CONCEPT MAPPING AS AN ASSESSMENT OF COGNITIVE LOAD AND MENTAL EFFORT IN COMPLEX PROBLEM SOLVING IN CHEMISTRY

by

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ABSTRACT

This research is an exploratory, descriptive study of students' cognitive load and mental effort related to complex problem solving in high school chemistry. From a cognitive point of view, the complexity associated with problem solving in chemistry can be understood from the context of cognitive load theory (CLT). The objective of this descriptive research using five high school student case studies is to understand the cognitive load phenomena students encounter while learning subject matter that requires complex problem solving, specifically chemical equilibrium. This study employed a mixed methods multiple case study design, in which each participating student (n = 5) is conceptualized as a case. Each student case self-reported their mental effort on eight chemical equilibrium problems. The mean for each students' mental effort and problem solving was reported. Each student completed an equilibrium concept map which was scored. The concept map scores are reported. The analysis compared mental effort score, quiz score and concept map score. There was an inverse relationship between mental effort and concept map score. The more complex the concept map (higher score) the less mental effort students report using to solve the problems. There was a positive relationship between mental effort score and quiz score; and a negative relationship between concept map score and quiz score. We believe these correlations indicate that the variables are related to cognitive load. Methodologically, we found that concept mapping is a valid assessment of cognitive load and mental effort. We believe that further larger studies are needed to substantiate these findings and explain how concept mapping can be used as a representation of cognitive load and student learning.

CHAPTER ONE

INTRODUCTION

Problem

Cognitive Load Theory and Cognitive Theory of Multimedia Learning are instructional theories that focus on the learner's working memory capacity while teaching a complex subject matter content to facilitate the connection between the working memory and long-term memory (Mayer, 2014; Sweller, Ayres, & Kalyuga, 2011). Both theories suggested several techniques for instructors to reduce or manage the learner's cognitive load imposed by the complexity of the subject matter content (intrinsic cognitive load). Cognitive load is the mental effort or mental activities one experiences in an educational event. According to the theories, learning is defined as a positive change in the learner's long-term memory and if nothing changed in the long-term memory then learning has not occurred (Sweller et al., 2011) . Based on this definition of learning, some teaching strategies have been suggested and empirically tested for effectiveness and usability in several educational classrooms. Some teaching and problem-solving strategies aiming to reduced or manage the intrinsic cognitive load have been tested in fields such as engineering, mathematics and statistics. In these studies students' success in problem-solving (error-rate) is considered an indirect indicator of cognitive load and a direct indicator of deep learning. Subjective scaling of mental effort followed the use of problem-solving to facilitate a direct measure of a learner's cognitive load invested in any given task. Both indirect and direct measurements, through problem solving and subjective ranking of mental effort, are widely utilized techniques for measuring cognitive load in educational settings (Ayres, 2006; Mayer, 2014; Sweller et al., 2011).

On the other hand, the Theory of Educating by Gowin (1981) and Learning Theory and the Theory of Meaningful Learning by Novak and Gowin (1984) consider learning from a constructivist point of view in which the learners are responsible for constructing their own knowledge. The construction of concepts and propositions are the core elements of the learning process in science education. In any educational event, linking the concepts and propositions held in the new subject matter content with what the learner already knows is crucial for learning to take place where teaching is perceived as the sharing of meaning between the teacher and the learner. Curriculum or subject matter content is perceived as knowledge claims of previous inquiries that required skills and value to make an educational event take place. Governance refers to the teacher's and students' control over the curriculum or subject matter, the shared meaning of the educative event. One of the techniques by which leaners and teachers share meaning of the subject- matter content is the use of concept mapping. Concept mapping is a graphical representation of the learner's conceptual understanding of the subject matter content shared in a form of an externalized and depicted propositional format.

Considering the theories described above, the use of concept mapping is not a novel idea in cognitive load theory body of research. From the teaching point of view, using concept mapping as an advanced organized is proven to be effective especially for subject matter content that is complex or possess a high intrinsic cognitive load (Andrew & Mayer, 2007). However, the use of concept mapping as a technique to assess and predict students' mental effort is unused in cognitive load theory studies and science education. This study was designed as an exploratory descriptive focus on using both quantitative and qualitative data acquisition to investigate the relationship among high school chemistry students' transfer performance test, mental effort and concept maps on learning a complex subject matter, Le Chatelier's principle. The following concept map provides the overall objective of the study.

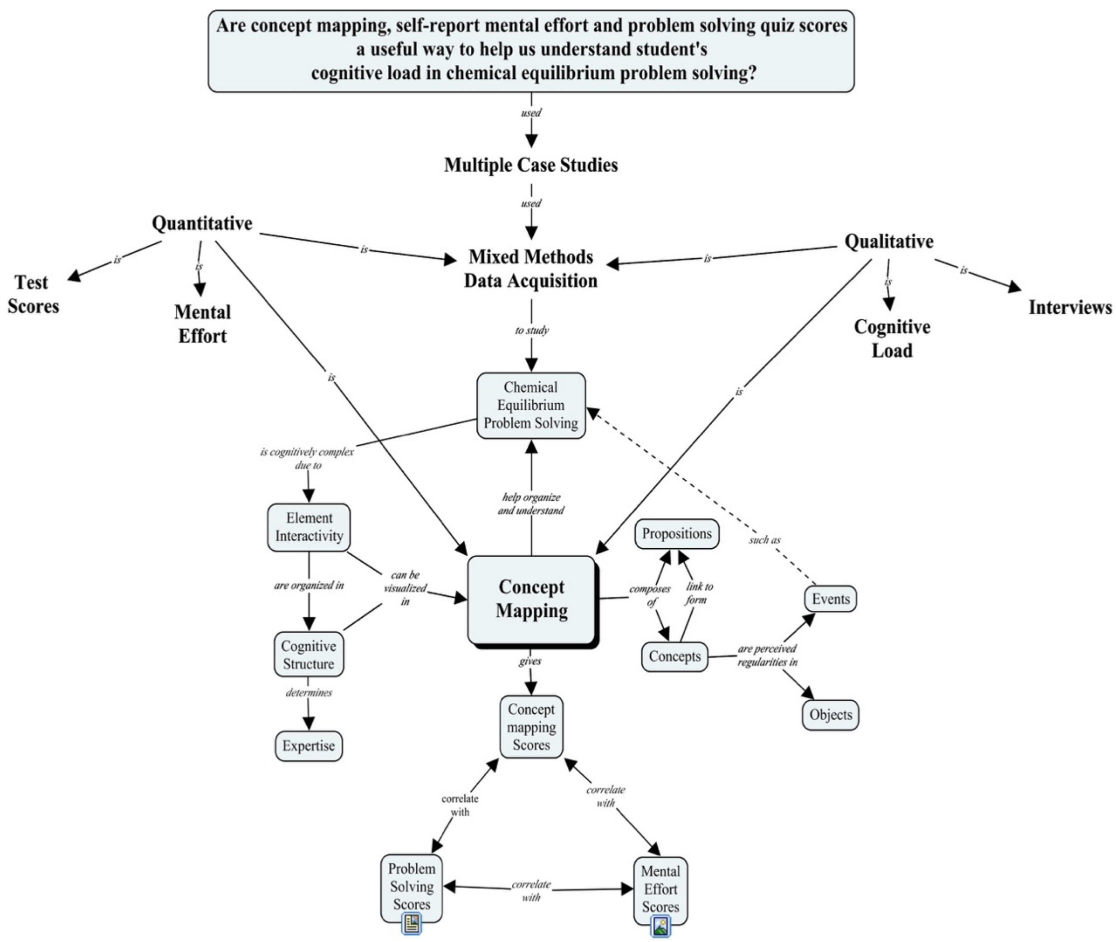

Figure 1. The overall objective of the study.

Research Questions and Hypotheses

The overall research question is: Are concept mapping, self-report mental effort and transfer problem-solving quiz scores a useful way to help us understand student cognitive load in chemical equilibrium problem solving? In order to answer the question, several sub-questions are:

1. What is the relationship between the subjects' perceived mental effort scores on the chemical equilibrium transfer performance quiz and the subjects' generated concept maps scores?

Hypothesis 1: The more complex the concept maps, the less mental effort to solve problems.

2. What is the relationship between subjects' subjective mental effort scores and subjects' performance scores on solving transfer complex chemical equilibrium problems?

Hypothesis 2: The lower the mental effort score, the higher the quiz score.

3. What is the relationship between subjects' concept mapping scores and subjects' score on the transfer performance quiz?

Hypothesis 3: There would be a positive relationship between concept map scores and quiz scores.

4. How does qualitative data analysis explain the relationship between the subjects' perceived mental effort scores and subjects generated concept maps scores on chemical equilibrium?

5. How does qualitative data analysis explain relationship between subjects' concept mapping scores and subjects' score on the transfer performance quiz?
6. Is concept mapping a useful technique in assessing student cognitive load and mental effort?

Hypothesis 6: Concept mapping is useful way to assess student mental effort and transfer complex problem solving.

CHAPTER TWO

LITERATURE REVIEW

The literature review discussed below is based on concepts and constructs driven from Cognitive Load Theory (CLT; Sweller, Ayres, & Kalyuga, 2011), Cognitive Theory of Multimedia Learning (CTML; Mayer, 2014), The Theory of Educating (Gowin, 1981) and The Theory of Learning (Novak & Gowin, 1984).

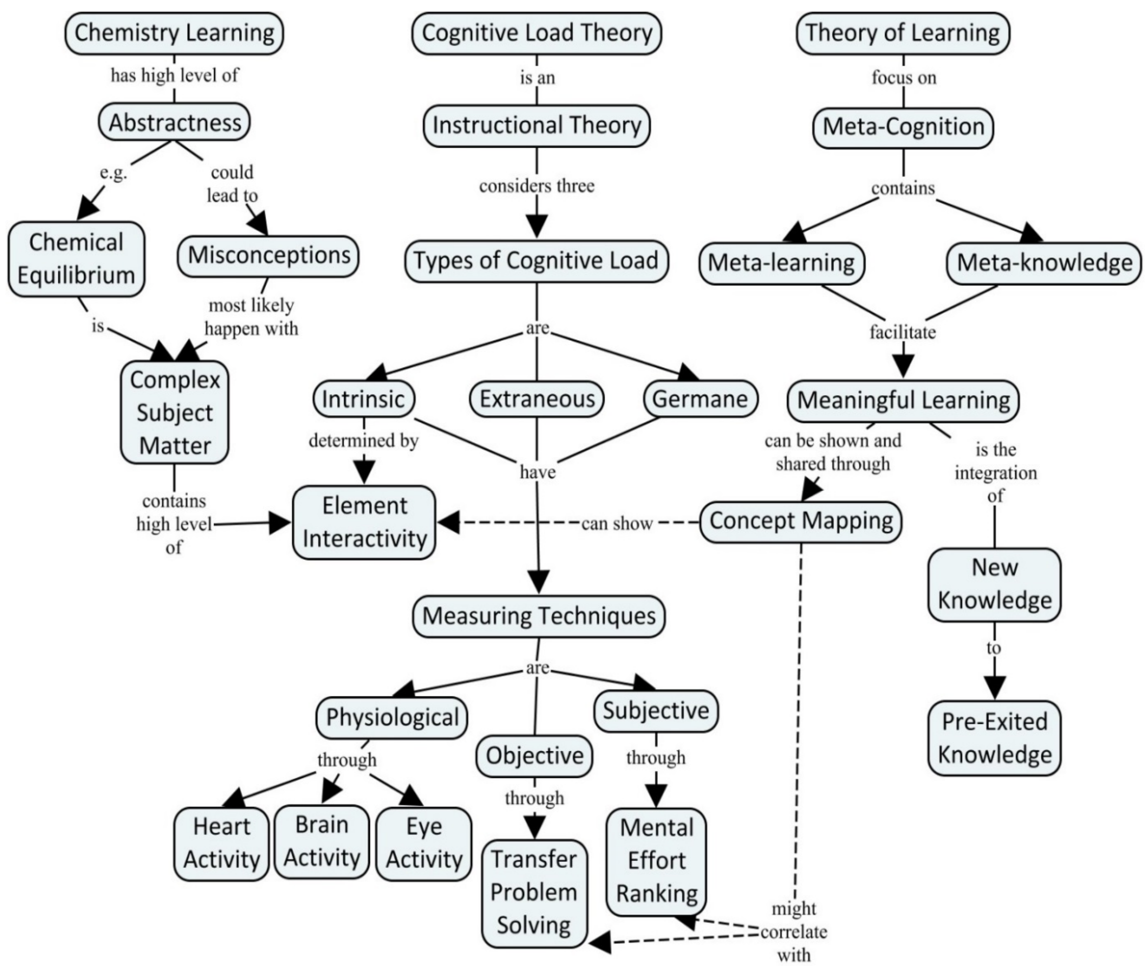

Figure 2. Literature review summary.

