-4 relate to the same reaction shown below. Circle your mental effort rating after each question:

$$2NO\ (g) + Cl_2\ (g) \leftrightarrow 2NOCl\ (g)$$

1. After equilibrium has been established, the concentration of NO is instantaneously increased, but the volume and temperature remain constant. When the concentration of NO is increased, the rate of the forward reaction will instantaneously be:

   (A) equal to the rate of the reverse reaction
   (B) greater than the rate of the reverse reaction
   (C) less than the rate of the reverse reaction

   Mental Effort: Very Little Little Moderate Large Very Large

$$2NO\ (g) + Cl_2\ (g) \leftrightarrow 2NOCl\ (g)$$

2. After equilibrium has been established, the concentration of NO is instantaneously increased, but the volume and temperature remain constant. When the concentration of NO is increased, the rates of the forward and reverse reaction will be instantaneously be:

   (A) equal to those at the initial equilibrium
   (B) greater than those at the initial equilibrium
   (C) less than at the initial equilibrium

   Mental Effort: Very Little Little Moderate Large Very Large

$$2NO\ (g) + Cl_2\ (g) \leftrightarrow 2NOCl\ (g)$$

3. After equilibrium has been achieved a catalyst is added to the system but other variables remain unchanged. The rate of the forward reaction will be:

   (A) equal to the rate of the reverse reaction
   (B) greater than the rate of the reverse reaction
   (C) less than the rate of the reverse reaction
   (D) either greater or less than the rate of the reverse reaction depending on whether the catalyst favors the forward or reverse reaction.

   Mental Effort: Very Little Little Moderate Large Very Large

$$2NO\ (g) + Cl_2\ (g) \leftarrow\rightarrow 2NOCl\ (g)$$

4. After equilibrium has been achieved a catalyst is added to the system but other variables remain unchanged. The concentration of Cl_2 will be:

   (A) less than at the initial equilibrium
   (B) equal to that at the initial equilibrium
   (C) greater than that at the initial equilibrium
   (D) greater or less than at the initial equilibrium depending of the effect of the catalyst.

   Mental Effort: Very Little Little Moderate Large Very Large

---

Questions 5-7 relate to the same reaction shown below. Each answer is to be given as A: greater than; B: less than; C: same as the first equilibrium; D: data insufficient for conclusion. Circle your mental effort rating after each question:

$$2CO\ (g) + Cl_2\ (g) \leftarrow\rightarrow COCl_2\ (g) \quad + \quad heat$$

5. The mixture is cooled to 150°C, keeping the volume constant. When the system returns to another equilibrium,

   (A) the mass of $COCl_2$ present will be _____

   Mental Effort: Very Little Little Moderate Large Very Large

   (B) the rate at which $COCl_2$ is being formed will be____

   Mental Effort: Very Little Little Moderate Large Very Large

   (C) the equilibrium constant will be ____

   Mental Effort: Very Little Little Moderate Large Very Large

$$2CO\ (g) + Cl_2\ (g) \leftarrow\rightarrow COCl_2\ (g) \quad + \quad heat$$

6. The volume of the system is halved by increasing pressure at constant temperature. When the system returns to another equilibrium,

   (A) the mass of $COCl_2$ present will be _____

   Mental Effort: Very Little Little Moderate Large Very Large

   (B) the concentration of $COCl_2$ present will be____

   Mental Effort: Very Little Little Moderate Large Very Large

   (C) the mass of CO present will be ____

   Mental Effort: Very Little Little Moderate Large Very Large

   (D) the concentration of CO present will be____

   Mental Effort: Very Little Little Moderate Large Very Large

$$2CO\ (g) + Cl_2\ (g) \leftarrow\rightarrow COCl_2\ (g) \quad + \quad heat$$

7. Some Cl_2 is removed form the system, the volume and temperature being kept constant. When the system returns to another equilibrium,

   (A) the mass of CO will be _____

   Mental Effort: Very Little Little Moderate Large Very Large

   (B) the equilibrium constant will be____

   Mental Effort: Very Little Little Moderate Large Very Large

   (C) the rate at which CO is being formed will be ____

   Mental Effort: Very Little Little Moderate Large Very Large

Please answer the two survey questions below:

1. How easy or difficult is it for you to understand chemical equilibrium at this moment?

   1 2 3 4 5 6 7 8 9

   Very Easy Very Difficult

2. How easy or difficult is it for you to work in this learning environment at this moment?

   1 2 3 4 5 6 7 8 9

   Very Easy Very Difficult

Appendix E

Treatment Scripts

Pre and Post-Test Phase

“This test consists of 7 multiple choice questions. Questions 1-4 have one correct answer. Questions 5-7 contain three separate questions, each with one correct answer. Please take this time to read the instructions for questions 1-4 and 5-7. Are there any questions? After each question, you will be asked to rank the mental effort spent on that question. Think of mental effort as how “hard” you have to think to solve each question. A question with high mental effort requires a lot of thought, and a question with low mental effort is one you can answer fairly quickly and does not require as much thought. Do you have any questions on what “mental effort” is? Mental effort will be ranked according to the following scale:

Very little
Little
Moderate amounts
Large amounts
Very large amounts

When you finish all 7 questions, you will be asked to answer two survey questions on a 9-point scale. Please take a few moments to read the instructions for the survey questions. For question 2, “learning environment” refers to the classroom atmosphere, how easy it is for you to understand the format of the survey, and other factors that relate not to chemistry, but to the materials and environment you are using. Does anybody have any questions? You may use pen or pencil to record your answers. You are allowed to write anywhere on the test. Your score on this test is purely confidential, and will not alter your grade in Advanced Placement Chemistry. When you are done, please leave your test face down on your desk, and I will come collect it from each of your individually.”

Treatment Phase

Screencast Pre-Training Group

"A screencast is a video recording of all computer screen activity, including voice, mouse clicks, and in this case, digital pen annotation. I have created a short screencast tutorial for you to watch. You will have 10 minutes and 52 seconds to watch the screencast to learn as much as you can about the subject presented. Please do not take notes during the screencast. During the allotted time, you are not allowed to visit any other programs, or applications on the computer. Please click on the desktop icon titled *screencast pre-training*. When I tell you to begin, you will plug in your earphones to the sound jack, and begin to watch the screencast. During the screencast you may increase or decrease the size of the video to suit your liking. You may also pause, or rewind the video, or parts of the video as many times as you like. Any questions? When you finish watching the screencast, you will be prompted to answer two survey questions on a 9-point scale. Please take this time to read the instructions for the survey questions. Are there any questions? Please begin."

Instructional Phase

"For the next 50 minutes, I will be giving an in-depth lecture on the basic concepts of chemical equilibrium. During the lecture, you may take notes on the scratch paper provided. You may ask clarifying questions, and may let me know if you need extra time to write down content before I move on. When you are done, you will be given a 14-question test on chemical equilibrium. This test consists of 7 multiple choice questions. Questions 1-4 have one correct answer. Questions 5-7 contain three separate questions, each with one correct answer. Please take this time to read the instructions for questions 1-4 and 5-7. Are there any questions? After each question, you will be asked to rank the mental effort spent on that question. Think of mental effort as how "hard" you have to think to solve each question. A question with high mental effort requires a lot of thought, and a question with low mental effort is one you can answer fairly quickly and does not require as much thought. Do you have any questions on what "mental effort" is? Mental effort will be ranked according to the following scale:

Very little
Little
Moderate amounts
Large amounts
Very large amounts

When you finish all 7 questions, you will be asked to answer two survey questions on a 9-point scale. Please take a few moments to read the instructions for the survey questions. For question 2, "learning environment" refers to the classroom atmosphere, how easy it is for you to understand the format of the survey, and other factors that relate not to chemistry, but to the materials and environment you are using. Does anybody have any questions? You may use pen or pencil to record your answers. You are allowed to write anywhere on the test. Your score on this test is purely confidential, and will not alter your grade in Advanced Placement Chemistry. When you are done, please leave your test face down on your desk, and I will come collect it from each of your individually. Let's begin the lecture."