Chemistry Learning

Chemistry is an abstract knowledge domain. The abstractness of most of its concepts is considered a major key in the learning difficulty of the domain (Rickey & Stacy, 2000). Gabel (1999) indicated that most of the misconception students normally possess is due to the complex nature of chemistry and the way chemistry is being taught. Symbols, chemical formals and chemical equations are means to represent both macroscopic and microscopic levels of matter as well as the use of mathematical formulas to understand the relationship within and between the two levels adds to the complexity nature of chemistry. Within the domain of chemistry, the chemical equilibrium is considered complex subject matter that learners find hard across educational levels and cultures and also is considered an active area for misconceptions (Banerjee, 1991; Garnett, Garnett, & Hackling, 1995; Hackling & Garnett, 1985). Several studies have been conducted concerning the difficulties associated with chemical equilibrium (Banerjee, 1991; Hackling & Garnett, 1985; Kaya, 2013; Niaz, 2007).

Chemical Equilibrium Learning

An interview study conducted by Hackling and Garnett (1985) targeted students' misconception regarding chemical equilibrium. Prior to conducting the study, the authors identified the equilibrium concepts through generating 27 sequence of propositions that leads to understanding of the application of Le Chatelier's principle. The propositions were based on the reaction between nitric oxide and chlorine forming nitrosyl chloride that went through a validation panel that consisted off tertiary lecturers and experienced chemistry teachers before it's used in the study. A common misconception of the 30 interviewed students were centered on students' understanding of the rate of reverse reaction, concentration change effects and distinguishing between complete and reversible reactions. The authors argued that the students' previous experience with completion reactions might be a factor that had influenced their conceptions regarding the relationship between the reactant and products of a system at the equilibrium.

Another study conducted by Banerjee (1991) investigated students' conceptual difficulties associated with learning about chemical equilibrium. A total of 162 undergraduate chemistry students participated in the study. A written test was constructed by the author and taken by students that contained 21 questions regarding chemical equilibrium. The assessment test consisted of eight short-answer questions that targeted conceptual understanding, seven multiple choice problems, three items on problem solving and three questions regarding the application of the concept to daily life. The results showed that students had several misconceptions regarding Le Chatelier's principle. Some of the students' misconceptions and conceptual difficulties provided in the study centered on equilibrium shifts as a response to a stress applied to the system and the concentrations before and after an equilibrium was being manipulated.

Niaz (2007) study considered the problem from different aspect. The aim was to investigate whether conceptual understanding proceeds computational application of the principle. A sample of 78 freshmen chemistry students participated in the study and completed an 11-item assessment on Le Chatelier's principle that contained both quantitative and qualitative aspects of the principle. Results showed that students who did well on the conceptual part of the assessment performed on average significantly better on the algorithmic section. However, students who performed well on the logarithmic aspect of the assessment did not show reflected results on their conceptual scores. The author concluded that understanding the underlying concepts of Le Chatelier's principle should proceed the algorithmic part as it is more conductive to learning. This conclusion stood against a widely accepted notion that students' ability to solve numeric problems would lead to their conceptual understanding of the underlying concepts of the principle.

Kaya (2013) investigated chemical equilibrium conceptual understanding from the teaching point of view. A total of 100 pre-service teachers participated in the study and were randomly assigned into two groups that were taught by the same instructor. The control group was taught without using argumentative activities while learning, whereas the experimental group was taught the same content using argumentative practices. A performance test and a written argumentation survey were administered to both groups. Results showed that on average the argumentation practices group significantly scored higher than the control group on the performance test and constructed more quality arguments on the written argumentation survey.

The complexity of Le Chatelier's principle makes it a difficult content area for both instructors to teach and for learners to fully comprehend. Le Chatelier's principle centers on how a system at the equilibrium state react or respond to a strain (e.g. changing temperature, concentration or pressure) to reach a new equilibrium state (Garnett et al., 1995; Hackling & Garnett, 1985). The complexity of the interrelated concepts makes it an active area for misconceptions across educational levels and cultures. We believe that complexity associated with the subject matter content can be better understood further from the perspective of Cognitive Load Theory.

Cognitive Load Theory

Cognitive Load Theory (CLT; Sweller, Van Merrienbore, & Pass, 1998) is based on the premises that emphasize the division of knowledge into biologically primary knowledge and biologically secondary knowledge. CLT is concerned with biologically secondary knowledge, that is, culturally acquired knowledge as in educational institutions and schools (Mayer, 2014; Sweller et al., 2011). CLT is based on the premises of the information processing theory that emphasize the human cognitive architecture consists of limitless long-term memory that stores information in forms of schema and limited working memory when dealing with biological secondary knowledge. For any learning task, the leaner must devote working memory resources to grasp the meaning of the task. Cognitive load is the portion of the working memory resources required for processing an instructional task at one time (Sweller et al., 2011).

CLT suggests instructional designs that account for the limitation of the working memory capacity to avoid cognitive overload. Cognitive overload occurs when the number of element held by the working memory exceeds its capacity. CLT extended the notion of human working memory capacity and state that working memory is subject to three types of loads when learning about a complex topic. The three main distinct types of cognitive load that must be considered in the instructional setting are intrinsic load, extraneous load and germane load (germane resources) (Clark, Nguyen, & Sweller, 2005; Mayer, 2014; Sweller et al., 2011).

Types of Cognitive Load

Intrinsic and extraneous cognitive load are imposed directly by the learning material and the design by which the material was presented. Intrinsic load is referring to the mental effort that imposed on the working memory by the complexity of a given task (information), and it depends on the leaner's prior knowledge (Sweller & Chandler, 1994; Sweller, van Merrienboer, & Paas, 1998). Extraneous load is the mental effort imposed on the working memory by irrelevant or badly designed instructional activities that end up hindering schema acquisition and learning (Clark et al., 2005). With respect to germane load, the working memory resources that are devoted to deal with the intrinsic load of the task for schema acquisition and automation is called germane resources. Whereas, the working memory resources that are devoted to deal with the extraneous load of the task that hinder the schema acquisition and automation is called extraneous resources (Sweller et al., 2011).

Intrinsic Load and Element Interactivity

The nature of the complexity in the intrinsic cognitive load is not derived from the number of elements that a learning task poses; however, it is derived from the concepts' or elements' interactivity in a learning task. Element interactivity is described to be the number of items or concepts that must be learned simultaneously because they are logically related for meaningful learning to occur (Sweller et al., 2011; Sweller & Chandler, 1994). Another aspect of element interactivity is that it can be estimated prior to presenting any information. For example, only learning the names of the chemical elements in a periodic table possesses a low element interactivity because each chemical element could be learned individually, therefore intrinsic cognitive load would be low for such a task. Whereas tasks such as synthesizing chemical equations or chemical equilibrium possess a higher element interactivity because several elements (concepts) should be considered simultaneously in the task for meaningful learning to occur, thus the task would possess a high intrinsic cognitive load (Clark et al., 2005; Mayer, 2014; Sweller et al., 2011). Full understanding occurs when the interacted elements can be processed within the limited working memory capacity through the formation of schema.

Managing Intrinsic Cognitive Load

CLT suggest several instructional strategies by which the complexity (intrinsic cognitive load) of the subject matter content can be reduced in a manner that fits with the learner working memory limited capacity. Manipulating the intrinsic cognitive load can be done by altering the knowledge of the learner using the pre-training strategy in order to equip the learner with specific prior knowledge (Mayer, 2014; Musallam, 2010; Sweller et al., 2011). Or by altering the nature of the task itself by utilizing the segmenting or isolate/interacting-elements where full understanding would be held to the last segment of the lesson.

Cognitive Load Methodology

Cognitive load theory is concerned with biological secondary knowledge teaching and learning and relies intensively on empirical studies designs and procedures (Mayer, 2014; Sweller et al., 2011). More precisely, the development of theory suggests several instructional techniques that would have a high probability in affecting the learner mental effort and transfer performance. With regards to optimizing the intrinsic cognitive load, the independent variables include normally a suggested teaching procedure and a conventional procedure (e.g. isolate/element vs no isolate/element teaching or pre-training vs no pre-training). The dependent variables commonly include techniques for the measurement of mental effort and task performance (near or transfer). The data analysis based on the aforementioned design includes a comparison analysis between the two independent variables based on the dependent variables. Results, when found significant coupled with recommended effect size, are attributed to the independent variable applied and are mostly in favor of novice leaners (Ayres, 2006; Mayer, 2014; Sweller et al., 2011).

Measuring Cognitive Load

Subjective Techniques

Self-rating measure asks the learner to subjectively and directly assess the mental effort or difficulty perceived while learning or after solving a problem. Self-ranking based on the assumption that students can assess their mental effort invested while learning or solving a problem. The method is widely used in the CLT literature due to its implementation ease, cost-effectiveness and reliability (Paas & Van Merriënboer, 1993) . Knaus, Murphy, and Holme (2009) modified the self-ranking scale to best fit chemistry education. However, Ayres (2006) found out that students' expertise level could influence the mental effort scale. Expert students' results on mental effort scale correlated better with their task performance as opposed to novice students who could provide misleading results. For example, a novice learner could solve a question with reporting high mental effort, or provide a wrong answer to a performance question with reporting low mental effort. Therefore, using the mental effort scale and performance could provide misleading results.

Objective Techniques

Measures that focus on students' performance on a task of interest are considered objective in the CLT. The complexity of a question is important and determined by the number of elements that have to be processed simultaneously in the working memory to reach the correct answer (Sweller et al., 1998). With respect to the objective methods, working memory load is based on accuracy and time spent on a task. Both accuracy and time spent on task are considered signs of cognitive load when the learner continues to search look for less effective problem-solving strategies. Thus, high level of error rate indirectly indicates intrinsic complexity of the task.

Physiological Techniques

Physiological techniques include measures of heart rate and heart rate variability as well as brain activities and eye activity. When compared with subjective techniques, the physiological teachings seemed to be less sensitive to variation in cognitive load which made it unreliable and invalid (Sweller et al., 1998).

Although the aforementioned rigorous design and procedures provided mixed results regarding the effectiveness of the recommended teaching strategies, they dominate the studies conducted under the CLT umbrella since its introduction. Cook, Zheng, and Blaz (2009) point out "the central question pertaining to the study of cognitive load still remains unanswered: when, how, and at what level do we know the learner is cognitively overloaded? In other words, how do we define cognitive load, and how do we measure it…?" Recent suggestion by Leppink and van den Heuvel (2015) have recommended other factors to be taken into account besides the common cognitive load resources intrinsic and extraneous. Factors such as emotion, assessment end terms and assessment criteria are suggested to be further studied as they could have an influence on our working memory ability to process information. Other suggestions were provided regarding the research methods and recommended the utilization of both innovative quantitative and qualitative methods to better understand the learners' cognitive load.

The Flipped Classroom

One of the emerging teaching methods that takes advantage of technology is the flipped classroom (Tawfik & Lilly, 2015). Although there is no single model for implementing the flipped classroom, most of the flipped classrooms share the same course structure: in-class and out-of-class teaching and learning component (DeLozier & Rhodes, 2017). In addition to the common course structure, the flipped classroom is a student-centered learning environment (Bergmann & Sams, 2015; Bishop & Verleger, 2013; DeLozier & Rhodes, 2017). In this method instructors remove content outside the classroom for students to interact with at their own pace, while in class time is allocated for in depth active learning (Bergmann & Sams, 2014, 2015). Through the use of pre-class videos, it has been perceived that the flipped learning best fits with knowledge that is procedural, factual, conceptual and metacognitive (Milman, 2012).

However, the rapid emergence of the flipped classroom from a teacher experience to many schools' and collages' classrooms made it an active subject to be grounded in several learning and teaching theories (Abeysekera & Dawson, 2015; Seery, 2015). From cognitive load theory perspective, efficient instruction such as, the flipped classroom, is considered effective when leads to instructional goals achievement with less mental effort (Clark et al., 2005). Minimal research has sought to understand the efficacy of a flipped classroom model especially through the educational theories lenses, such as cognitive load theory (Abeysekera & Dawson, 2015).

Concept Mapping

The notion of concept map roots back to the work of Novak & Gowin (1984). In their book, *Learning How to Learn*, they provided a detailed understanding of the topic as a meta-cognitive tool. The term meta-cognitive or "thinking about one's thinking" is an umbrella that holds both meta-knowledge and meta-learning strategies. Meta-knowledge refers to knowledge that deals with the very nature of knowledge and knowing or how knowledge is constructed, whereas, meta-learning refers to learning that deals with very nature of learning or how meaningful learning occurs (Novak & Gowin, 1984). Meaningful learning refers to the integration of new knowledge to a pre-exited relevant knowledge in the cognitive structure (Novak & Tyler, 1977).

Concept mapping is a tool to present concepts in a relation to other related sub-concepts that exist within an individual's cognitive structure or long-term memory. In his theory of education, Ausubel (1977) suggested presenting the more general concepts (superordinate) first then the less general concepts (sub-ordinate) in hieratical fashion. Propositions are used to connect the concepts together in a meaningful way. For constructing a concept map, one starts with a general concept (node) or more general concept that could contain or progressively differentiate into several sub-concepts (nodes) that are more specific details in a hieratical fashion (Novak & Gowin, 1984). Nodes are then connected with labeled links that represent the relationships between concepts. A word or a phrase is placed on the link to specify the nature of the relationship between the concepts (Novak & Tyler, 1977).

Furthermore, Cañas and Novak (2009) provided four different characteristics that distinguish concept maps from other knowledge representation tools. The characteristics included the use of propositional structure, hierarchical structure, focus question and cross-links. The propositional structure indicate that one should be careful when connecting two concepts with a linking phrase. That is, a proposition that is conducted by connecting two concepts with a linking phrase should form a claim or unit of meaning in which a proposition is a short sentence. Another common characteristic of concept mapping is that the map should be organized in a hierarchical fashion that is, the more general concepts come in the top of the map followed by the least general or more specific concepts. The focus question determines the problem or issue that the concept map should solve; and helps in providing a context for the concept map. And finally, the inclusion of cross-links which are links or explicit relationship between two concepts from different segments or domains in a concept map.

This deep analysis of concepts in any given subject through the utilization of concept mapping promote meaningful learning as connection between concepts are meaningfully generated that requires a higher order thinking skill. The technique is also informative for teacher as it illustrates how the students understand a concept (Ruiz Primo & Shavelson, 1996). From cognitive psychology point of view, misconception happens as the students developed false connection between concepts or false proposition which require interactive reconciliation of concepts in which students understand the new meaning of a concept in relation to other concepts. The ability to visualize the students work, provide educators with the opportunity to locate the student’s misconception. The students’ ability to extract concepts, that is, order them in a hierarchical fashion in which superordinate comes first followed by subordinate concepts and connect the concepts with the appropriate proposition would help them towards meaningful learning (Novak, 1990; Novak & Tyler, 1977).

The idea of concept maps could be considered as a tool to reduce students cognitive load generated by the complexity of the subject matter (intrinsic load) (Andrew & Mayer, 2007). From the cognitive load perspective, students are considered naïve if they lack the ability to connect ideas behind a concept in a holistic way, whereas, expert students can draw connections between concepts which Mayer (2014) calls element interactivity. Element interactivity is associated with learning materials that are complex in nature such as chemistry and biology. To achieve meaningful learning, the learner should not just understand how each element or concept operates individually, but they also need to understand how the elements or concepts operate together to understand the relationships between the concepts (cognitive system). Next, Figure 3 illustrates how the utilization of concept mapping could possibly help in assessing students' cognitive load while learning and solving complex transfer problems.

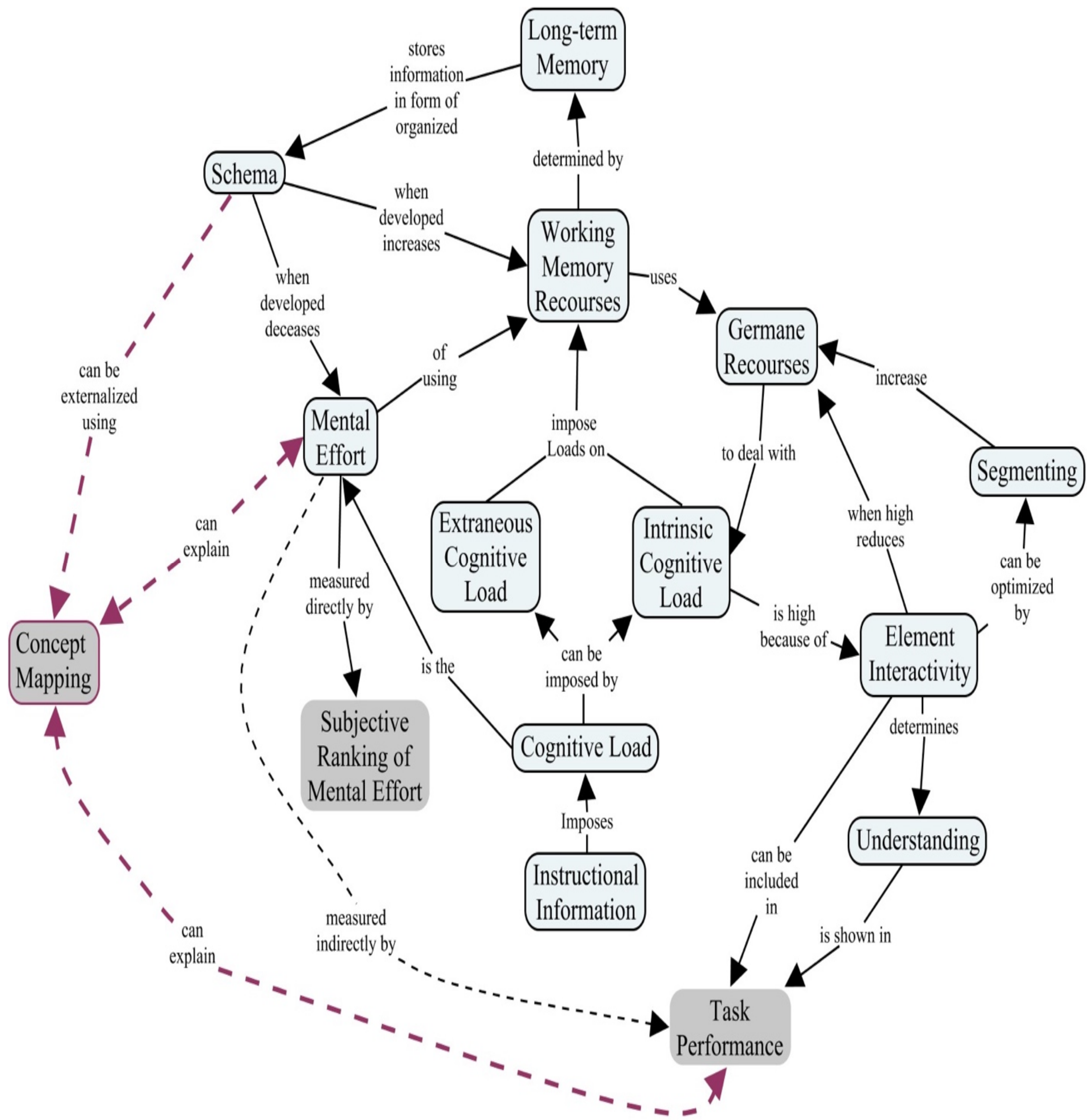

Figure 3. A Transition from the literature review to the methodology.

CHAPTER THREE

RESEARCH METHODOLOGY AND DATA ACQUISITION METHODS

This study used a mixed method (explanatory sequential) multiple case study design to understand the cognitive load phenomena subjects experience while learning a complex subject matter, Le Chatelier's principle, in the high school chemistry classroom. This is an epistemological constructive study that seeks subjective responses from the participants regarding their experience in the study (Creswell, 2013). Figure 4 illustrates the general steps taken for understanding subjects' cognitive loads.

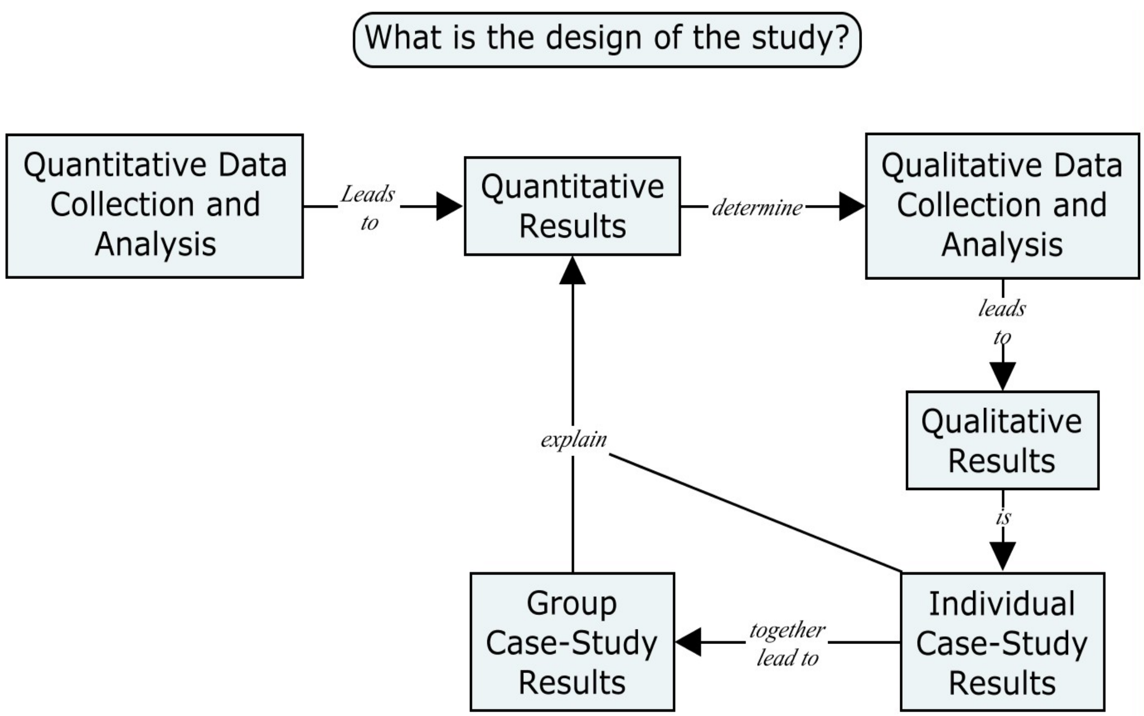

Figure 4. The general design of the study.

Research Methodology

This study is conducted using a multiple case study approach. It employed a mixed methods multiple case study design, in which each participating subject (n = 5) is conceptualized as a case. Case studies of subject learning are particularly helpful in understanding the internal dynamics of cognitive processes, and including multiple cases capitalizes on individual variation and permits an examination of how factors may influence learning (Creswell, 2015). The data interpretation is focused on relations among the study variables to describe the subjects' experience when learning about Le Chatelier's principle.

Research Settings

Researcher

I am a doctoral candidate in the Curriculum and Instruction program at Montana State University. My previous education includes a B.S in biology majoring in microbiology and a M.S in science and science education (MSSE). I have taught and co-taught in a science flipped classroom setting teaching elementary and high-school homeschooled students in the past five years. I was also invited several times in the last two years as a guest instructor to teach undergraduate subjects about the utilization of the flipped classroom strategy. In my doctoral dissertation, I am focusing on explaining the subjects' cognitive load and mental effort invested in solving complex problems with the utilization of concept mapping. The previous work on this topic required me to be more aware about my biases regarding the topic of this paper.

Teacher

The classroom instructor has been a science educator for nearly 40 years. He has 30 years of experience with K-12 science teaching as well as university level teaching. His personal education includes a B.S. in elementary education, a M.S. in curriculum and instruction (science emphasis) and an EdD in curriculum and instruction. His professional expertise includes online and face-to-face teaching, teacher efficacy, classroom research, NGSS and professional development.

Regarding this study, the teacher utilized the flipped classroom model as a general teaching strategy that consisted of face-to-face and online teaching components. He also used the 5E learning cycle in a specific teaching and learning model. The teaching strategy and model are being used by the teacher in various ways depending on the subject matter. For teaching about chemical equilibrium, the whole process will be described in the section of chemical equilibrium instruction bellow.

Subjects

A total of five high school subjects between 16 and 18 years old participated in this study. The participants consisted of two males and three females who were taking the chemistry course in a private high school in Bozeman, Montana USA. The study focused on the subjects' experience after learning about Le Chatelier's principle subject. Subjects were coming to the class once a week, every Thursday from 8:15 A.M to 9:30 A.M.

Instruction

The instruction part was divided into two sections: pre-training and chemical equilibrium instruction. The pre-training section included introducing the subjects to the notion of constructing a concept map and subjectively scaling mental effort. The chemical equilibrium section centered on teaching the subject matter, Le Chatelier's principle, utilizing the 5E learning cycle.

Pre-training. Both concept mapping and mental effort training were conducted face-to-face, video-recorded and uploaded into the class website.

Concept Mapping. Subjects were introduced to the notion of concept mapping four weeks before conducting the study. The training included teaching subjects how to create a concept map that starts with a key concept that could be differentiated to some general concepts followed by less general concepts followed by a specific example. Several examples were provided to the subjects to illustrate the use of concept mapping. Subjects practiced the activity of generating concept maps both in class and as homework before generating the concept map for this study.

Mental Effort. Subjects were introduced to the notion of mental effort through several mathematical problem-solving examples. First the scale was drawn by the researcher on the white board, then, a mathematical problem was given to the student to solve it. After solving the problem, subjects were asked "subjectively, how mentally difficult was it for you to find the right answer?" Subjects were asked to scale their invested mental effort from one to five, where one represents very little effort and five indicates very high effort invested. Several mathematical examples were provided to the subjects followed by mental effort scaling to familiarize the subject with the instrument. Subjects practiced the activity of scaling their mental effort several times in class before the post-test of this study.