Appendix F

Screencast Pre-Training Materials

Screencast Pre-Training Document Template

Key Definitions

Chemical Reaction

Reaction Rate

Chemical Equilibrium

Equilibrium Shift/Le Chatelier's Principle

Equilibrium Constant (K)

Factors That Affect Chemical Equilibrium (Zumdahl, 2007)

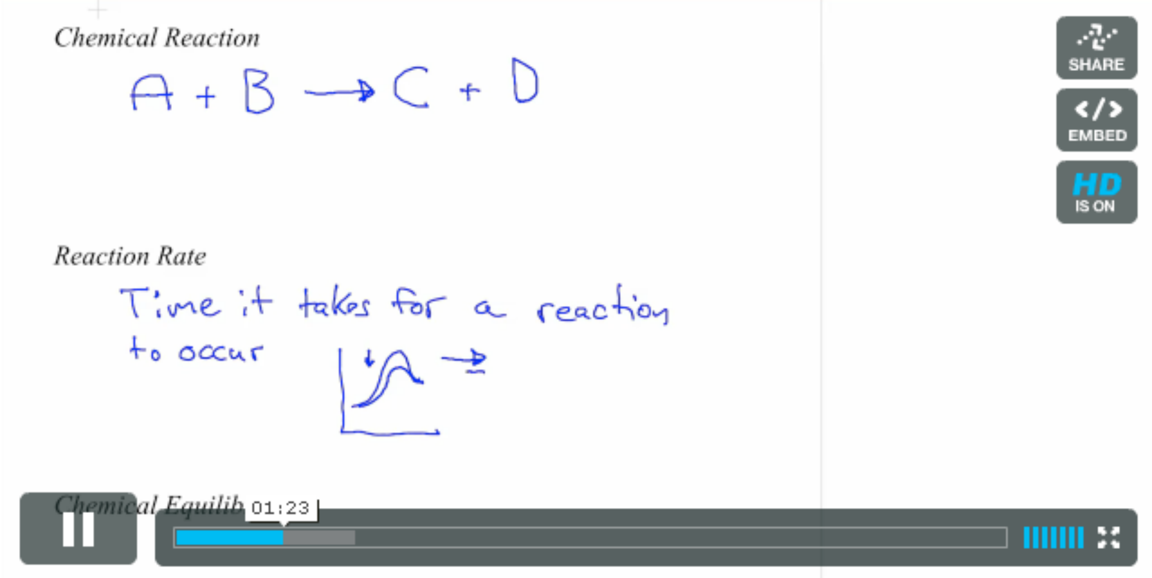
Concentration Effects

Temperature Effects

Pressure/Volume Effects

Screenshots of Pre-Training Screencast

1 minute and 23 second mark



Chemical Reaction

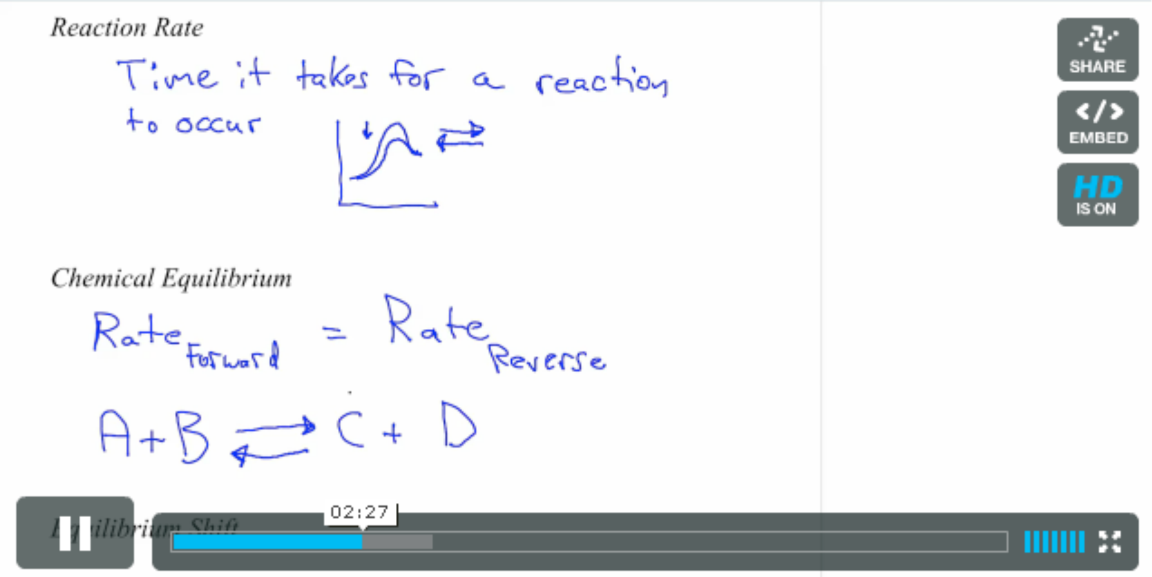