Chemical Equilibrium Instruction. The chemical equilibrium content was taught in a flipped classroom setting. In this instructional strategy subjects are encouraged to have activities related to the subject matter in the class time. As homework, subjects were provided with subject matter (content) to study at their own pace. Coupled with the flipped classroom strategy, the 5E learning cycle was utilized as an instructional design in teaching subjects about the subject matter. Also, the classroom has a website (game.classcraft.com) for content delivery, discussions, and homework guidelines. Living by Chemistry (Stacy, 2010), was the official textbook for this course. For this study, Le Chatelier's principle was the focused subject matter. Each step of the 5E cycle will be described in detail next.

Engaging and Exploring. These two stages were taught together in the class time. The teacher prepared several activities that centered on the effects of concentration, pressure and temperature in five different phenomena. The experiential demonstrations were, the crushed can experiment, the balloon in the cold experiment, the balloon over the steam experiment, the egg in the bottle experiment, the bubble on the dry ice cloud experiment and finally, the marshmallow in the syringe experiment. The subjects were engaging through generating several questions for explaining the phenomena and physically conducting the last two experiments on their own. Subjects wrote their notes and questions, and the whole engaging and exploring process that took place in-class was video-recorded by the researcher. As homework, the subjects were asked to look over their notes and questions to construct a Claims-Evidence-Reasoning chart for each experiment and to construct a concept map that explains one of the phenomena.

The following class-time started with Le Chatelier's principle performance (pre-test). After the quiz, subjects were engaged in discussion about their homework. Finally, the rest of the class time was allocated to concept mapping discussions. Some recommendations were provided to subjects regarding their concept map projects such as, clarity of the concepts provided, hierarchical maps, and linking words. The class time ended with a group generation of a concept map with taking the above recommendations into account.

Explaining. As homework and through the designated classroom website (game.classcraft.com) subjects were delivered the subject matter content. The homework consisted of watching a 12-minute didactic YouTube video, "equilibrium," from Bozeman Science channel regarding chemical equilibrium, followed by reading the textbook pages, unit six: section one titled "chemical equilibrium," pages 569-596. Then, the website's guidelines directed the subjects to watch another seven-minute didactic YouTube video from the same channel regarding Le Chatelier's principle, followed by reading the textbook, unit six: section two titled "changing conditions at equilibrium," pages 597-611. Subjects were asked to take notes and write questions about the subject matter to be further discussed in the next class meeting.

Elaborating. This part of the cycle took place in-class as subjects brought their comments, notes and questions for further discussion. The teacher provided an in-depth instruction about both chemical equilibrium as well as Le Chatelier's principle. The instruction also included watching a video that explains the phenomena further. Subjects were also provided with exercise problems from the textbook page 602 to think about and solve both individually and as a group. The whole elaborating process was video-recorded by the researcher. As homework, subjects were asked to create Claim-Evidence-Reasoning chart of Le Chatelier's principle.

Subjects were also provided with YouTube videos from CmapTools channel explaining the basics of how to download and use the CmapTools software for both Windows and IOS devices. The length of each video was two minutes long. The training included how to use the Cmap canvas to create concept nodes, linking words, propositions, moving concepts and linking words on the canvas, as well as saving, printing and sharing Cmap projects.

Evaluating. This part of the cycle was designed for gathering records (quantitative and qualitative data) about subjects learning that included conducting the performance quiz (post-test), subjects' concept maps about Le Chatelier's principle and subjects' interview. In-class, subjects were given the performance post-test to solve. The time for solving the quiz was 30 minutes and subjects could turn-in the test whenever they feel comfortable with their answers. Time after the test was spent on discussing the use of CmapTools software and the researcher provided some examples related to different topics. For a homework, subjects were asked to generate a concept map using CmapTools that graphically represented their understanding of Le Chatelier's principle under the focus question of "how does Le Chatelier's principle work?" Subjects were asked to print out and bring their maps to class the following week which was entirely allocated for the subjects' interviews.

Mixed Methods Data Acquisition

Quantitative Data

Performance. The performance assessment consisted of 14 multiple choice transfer complex problems adapted from Musallam (2010) to assess subjects' performance on the chemical equilibrium concept that was first developed by Banerjee (1991) and Hackling and Garnett (1985). The questions were designed in a manner that tested the subject's deep conceptual understanding of Le Chatelier's principle (Appendix B). No algometric calculations were needed to reach the final answer. Each question was considered complex based on the cognitive load theory framework. The complexity of each item of the assessment quiz originates from the high number of element interactivity, that is, the number of concepts the subject would hold in the working memory to achieve the right answer. Each question has an element interactivity of 6, which was considered high, based on the cognitive load theory framework (Musallam, 2010). Students were not instructed to solve this type of problem either in class or as homework.

Subjective Cognitive Load. Immediately after solving each question of the transfer performance assessment, students' subjective mental effort ranking scale was used. The scale was first developed by Paas and Van Merriënboer (1993) and was widely used and supported by the cognitive load theory educational research. Knaus et al. (2009) developed a mental effort scale that fits with chemistry learning which was used in this study. The scale consists of five indicators or descriptors (very little, little, moderate, large, very large) of mental effort. It was used after each item of the transfer performance assessment, that is, 14 scales for the 14 performance questions.

Concept Maps. As a homework after the completion of the post-test, subjects generated concept maps that represented their conceptual understanding of Le Chatelier's Principle. The software CmapTools was utilized individually by each subject for the Cmap construction. The subjects generated their Cmap projects based on their understanding of the chemical equilibrium lesson, Le Chatelier's principle. One concept map regarding Le Chatelier's principle was collected from each subject. A total of five maps was collected from the subjects prior to the subject's interview.

Qualitative Data.

Subject Interviews. Subjects were interviewed one week after the subjects' performance and concept mapping assessments. Through a clinical interview, subjects were asked to describe how they solved problems, their relative mental effort and the structure of their concept maps. The interview format was semi-standardized in which the interview questions and tasks were asked when suitable (Appendix C). The interview used a supplementary video (*interview video*) that was utilized to probe subjects' thinking as well as reasoning in their responses. The supplementary video was utilized to keep the students focused on the task and to encourage their thinking process (Novak & Gowin, 1984). The interview video was designed by the researcher with the length of one minute and 47 seconds and contained three different scenarios. In the three scenarios, a system at the equilibrium state was being stressed by manipulating either the systems' concentration, temperature or pressure, at the time. After each scenario, the researcher would stop the video and ask the subject several questions that seek explanation (knowledge claims) of the phenomena (event) that had been looked at, based on Le Chatelier's principle. This would encourage the subjects to apply their understanding through generating knowledge claims about the scientific phenomena being watched and questions being asked (Mintzes, Wandersee, & Novak, 2005; Novak & Gowin, 1984). Moreover, the interview contained questions regarding the subjects' experience with both the first performance quiz (pre-test) as well as the second performance quiz (post-test). Also, questions regarding subjects' experience with subjectively scaling their mental effort in both pre-test and post-test were asked. For each subject, the interview was less than 18 minutes in length. Each interview was recorded using an audio recording device for further analysis.

Data Analysis and Scoring

Mental Effort Score

The mental effort score is self-reported on a scale of 1 to 5 with 5 being the greatest effort. Subjects scored their effort after completing each item of the transfer problem-solving quiz. The total mental effort was summed then averaged to represent both individual and group mental effort invested in the quiz.

Performance Quiz Score

The transfer problem-solving quiz score is the number of correct answers out of a total of 8 questions and 14 items in total. The total score is 14 points.

Concept Mapping Score

The concept mapping score was calculated using the Novak and Gowin (1984) suggestions: correct proposition was given one point; each level of hierarchy was given five points; cross links were given 10 points if valid and two points if not valid; examples were given one point each.

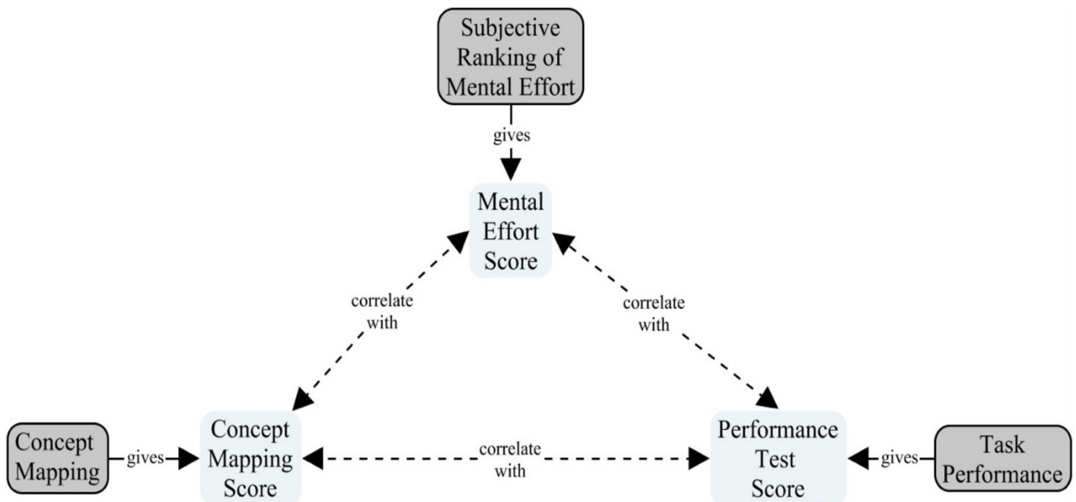

Figure 5. The general design of the study.

Clinical Interview Analysis

The clinical interview analysis was divided into three major categories: subjects' answers regarding the subject matter, experience with mental effort scale and experience with concept mapping questions. Questions regarding the subject matter were further divided into broad and narrow sub-categories which were centered around the framework of Le Chatelier's principle. Broad questions targeted a general understanding of the principle, that is, the general concepts making up the principle. The narrow questions were asked based on the interview video generated by the researcher. The video had four scenarios where each of Le Chatelier's principle stressors was being manipulated at one time, thus, a major category of the narrow questions was named "effects of changing the system's conditions." The scenarios were increasing the system's concentration, increasing and decreasing the system's temperature, and increasing the system's pressure, thus, three codes were generated and named "concentration manipulation, temperature manipulation and pressure manipulation." A student's answers to each of the designated code were then quoted in terms of claim and reasoning. Each quote that provided a full answer was then treated as a knowledge claim. Each student's knowledge claims were then analyzed for indicated corresponding conceptual theory that guided the claims. Subjects' interpretation for each scenario (event) was quoted as a knowledge claim. The knowledge claims to each stressor of Le Chatelier's principle were then analyzed (Figure 7). Analyzing a subject's records would lead to the subject's propositions that shape the knowledge structure regarding the event as depicted in Figure 6. Questions regarding both mental effort and concept mapping experience were broad and centered on the subjects' familiarity with the instrument utilized in the study.

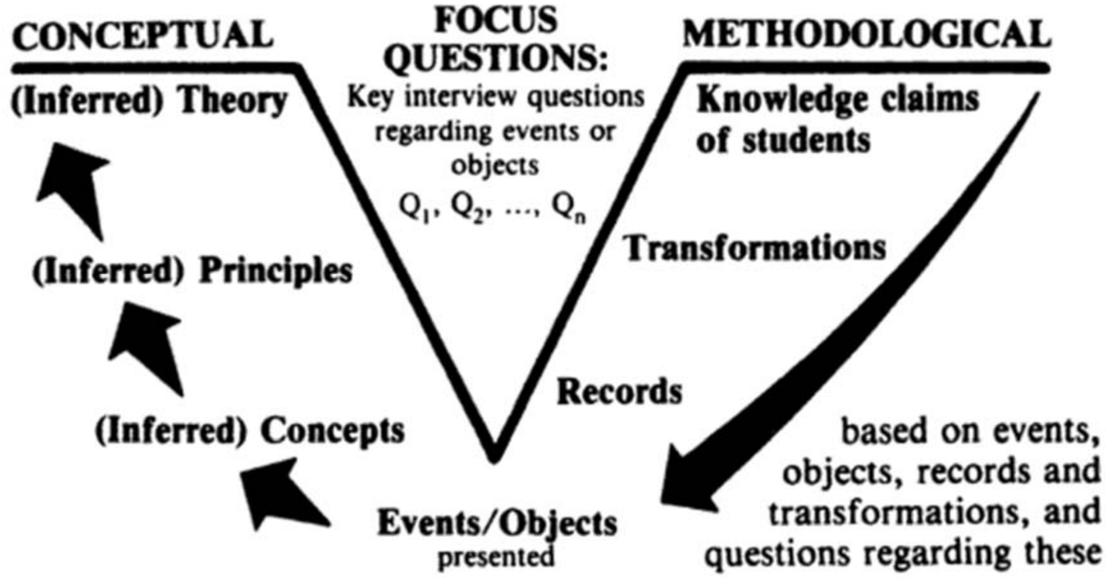

Figure 6. The Vee diagram utilized for interpreting subject's responses to the narrow questions regarding Le Chatelier's principle. It shows how subject's knowledge claims in a clinical interview would infer subject's conceptual framework. Adopted from (Novak & Gowin, 1984).