$A + B \rightarrow C + D$

Reaction Rate

Time it takes for a reaction to occur

Chemical Equilib

2 minute and 27 second mark



Reaction Rate

Time it takes for a reaction to occur

Chemical Equilibrium

$\text{Rate}_{\text{Forward}} = \text{Rate}_{\text{Reverse}}$

$A + B \rightleftarrows C + D$

Equilibrium Shift

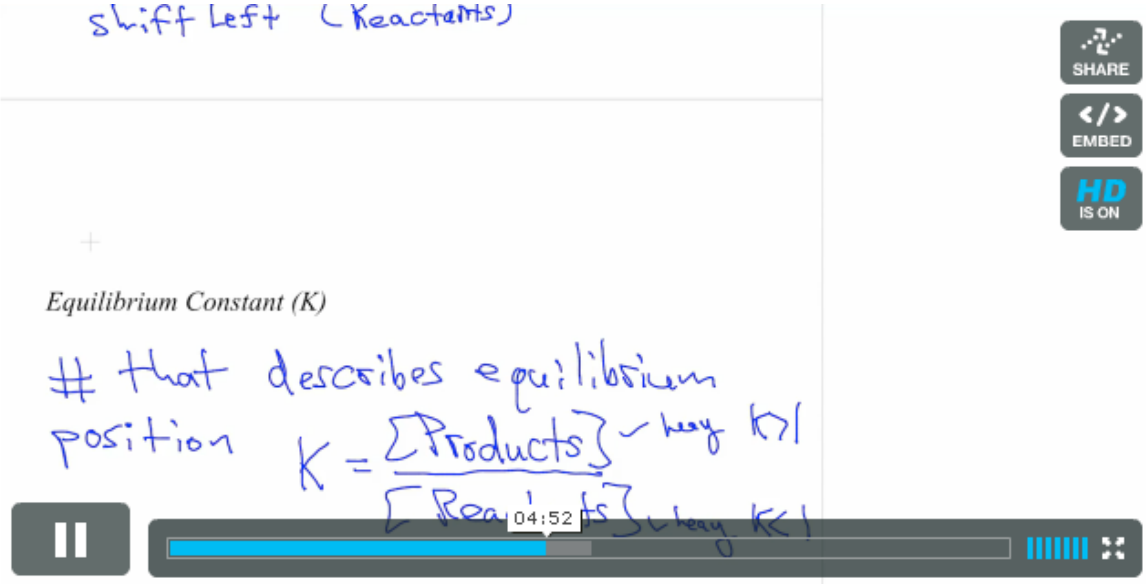
3 minute and 48 second mark

Equilibrium Constant (K)

Factors That Affect Chemical Equilibrium

Concentration Effects

4 minute and 52 second mark



shift Left (Reactants)