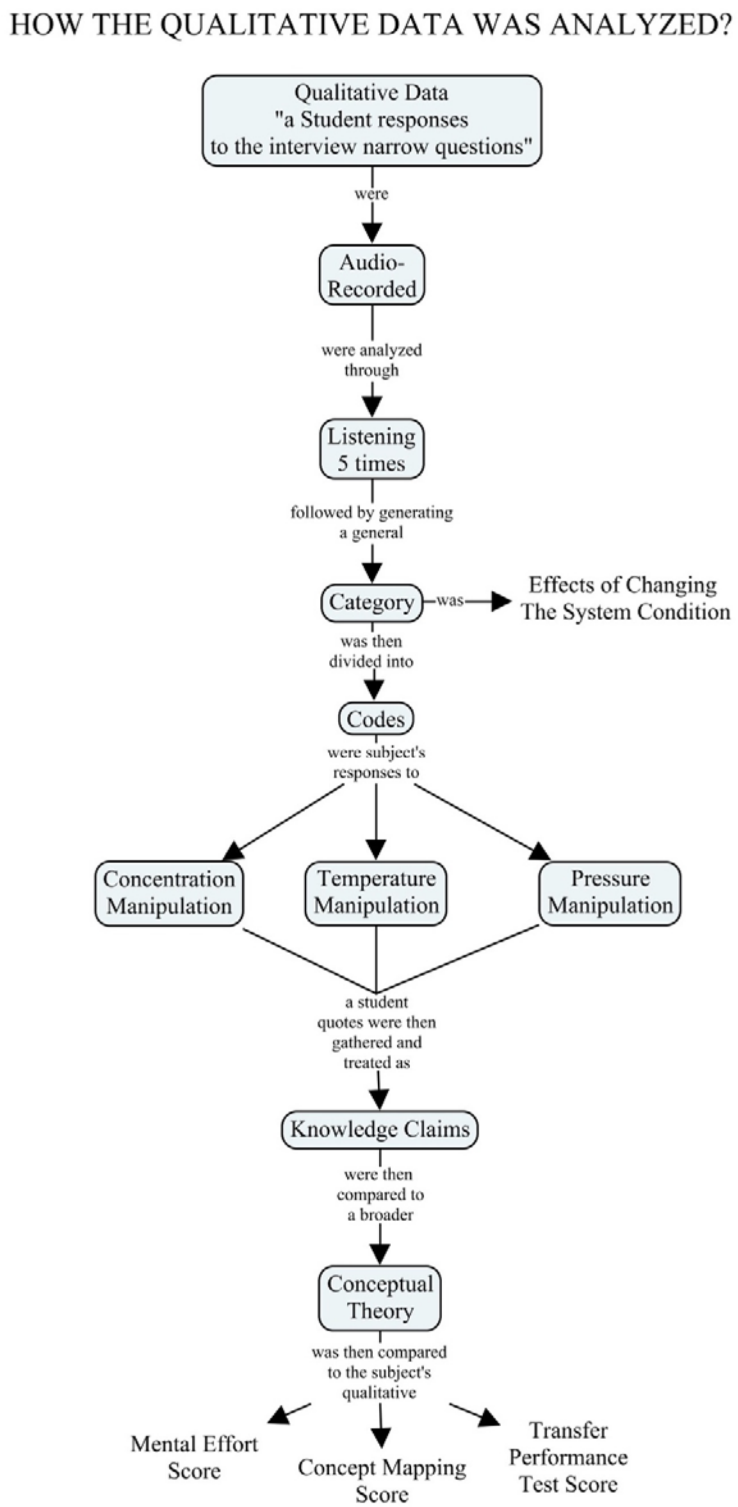

Figure 7. Qualitative data analysis.

CHAPTER FOUR

RESULTS

Subject Scores and Descriptive Analysis

For each subject, mental effort, concept mapping and transfer quiz performance raw scores were calculated and then summarized in Table 1. A descriptive statistical analysis of each variable in the study was also calculated. The mean number for subjects' mental effort invested while solving the transfer performance quiz was 3.44 (*SD* = 0.58). The highest mental effort raw score was 62 while the lowest was 39. The mean number of the subjects' concept mapping scores was 37.4 points (*SD* = 12.22) with 60 points being the highest score and 26 points the lowest. Subjects points on the transfer performance quiz had the mean number of 7 points (*SD* = 1.79), with 9 points being the highest score gained and 4 the lowest (Table 2).

Table 1. Mental Effort, Concept Mapping and Performance Quiz Total Scores for Each Subject.

Subject	Mental Effort	Concept Mapping Score	Performance Score
1	62	26	8
2	39	60	4
3	44	32	8
4	52	29	6
5	44	40	9

The table above shows the raw scores of subjects' transfer performance quiz, mental effort invested in solving the performance quiz and concept mapping. The raw scores were used for descriptive analysis depicted in Table 2. For the subjects' mental effort mean, the mean of each subject's mental effort invested in the test was calculated first. Then, the group mean of all subjects was calculate and presented in Table 2.

Table 2. Descriptive Analysis of Subjects' Mental Effort, Concept Mapping and Transfer Performance Quiz Scores.

Subjects' Scores	Mean Scores *M*	Standard Deviation *SD*
Mental Effort	3.44	0.58
Concept Mapping	37.4	12.22
Transfer Performance	7.0	1.79

<u>Pearson's Correlation Analysis</u>

The raw scores were also used to conduct the correlation testing to investigate relationships among the variables. Table 3 shows a Pearson's correlation results among the study's three variables: subjects' transfer quiz scores, mental effort invested in solving the transfer performance quiz scores, and concept mapping scores. Based on Pearson's correlation results, there was a strong negative relationship between subjects' mental effort scores and concept mapping scores with a correlation coefficient of (-0.78). It was also revealed that there was a moderate positive correlation between subjects' mental effort scores and transfer performance scores with a correlation coefficient of (0.34) and a strong negative correlation between subjects' concept map scores and quiz performance scores with a correlation coefficient of (-0.64).

Table 3. Pearson Correlation Analysis Between Subjects' Mental Effort, Concept Mapping and Performance Quiz Scores.

	Mental Effort	Concept Mapping Score	Performance Score
Mental Effort Score	1		
Concept Mapping Score	-0.782321505	1	
Performance Score	0.346794345	-0.649351616	1

Hypothesis Testing Correlational Analysis

First Research Question

What is the relationship between the subjects' perceived mental effort scores and subjects' generated concept map scores on chemical equilibrium?

The first research question investigated a possible relationship between students' subjective *mental effort* invested while solving the transfer *performance quiz* and their scores on constructing a *concept map* regarding the same topic. Subjects' *mental effort* score was measured as subjects subjectively responded to how much mental effort they invested after solving each of the Le Chatelier's principle problems (transfer performance quiz). Subjects' *concept map* scores were measured based on the number of propositions, hierarchical levels, and integrative cross-links in their concept map project that was under the question of how Le Chatelier's principle works.

A Pearson correlation test was conducted to investigate the relationship between the two numerical variables (Table 4). Based on Pearson's correlation results, there was a strong negative relationship between subjects' *mental effort* scores and subjects' *concept mapping* scores with a correlation coefficient of (-0.78). Therefore, we accept the hypothesis that the more complex the *concept map* generated by the subjects the less *mental effort* they would invest to solve chemical equilibrium problems.

Table 4. Pearson Correlation Analysis Between Subjects' Mental Effort and Concept Mapping Scores.

	Mental effort Score	Concept Mapping Score
Mental Effort Score	1	
Concept Mapping Score	- 0.782	1

Second Research Question

What is the relationship between subjects' subjective mental effort scores and subjects' performance scores on solving complex chemical equilibrium problems?

The second research question investigated a potential relationship between subjects' subjective *mental effort* invested while solving the transfer *performance quiz* regarding Le Chatelier's principle and their performance scores on the same topic. Subjects' *mental effort* score was measured as students subjectively responded to how much mental effort they invested after solving each of the Le Chatelier's principle problems (transfer performance quiz). The subjects' *performance score* was measured based on the total of the correct answers.

A Pearson correlation test was conducted to investigate the relationship between the two numerical variables (Table 5). Based on Pearson's correlation results, there was a moderate positive relationship between subjects' *mental effort* scores and subjects' *performance quiz* scores with a correlation coefficient of (0.34). Therefore, we reject the hypothesis that the lower the *mental effort* would be invested to solve chemical equilibrium problems, the higher the *performance quiz* score.

Table 5. Pearson Correlation Analysis Between Subjects' Mental Effort and Performance Quiz Scores.

	Mental effort Score	Performance Quiz Score
Mental Effort Score	1	
Performance Quiz Score	0.346	1

Third Research Question

What is the relationship between subjects' concept mapping scores and subjects' score on the performance quiz?

The third research question investigated a possible relationship between subjects' scores on constructing a *concept map* regarding Le Chatelier's principle and their *performance quiz* scores on the same topic. Subjects' *concept map* scores were measured based on the number of propositions, hierarchical levels, and integrative cross-links in their concept map project that was under the question of how Le Chatelier's principle works. Subjects' transfer *performance quiz* score was measured based on the total of the correct answers of Le Chatelier's principle quiz.

A Pearson correlation test was conducted to investigate the relationship between the two numerical variables (Table 6). Based on Pearson's correlation results, there was a strong negative relationship between subjects' *concept mapping* scores and subjects' transfer *performance quiz* scores with a correlation coefficient of (- 0.64). Therefore, we reject the hypothesis that there is a positive relationship between subjects' *concept map* scores and subjects' *performance quiz* scores, as a strong negative correlation (-0.64) was found.

Table 6. Pearson Correlation Analysis Between Subjects' Concept Mapping and Performance Quiz Scores.

	Concept Mapping Score	Performance Quiz Score
Concept Mapping Score	1	
Performance Quiz Score	- 0.649	1

Next, the qualitative results will be used to explain the quantitative results obtained as depicted in figure 4. Subjects interview as well as concept maps projects will be analyzed to explain the quantitative data. In the following section, data from each subject will be analyzed first, then a summary of all the subjects' qualitative results will be provided.

Subject 1

Data from the *performance quiz* indicated that the subject gained eight points out of 14. The points were gathered as the subject answered half of each of the following category questions correctly: two points in adding a catalyst to the system, three points in changing the system's concentration and three points in changing the system pressure. All questions regarding changing the system temperature and reaction rate were not answered correctly. Averaged subjective *mental effort* scale results indicated that the subject had a high mental effort while solving the *performance quiz*.

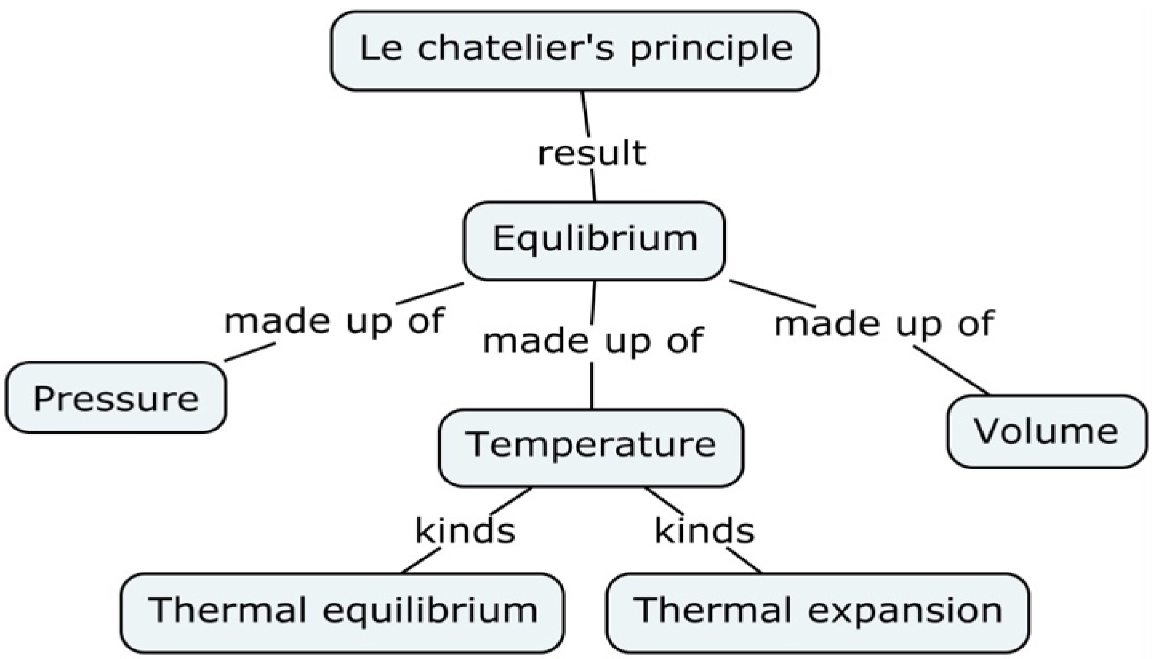

Figure 8. Subject #1 Concept Map.

The *qualitative analysis* regarding the construction of the *subject's Cmap* shows that the map was constructed in a hierarchical fashion with Le Chatelier's principle being the root concept of the map (Figure 8). The linking phrases provided did not fully explain the relationships among concepts. The *qualitative analysis* of the subject concept map regarding how Le Chatelier's principle works indicated that the *Cmap* contained most of the essential concepts related to chemical equilibrium. The *Cmap* missed the concept concentration as a major stressor that could affect the equilibrium based on Le Chatelier's principle. The map was given a score of 26 points as shown in Table 7.

Data from the *subject interview* showed that the subject had no difficulties with using concept mapping for knowledge representation. The subject preferred using CmapTools over paper and pencil and when asked why, answered "I like it because I am more of a computer person, so I enjoy it. And I found when I mess up I can fix it quickly and easily, I can also play around and change the position of the concepts." Also, the subject had a previous experience with a different knowledge representation tool that is similar to concept mapping, mind mapping, that was used in a previous science course.

Table 7. Subject #1 Concept Map Scoring Result.

Criterion	Propositions x1	Hierarchical Levels x5	Integrative cross-links x10
Score	6 x1	4 x 5	0 x10
			Total Score
			26

Through the *subject interview* it seemed that the subject had a general understanding of Le Chatelier's principle. The subject provided a general understanding of how the principle works as said "changing pressure, temperature, volume affect a reaction that is at equilibrium." The subject used the generated *Cmap* to show how the principle works although the concept concentration was missing in the *Cmap*. When asked, using the *interview video*, how changing concentration would affect a reaction at the equilibrium, the subject took time to think and answered correctly "The equilibrium will shift to the left." And when the subject was asked why, they replied "because the left side would have less concentration, so it will shift to the left. The color changed because the concentrations of the reactant side increased as water was added so the equilibrium shifted to the left." The subjects' answer was reflected in the *Performance quiz.* All the questions regarding manipulating the system's concentration were answered correctly with a "very high" mental effort.

When asked to predict the direction the system reaction would shift to as the system temperature increased in the *interview video*, differentiating between endothermic and exothermic reactions was a difficult task for the subject as the subject said "I do not know I think … the forward reaction is exothermic because color changed. Right?" When asked what about the other side of the reaction, the subject said, "the other side is also exothermic reaction. Right?" It seemed that the subject used the collision theory framework to answer the question, which is a faulty answer based on Le Chatelier's principle. Also, the subjects could not provide a clear justification of the color change as the concentrations changed. This was also reflected in the subject answers in the performance quiz as the subject missed all points regarding changing the temperature of a system at the equilibrium state. Moreover, the mental effort average for solving a problem regarding temperature change items, was ranked “very high” by the subject.

Although the subject provided the concept temperature in the *Cmap*, the temperature concept was further differentiated into thermal equilibrium and thermal expansion. The concepts of exothermic and endothermic were not provided as a major sub-concept of temperature in Le Chatelier’s principle which are significant concepts to understand how the principle functions.

In contrast, the subject showed a clear understanding regarding the effect of changing pressure to a system at the equilibrium. When asked, through the *interview video*, to predict what would happen to the system as the pressure is being increased, the subject took some time to think and responded, “The reaction will shift to the left I think but I do not know.” When asked to consider the number of moles in each side, the subject replied, “There are less moles in the products side of the equation so shifting to the right will reduce the stress. Right? Ohh… so it will shift to the right.” Moreover, data from the *performance quiz* showed similar results as the subject correctly answered most of the questions regarding changing the pressure of a chemical reaction at the equilibrium state with a “very high” mental effort.

Finally, when asked about the experience with the *performance quiz* (pre-test) and *mental effort* rating activity, the subject said, “I did not understand the questions at all, and I was just guessing my mental effort.” However, in the second *performance quiz* (post-test) the subject was able to scale the mental effort associated with solving each question and said, “The second exam, I understood the words in the questions but still it was a very hard quiz and my mental effort was moderate to large I would say.”

Table 8. Subject 1 Answers to The Narrow Research Question regarding Le Chatelier’s Principle.

Question	Claim	Reasoning
What would happen to the system as we increase one of the products concentration?	“The reaction would shift to the left.”	“Because the left side would have less concentration, so it will shift to the left. The color changed because the concentrations of the reactant side increased as water was added so the equilibrium shifted to the left.”
What would happen to the system as we increase the temperature?	“I do not know. I think the forward reaction is exothermic.”	“The forward reaction is exothermic because color changed. Right? The other side is also exothermic. Right?”
What would happen to the system as we increase pressure?	“The reaction will shift to the left I think but I do not know.”	“There are less moles in the products side of the equation so shifting to the right will reduce the stress. Right? Ohh… so it will shift to the right.”

<u>Subject 1 Summary</u>

The subject scored eight points out of 14 in the *performance quiz* with an average of high *mental effort*. The subject’s *Cmap* was given the score of 26. The *Cmap* was clear and constructed in a hierarchal fashion with Le Chatelier’s principle as a root concept. It included most of the essential concepts, however, the propositions were not stated clearly. It seemed that the subject was confused as they were trying to use both reversible and completion reactions frameworks. The subject considered the performance quiz to be very hard to solve as well as the topic to be very hard to understand. Based on the *subject interview* data, *mental effort* is easier to be subjectively scaled as the subject has some understanding of the concepts provided in the *performance quiz*.

Subject 2

Data from the *performance quiz* indicated that the subject gained four points out of 14. The points were gathered as the subject answered half of each of the following category questions correctly: the reaction rate, adding a catalyst to the system, and changing the system pressure. All questions regarding changing the system temperature and changing the system concentration were not answered correctly. Averaged subjective *mental effort* scale results indicated that the subject had a low mental effort while solving the *performance quiz*.

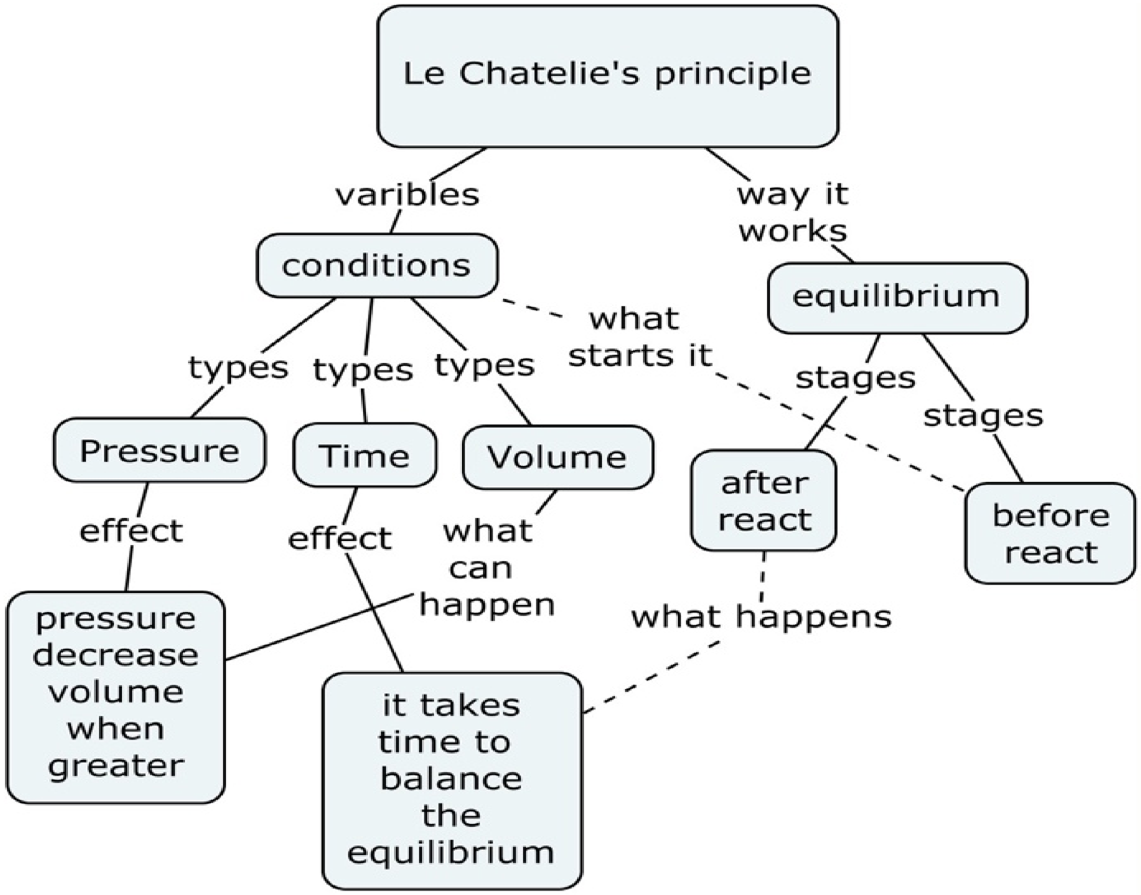

Figure 9. Subject # 2 Concept Map.

The *qualitative analysis* regarding the construction of the *subject Cmap* shows that the map was constructed in a hierarchical fashion. The linking phrases provided explained the relationships among concepts. The *qualitative analysis* of the subject concept map regarding how Le Chatelier's principle works indicated that the *Cmap* contained some of the essential concepts related to chemical equilibrium (Figure 9). In the *Cmap*, the variable (time) was included as a major stressor that could affect the equilibrium, which was not indicated in the instruction or by Le Chatelier's principle. Both temperature and concentration were missing in the map as essential major factors that change the chemical equilibrium. The map was given a score of 60 points as it contained two unique cross links (Table 9).

Table 9. Subject # 2 Concept Map Scoring Result.

Criterion	Propositions x1	Hierarchical Levels x5	Integrative cross-links x10
Score	20 x1	4 x 5	2 x 10
			Total Score
			60

Data from the *subjects' interview* revealed that the subject had no difficulties constructing the map in a hierarchical fashion. The subject said, "I am just making bubbles and putting some ideas starting with main topic, subtopic…"Also, the subject preferred constructing the concept map using pencil and paper over utilizing the *CmapTool*. When asked for a rationale, the subject responded, "I like doing it on paper rather than using the *CmapTool* because it is a bit hard to put stuff on the map fast, unless I learned the shortcuts."

It seemed that the subject had some misunderstanding and misconception about Le Chatelier's principle. When asked to explain Le Chatelier's principle the subject responded, "What it is, is three variables. Pressure, time and volume. And it goes around the equilibrium. Equilibrium is where when you add more products and time takes its course it adds more pressure and the products will mold into each other I guess. When the products and reactants rates are equal then that the equilibrium. So, $PV = nRT$." When asked why time is considered important for the equilibrium, the subject said that "the T represents time in the equation," whereas it represents temperature. Considering time as a major factor that affects a system at the equilibrium state is one of the common misconceptions subjects hold when learning about Le Chatelier's principle (Hackling & Patrick, 1985). This misconception could explain why the subject did not included time instead of temperature in the *Cmap* as a major factor that affects a reaction in the equilibrium state. Also, it could explain why the subject could not solve the problems that focused on the effects of changing the temperature and concentration in the *performance quiz*.

However, when the subject was asked in the *interview video* to predict the direction of the shift in the system as a result of adding a product to the system, the subject answered correctly to the left. When asked why, the subject responded, "It will shift to the left, because it needs water to make that. Because we have more water molecules, the system will shift to the left to decrease water molecules because we have more water. That's right?" Although they provided the right answer in the *interview*, the subject could not solve the same question in the *performance quiz*. This could be because in the *performance quiz*, the subject had to predict what would happen as a result of removing instead of adding some of a reactant in the system.

When asked to predict the direction the system reaction would shift to as the system temperature increased in the *interview video*, the subject had some difficulty differentiating between endothermic and exothermic reactions. However, when asked to answer question 5 from the *performance quiz* thinking out loud, the subject said, "when heat is reduced the mass will not change but the concentration of 2 CO_2 and CL_2 will go up and the concentration of $COCL_2$ will go down.” This is a faulty answer based on Le Chatelier’s principle.

Regarding pressure as a stressor on a reaction at the equilibrium state, the subject predicted correctly where the reaction would shift. However, when asked for a justification, a fundamental misunderstanding appeared regarding the state symbol $_{(g)}$. The subject thought the $_{(g)}$ symbol represented the number of grams, whereas, it represents the element’s physical state. The subject said, “The reaction will shift to the right because, there were more grams on the right side of the equation, the $_{(g)}$ means grams.” After clarification of what $_{(g)}$ stands for, the subject said, “When pressure is increased, the equilibrium will shift to the side where more moles in it because there is less space I think.” The subject’s answer was based on the atomic number of the oxygen element in the product side $N_2O_{4\,(g)}$ and not for the molecule number. This is also a faulty answer based on Le Chatelier’s principle. Although the subject provided some faulty answers, Le Chatelier’s’ principle was the framework for the subjects thinking and reasoning.