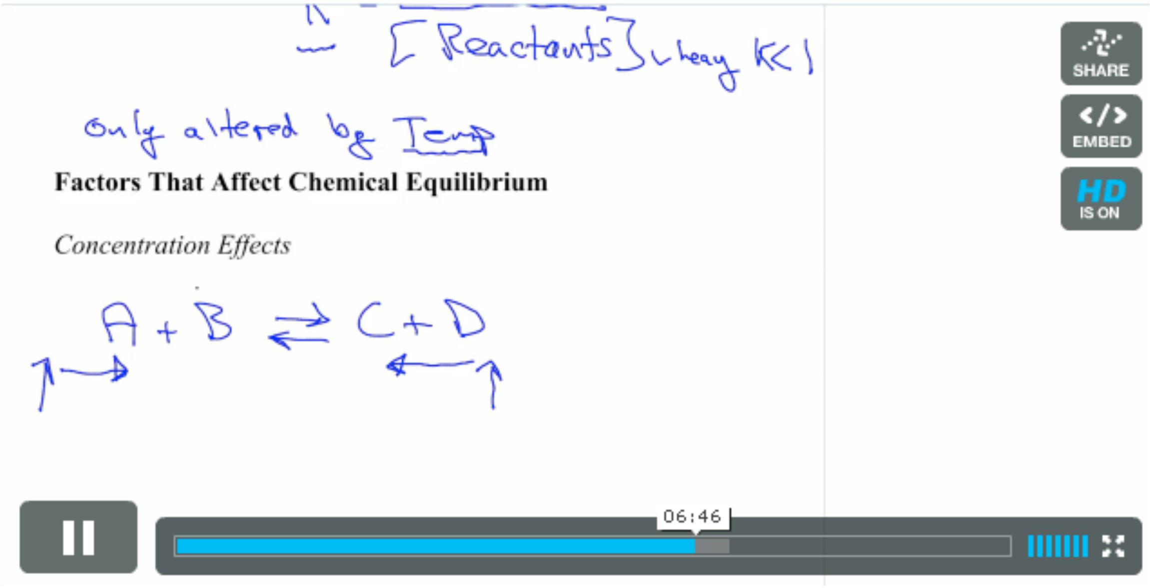
Equilibrium Constant (K)