Finally, when asked to reflect on the experience of subjectively scaling *mental effort* in the *performance quiz* (pre-test), the subject responded that “I thought the mental effort a little bit hard to do because I found myself not having much mental effort when I did not know what it was at all. I do not know what it is!” However, subjectively scaling the *mental effort* was easier with the post-test as the subject had learned the lesson concepts, “And then when I did know what it was, it was higher because I had to think about the answer.”

Table 10. Subject 2 Answers to The Narrow Research Question regarding Le Chatelier's Principle.

Question	Claim	Reasoning
What would happen to the system as we increase one of the products concentration?	"The reaction will shift to the left."	"Because it needs water to make that. Because this will increase the water molecules and the system will shift to the left because we have more water."
What would happen to the system as we increase the temperature? (Performance quiz, question 5)	No claim	"When heat is reduced the mass will not change but the concentration of 2 CO2 and CL2 will go up and the concentration of COCL2 will go down."
What would happen to the system as we increase pressure?	"Reaction will shift to the right."	"Because, there were more grams on the right side of the equation, the (g) means grams …when pressure is increased the equilibrium will shift to the side with more moles in it because there is less space."

Subject 2 Summary

The subject scored four points out of 14 in the *performance quiz* with an averaged low *mental effort*. The subject's *Cmap* was given the score of 60. The *Cmap* was clear and constructed in a hierarchal fashion with Le Chatelier's principle as a root concept. The subject's *Cmap* focused mostly on the effect of pressure on a system at the equilibrium state. It lacked other essential concepts such as temperature and concentration. The *Cmap* included time as a major stressor to a system at the equilibrium, which is a common misconception in the chemical equilibrium learning. During the interview, Le Chatelier's principle was the framework for the subject's answers. The interview data revealed that the subject had some misunderstanding concepts within Le

Chatelier's principle that could have affected the subject *performance quiz* score and the concepts provided in the *Cmap*. The subject had some difficulties with subjectively scaling the invested mental effort in the *performance quiz* (pre-test). However, mental effort was easier for the subject in the post-test as the concepts were learned.

Subject 3

Data from the *performance quiz* indicated that the subject gained eight points out of 14. The points were gathered as the subject answered the following category questions correctly; one point in the reaction rate, two points to adding a catalyst to the system, three points to changing the system pressure and two points to changing the system concentration. All questions regarding changing the system temperature were not answered correctly in the *performance quiz.* The averaged subjective *mental effort* scale results indicated that the subject had a moderate *mental effort* while solving the *performance quiz*.

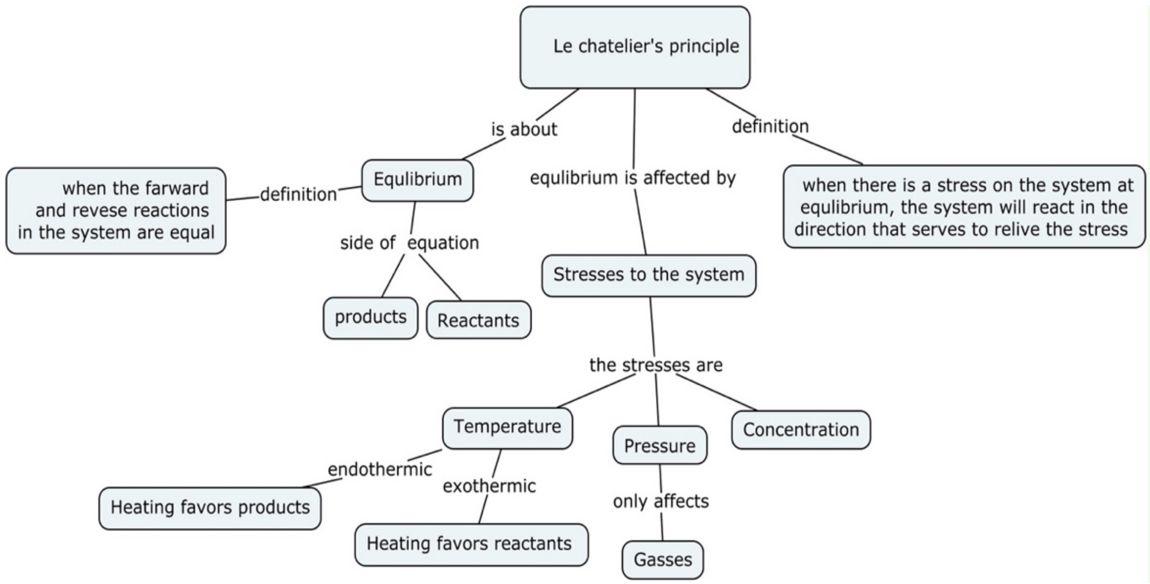

Figure 10. Subject # 3 Concept Map.

The *qualitative analysis* regarding the construction of the *subject Cmap* indicates that the map was formed in hierarchical fashion as more general concepts were provided first followed by more specific concepts. The linking words provided were appropriate to explain the relationships among the concepts. The *qualitative analysis* of the *subject Cmap* regarding how Le Chatelier's principle works indicated that the *Cmap* contained all the essential concepts related to chemical equilibrium. The map placed Le Chatelier's principle as the root concept and contained valid definitions of Le Chatelier's principle as well as chemical equilibrium. The *Cmap* indicates that the subject had a deep understanding of Le Chatelier's principle as more detailed concepts and valid propositions were provided. For example, indicating explicitly that pressure only affects gases and the effect of temperature on a system at the equilibrium depends on whether the forward reaction is endothermic or exothermic. Although the *Cmap* lacked cross- links, the concepts that Le Chatelier's principle holds were differentiated properly (Figure 10). Based on the quantitative analysis, the *Cmap* was given 32 points (Table 11).

Table 11. Subject # 3 Concept Map Scoring Result.

Criterion	Propositions x1	Hierarchical Levels x5	Integrative cross-links x10
Score	12 x 1	4 x 5	0 x 10
			Total Score
			32

Data from the *subject interview* showed that the subject was a little confused about using the *Cmap* as a tool for knowledge representation as the subject had no previous experience with the *CmapTool.* The subject said, "I was confused at first about what supposed to graph and where." However, as the subject placed the concepts on the map and drew a connection among them it was easier to have a holistic understanding of the topic as the subject reported, "But eventually it made more sense." It appeared that the subject had a previous experience with a different knowledge representation tool, mind mapping, that was used in a different course for summarizing what the subject had learned throughout the course. But the subject had no experience with deeply graphing a specific topic as the subject reported, "It was the first time for me to try this version of concept mapping. I used to use a different type of concept mapping. But it is my first time to go in specifics." It could be possibly true that the previous experience with a relatively similar knowledge organization tool, made it easier for the subject to adapt to *CmapTool* and to construct a relatively a well-developed *Cmap* about chemical equilibrium.

Through the *subject interview* it seemed that the subject had a general understanding of Le Chatelier's principle. The subject used the generated *Cmap* to show how the principle works. When asked, using the *interview video*, how changing concentration would affect a reaction at the equilibrium, the subject answered quickly and correctly. Also, while answering the question, the subject was focusing on changes on both sides of the equation, as said, "The equilibrium will shift to the side with less concentration so to the left, to react to the stress applied. This will decrease the concentration of the other product and increase the concentration of the reactants so the equilibrium will shift to the left." It seemed that the subject had Le Chatelier's principle as a framework to answer the interview questions. Similarly, the subjects answered most of the questions regarding manipulating the system's concentration correctly in the *Performance quiz,* with a moderate mental effort.

Also, through the *subject interview* with using the *interview video* the subject was asked to predict what would happen to a system at the equilibrium stage as temperature is being increased and decreased. Although it took time to determine whether the forward reaction is endothermic or exothermic, the subject answered the question correctly and said, "The forward reaction is endothermic, so increasing heat will shift the equilibrium to the right to make more product. Decreasing the temperature will shift the equilibrium to the left to make more reactants." Although the *subject concept* map and *subject interview* data showed that the subject had a clear understanding of the temperature possible effects on a chemical reaction at the equilibrium, the subject missed the points regarding the effect of temperature affects in the *Performance quiz,* and invested a moderate *mental effort* in answering questions regarding temperature.

Likewise, the subject showed a clear understanding regarding the pressure effects. When asked, through the *interview video*, to explain how the system would react as the pressure is being increased, the subject answered after thinking for a while, “The equilibrium will shift to the right.” When asked for a justification, they replied, “To release the stress as there are less moles in the products side of the equation.” Through the subjects reasoning it could be anticipated that the subject was familiar with the equilibrium framework. Moreover, data from the *performance quiz* showed similar results as the subject correctly answered most of the questions regarding manipulating pressure of chemical reaction at the equilibrium with a moderate mental effort.

Finally, when asked about the experience with the *performance quiz* (pre-test) and *mental effort* rating activity, the subject said, “I did not know anything about the topic. I did not know about the chemical equilibrium and Le Chatelier’s principle… it was hard to pick the right answer because I did not know the material. I did not know what I was reading at all so it was challenging to ask me about my mental effort.” However, in the second *performance quiz* (post-test) the subject was able to scale the mental effort associated with solving each question and said, “The second exam, probably the mental effort went up, because this time I knew what I am reading about and I knew how to solve it so I just needed to think about it and go through it.”

Table 12. Subject 3 Answers to The Narrow Research Question regarding Le Chatelier's Principle.

Question	Claim	Reasoning
What would happen to the system as we increase one of the products concentration?	"The equilibrium will shift to the side with less concentration. So, to the left."	"To react to the stress applied. This will decrease the concentration of the other product and increase the concentration of the reactants so the equilibrium will shift to the left."
What would happen to the system as we increase the temperature?	"The forward reaction is endothermic, so increasing heat will shift the equilibrium to the right."	"To make more product. Decreasing the temperature will shift the equilibrium to the left to make more reactants."
What would happen to the system as we increase pressure?	"The equilibrium will shift to the right."	"To release the stress as there are less moles in the products side of the equation."

Subject 3 Summary

The subject scored eight points out of 14 in the *performance quiz*, with an averaged moderate *mental effort*. The subject's *Cmap* was given the score of 32. The *Cmap* was clear and constructed in a hierarchal fashion with Le Chatelier's principle as a root concept. It included all the essential concepts as well as valid propositions. Although the subject missed points regarding the effect of manipulating the temperature of a system at the equilibrium in *the performance quiz*, the *Cmap* and *interview data* revealed that the subject had a clear conceptual understanding of the concept. The subject used Le Chatelier's principle as framework to answer the interview questions. Based on the *subject interview*, *mental effort* is easier to be subjectively scaled if the subject understands completely the concepts provided in the questions. Therefore, providing the *mental effort* scale in the first *performance quiz* (pre-test) was challenging for the subject to deal with.

Subject 4

Data from the *performance quiz* indicated that the subject gained six points out of 14. The points were gained as the subject answered the following category questions correctly: one point in the reaction rate, one point to adding a catalyst to the system, one point in changing the system's temperature, two points to changing the system's pressure and one point in changing the system' concentration. Averaged subjective *mental effort* scale results indicated that the subject had a large *mental effort* while solving the *performance quiz*.

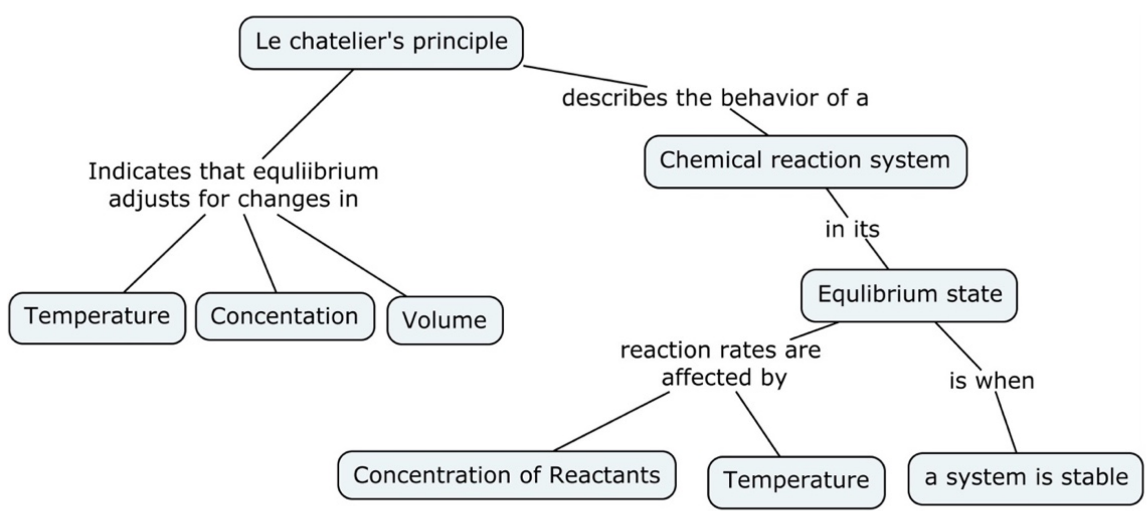

Figure 11. Subject #4 Concept Map.