that describes equilibrium position

K = [Products] ← heavy K>1

[Rea ts] ← heavy K<1

6 minute and 46 second mark



[Reactants] when K<<1

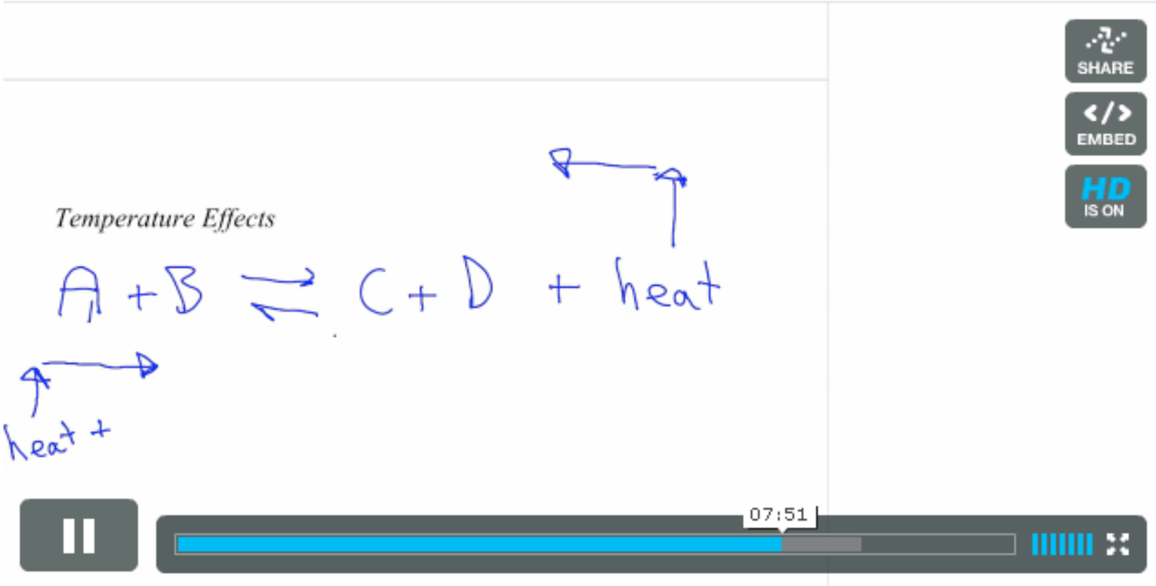
Only altered by Temp

Factors That Affect Chemical Equilibrium

Concentration Effects

$A + B \rightleftharpoons C + D$

7 minute and 51 second mark

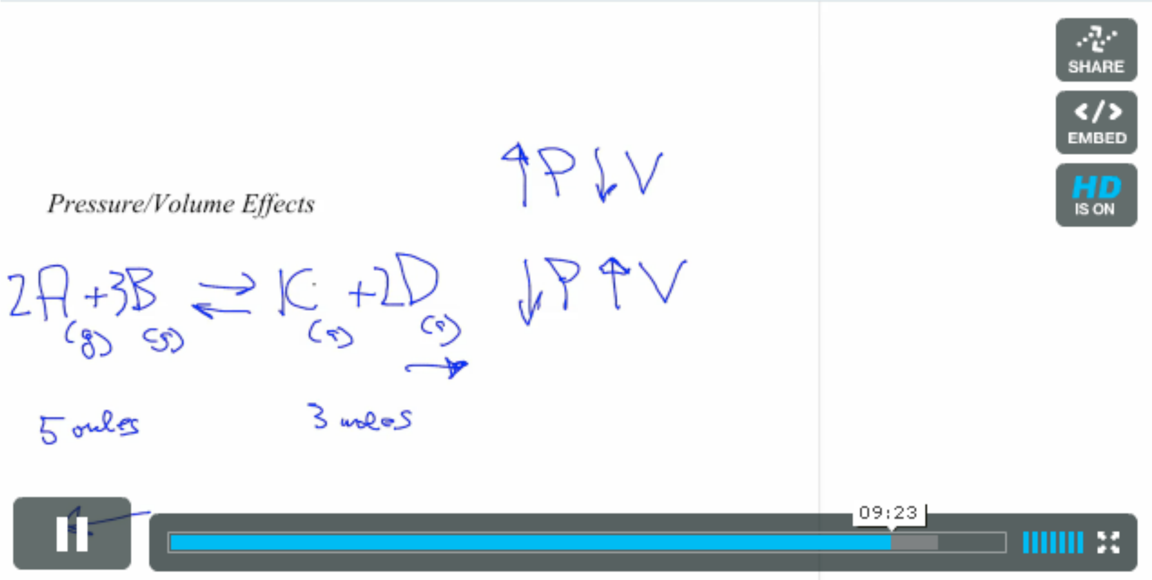


Temperature Effects

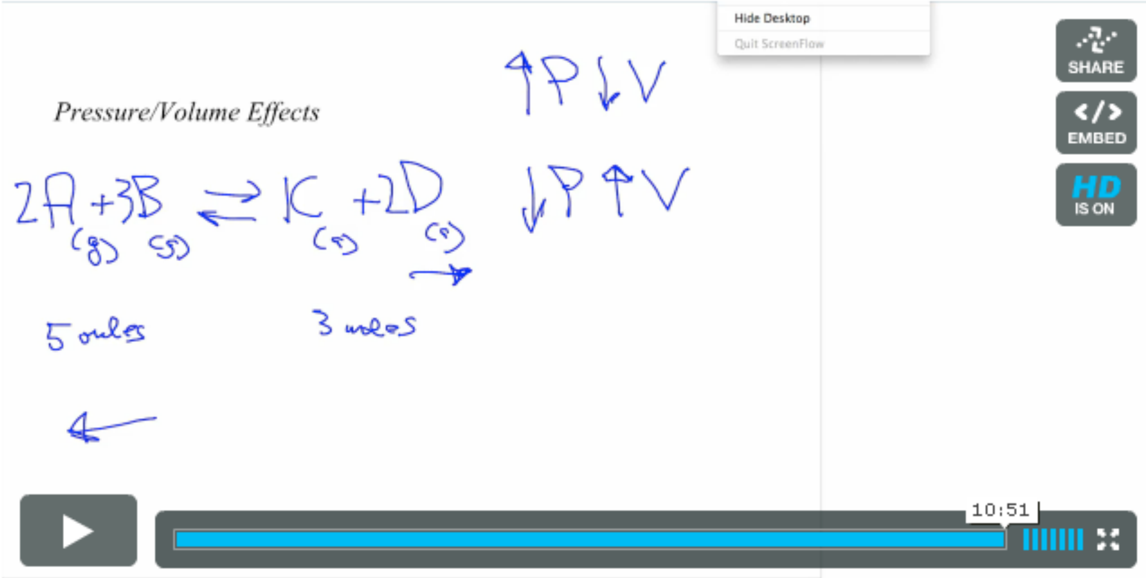
$A + B \rightleftharpoons C + D + \text{heat}$

heat +

9 minute and 23 second mark



10 minute and 52 second mark



Screencast Web Address

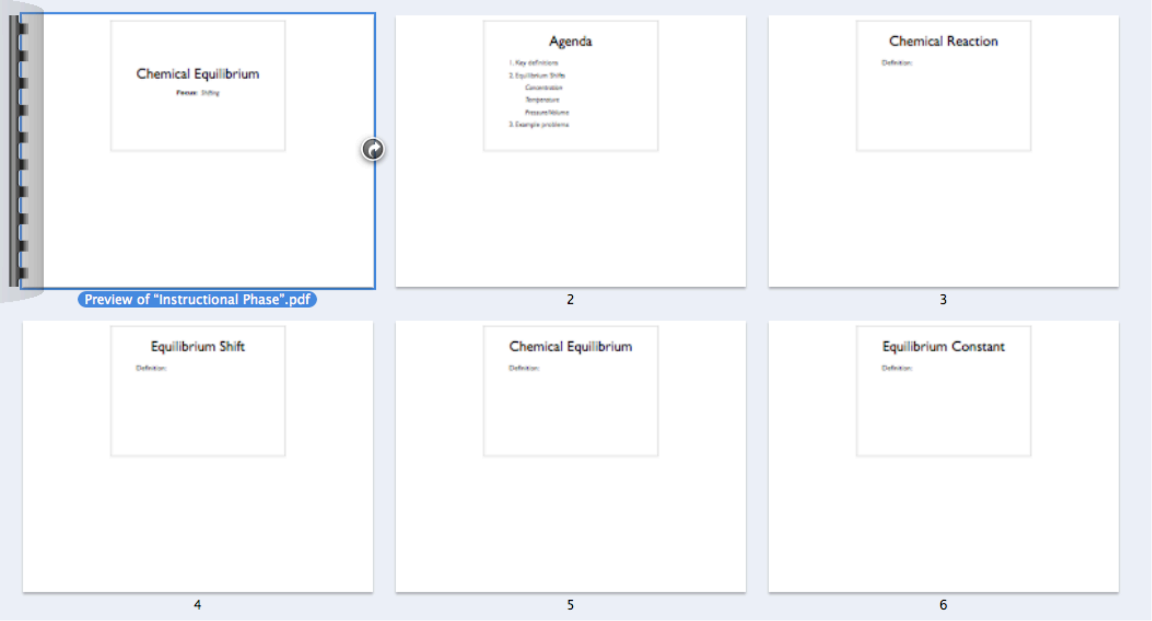
To view the pre-training screencast enter the below URL into your Internet browser:

http://www.vimeo.com/10362131

Appendix G

Instructional Slides

Empty spaces on each slide was used for digital pen annotation during the lecture.



Chemical Equilibrium

Focus: Shifting

Agenda

1. Key definitions
2. Equilibrium Shifts
   - Concentration
   - Temperature
   - Pressure/Volume
3. Example problems

Chemical Reaction

Definition:

Equilibrium Shift

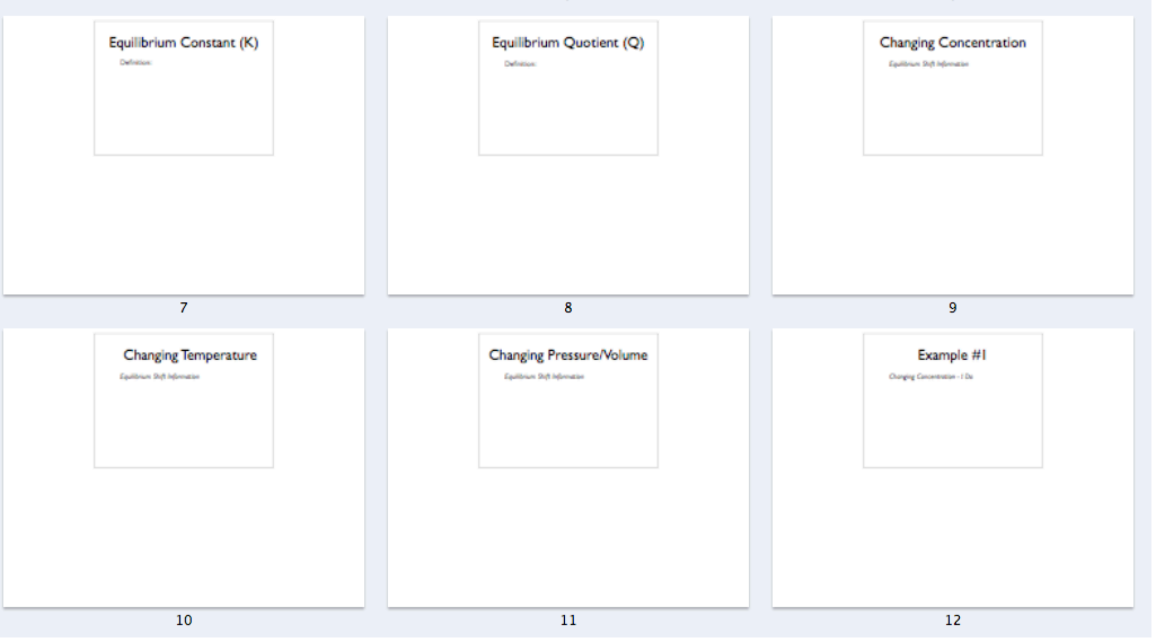
Definition:

Chemical Equilibrium

Definition:

Equilibrium Constant

Definition:



Equilibrium Constant (K)

Definition:

Equilibrium Quotient (Q)

Definition:

Changing Concentration

Equilibrium Shift Information

Changing Temperature

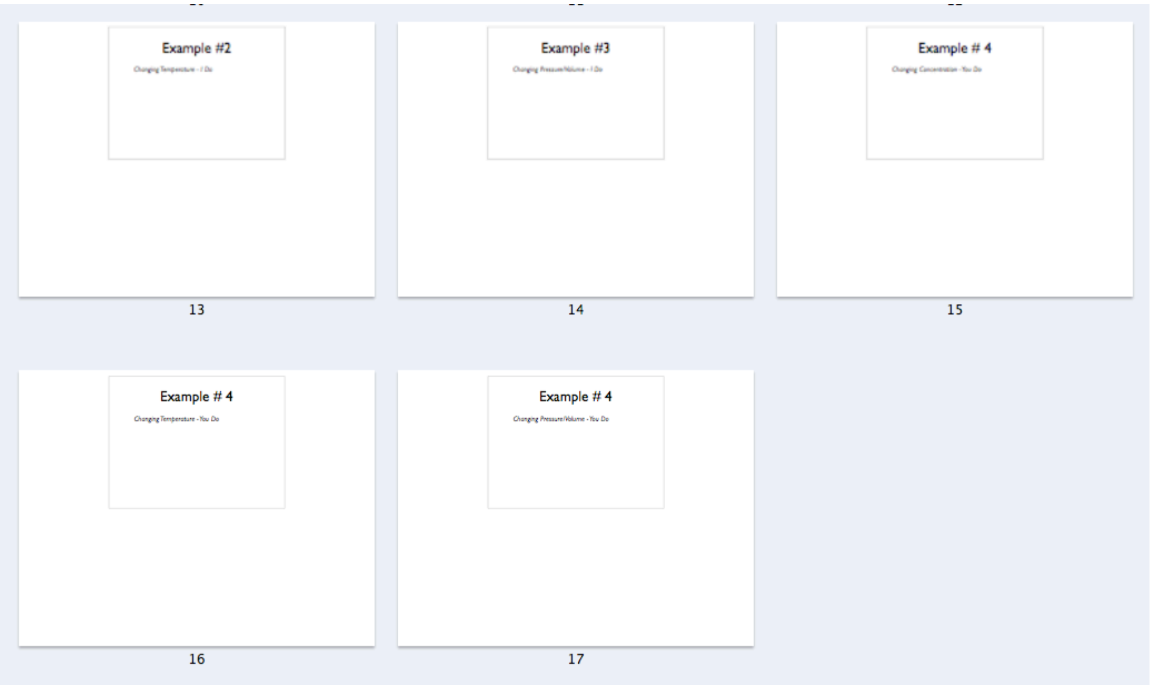
Equilibrium Shift Information

Changing Pressure/Volume

Equilibrium Shift Information

Example #1

Changing Concentration - I Do



Example #2

Changing Temperature - I Do

13

Example #3

Changing Pressure/Volume - I Do

14

Example # 4

Changing Concentration - You Do

15

Example # 4

Changing Temperature - You Do

16

Example # 4

Changing Pressure/Volume - You Do

17