The *qualitative analysis* regarding the constriction of the *subject Cmap* indicates that the map was formed in a hierarchical fashion with Le Chatelier's principle being a root concept, and more general concepts were followed by less general concepts. The *subject Cmap* contained several linking words that joined the concepts together in a meaningful way. But, some of the main concepts were provided in the linking words such as equilibrium and reaction rate.

The *qualitative analysis* of the *subject Cmap* regarding how Le Chatelier's Principle works indicated that the *Cmap* contained most of the essential concepts related to chemical equilibrium (Figure 11). Having some of the main concepts on the linking phrases space made it difficult to look how the propositions are being formed, based on concept map learning. The map lacked the concept volume as one of the major factors that could affect a system's reaction rate. Also, only the concentration of the reactants is perceived by the subject to be influencing the reaction rate. Based on the quantitative analysis, the *Cmap* was given 29 points (Table 13).

Table 13. Subject # 4 Concept Map Scoring Result.

Criterion	Propositions x1	Hierarchical Levels x5	Integrative cross-links x10
Score	9 x 1	4 x 5	0 x 10
			Total Score
			29

Data from the subject interview showed that although they had no previous experience with concept mapping before, the subject perceived the task of constructing a concept map to be easy in general. The subject also indicated that the difficulty of constructing the map is subject dependent and constructing a map regarding Le Chatelier's principle was a relatively hard task, "I think it depends on the subject… it made me to think about the topic in a different way that I am not used to." The subject also mentioned that this way of thinking regarding a topic is relatively hard as said "I think it is harder for me than it might be for other people who think like that, because I don't really. But it is fine. It is not too bad." Regarding the effectiveness of using concept mapping, the subject indicated that the tool helped in understanding the topic deeply as said, "it helped me understand the topic deeper as it made me think about the topic more than I would, if I just read the chapter."

The *subject interview* using the *interview video* showed that the subject had some misunderstanding of Le Chatelier's principle. Regarding the concentration's affect, the subject was unable to explain how a system would react as one of the product's concentration was being increased as the subject said, "When we add water to the system, the system will be less concentrated." And when asked why, they responded, "Because the system was not balanced… when we add more water, the concentration of the product side will increase and the concentration of the reactant side would decrease because we added more water." This misunderstanding was reflected in the *subject Cmap* as it stated that "reaction rate is affected by the concentration of reactants" which could show that the subject could not differentiate between completion and reversible reactions, which is a common misconception in chemical equilibrium learning. It could be inferred here that the subject was applying the framework of the collision theory principles to solve problems that require applying the framework of the equilibrium theory. Similarly, data from the performance quiz showed that the subject could solve one out of three questions regarding manipulating the concentration of a system at the equilibrium state with a large mental effort.

Also, through the *subject interview* using the *interview video* the subject was asked to predict what would happen to a system at the equilibrium stage as its temperature is being manipulated. The subject was unable to differentiate between endothermic and exothermic reactions. Regarding the effect of increasing the system's temperature in the *interview video* the subject said, "I do not know… the reaction is endothermic because the heat was absorbed in the reaction to produce products." However, the subject was hesitating in answering the question regarding reducing the system temperature. It could be because the subject might hold the notion of the completion reaction while solving a reversible reaction problem as the subject said, "It is still an endothermic reaction as it still absorbing heat." It seemed that the subject could not conceptualize the fact that the system is both endothermic and exothermic at the same time. Also, the subject always thinks about the reaction in its forward direction. This was reflected in the performance quiz data as it indicated that the subject correctly solved one out of three questions regarding manipulating the system's temperature with a large mental effort.

Regarding the pressure effects on a system at the equilibrium, data from the *subject interview* showed that the subject could not explain how pressure might affect the system, with applying Le Chatelier's principle. Using the *interview video* the subject was asked to predict how the system would react as the pressure was being applied on the system. The subject was asked, "Which part of the equation we are increasing the pressure on?" When told it is a system, and the system has both sides of the equation in it, the subject answered, "I do not know. The system will shift to the right maybe." When asked why that would happen, they answered, "I do not really know. I just guessed." Here, it is also possible that the collision theory principles dominated the subject's conceptual framework for answering the question. Data from the *subject Cmap* also showed that the subject missed the concept pressure or volume as a factor that could affect the reaction rate. Moreover, data from the subject's performance quiz shows that the subject solved two questions out of four correctly regarding manipulating the system pressure with a moderate mental effort.

Table 14. Subject 4 Answers to The Narrow Research Question regarding Le Chatelier's Principle.

Question	Claim	Reasoning
What would happen to the system as we increase one of the products concentration?	"When we add water to the system, the system will be less concentrated."	"Because the system was not balanced… when we add more water, the concentration of the product side will increase and the concentration of the reactant side would decrease because we added more water."
What would happen to the system as we increase the temperature?	I do not know.	"I think the reaction is endothermic because the heat was absorbed in the reaction to produce products."
What would happen to the system as we increase the temperature?		"It is still endothermic reaction as it still absorbing heat."
What would happen to the system as we increase pressure?	"I do not know. The system will shift to the right maybe."	"I do not really know. I just guessed."

Subject 4 Summary

The subject scored six points out of 14 in the *performance quiz* with an averaged large *mental effort*. The *subject Cmap* was given the score of 29. The *subject Cmap* was clear and constructed in a hierarchal fashion with Le Chatelier's principle as a root concept. However, some of the main concepts were provided in the liking words such as, equilibrium and reaction rate. The interview data revealed that the subject had some misunderstanding of Le Chatelier's principle as the subject might tend to apply the completion reaction principles while solving reversible reaction problems that require applying Le Chatelier's principle. This could have affected the subject *performance quiz* score and the concepts provided in the *Cmap*.

Subject 5

Data from the *performance quiz* indicated that the subject gained nine points out of 14. The points were gathered as the subject answered the following category questions correctly: two points in the reaction rate, two points to adding a catalyst to the system, one point in changing the system's temperature, two points to changing the system's pressure and two points in changing the system' concentration. Averaged subjective *mental effort* scale results indicated that the subject had a moderate *mental effort* while solving the *performance quiz*.

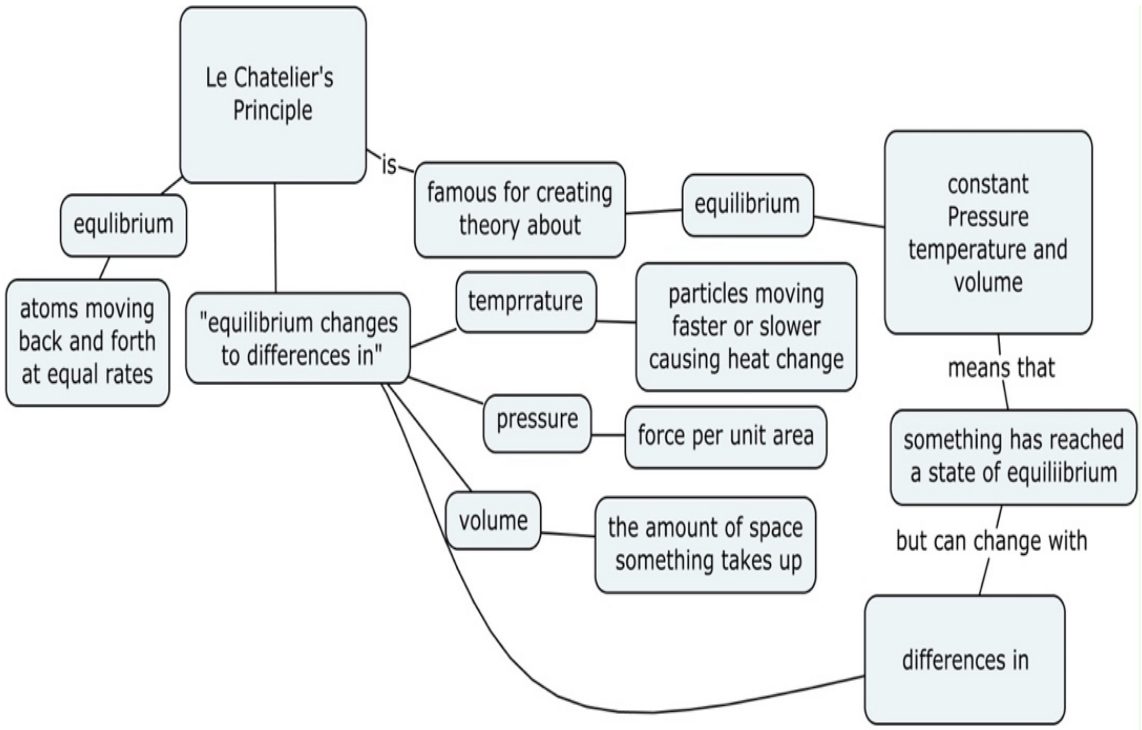

Figure 12. Subject #5 Concept Map.

The *qualitative analysis* regarding the constriction of the *subject Cmap* indicates that the map was formed in hierarchical fashion with Le Chatelier's principle being a root concept and more general concepts were followed by more specific concepts. Although some were provided, the *Cmap* lacked some linking phrases that describe the relationship among concepts. Also, some of the concepts' nodes contained both the concept and the linking words together.

The *qualitative analysis* of the *subject Cmap* regarding how Le Chatelier's principle works indicated that the *Cmap* contained all the essential concepts related to chemical equilibrium (Figure 12). Having the linking words inside the concepts' nodes made it difficult to look at how the propositions are being formed, based on concept map learning. The *Cmap* contained clear definitions of chemical equilibrium, temperature, pressure and volume. The map lacked the concept concentration as one of the major factors that could affect a system at the equilibrium state. Based on the quantitative analysis, the *Cmap* was given 40 points (Table 15).

Table 14. Subject # 5 Concept Map Scoring Result.

Criterion	Propositions x1	Hierarchical Levels x5	Integrative cross-links x10
Score	10 x 1	4 x 5	1 x 10
			Total Score
			40

Data from the *subject interview* showed that the subject was familiar with the notion of concept mapping. Previous experience with similar version concept mapping might have made it easier for the subject to adapt as well as use the tool as the subjects said, “It has been really good. It got easier as I have gone with different things. Some time you end up with a way simple map and sometimes you end up with weird endings… it is not my first time doing concept mapping. Last year I did something similar with my physical science class.” The subject also mentioned that placing the linking phrases was a challenging task while building the *Cmap*, and said, “It was a little hard to put linking words sometimes.”

Through the *subject interview* it seemed that the subject had a general understanding of Le Chatelier’s principle. The subject used the generated *Cmap* to show how Le Chatelier’s principle functions. When asked to explain what chemical equilibrium is, the subject responded, “It is atoms moving back and forth in a system at equal rates in a constant pressure, temperature and volume. And it can be affected by concentration and temperature and volume." When asked, using the *interview video*, how changing concentration would affect a reaction at the equilibrium, the subject answered correctly, to the left, and when asked for a justification the subject said, "I think it would not be at the equilibrium any more as the concentration changes by adding water. The equilibrium will shift to the left because changing the concentration of one side will affect the system's state of the equilibrium. And the concentrations will change." Similarly, the subject correctly answered the questions regarding the effects of manipulating the system's concentration in the *performance quiz* with a moderate mental effort, even though the *subject Cmap* lacked the concept of concentration in it. The subject's reasoning was based on Le Chatelier's principle framework.

Regarding the effect of temperature on the system at the equilibrium state, the *subject interview* data revealed that the subject conceptually understands the difference between endothermic and exothermic reactions as said, "It is endothermic when the reaction keeps the heat energy inside and exothermic is when the heat goes out." When asked, using the *interview video,* to predict what would happen when the temperature of a system at the equilibrium state increases, the subject answered correctly. Although they answered the question correctly, the subject was hesitating about the right answer. The subject knew about the difference between exothermic and endothermic reactions. But applying the knowledge to the scenario provided took the subject some time. This could possibly explain why the subject scored low on the questions that focused on the effect of temperature on a system at the equilibrium state in the *performance quiz,* as determining whether the reaction is endothermic or exothermic is a key concept for solving the problem.

Finally, when asked about the experience with the *performance quiz* (pre-test) and *mental effort* rating activity, the subject said, “In the first exam, I did not know anything. I did not understand what the words were saying. I was just guessing the right answer. So, I did not have much mental effort because I did not understand it. Because I did not know how to think about it. The questions were hard to think about.” However, in the second *performance quiz* (post-test) the subject could scale the mental effort while solving each question and said, “In the second exam, I understood the topic so I could try to figure out the right answer. And it was easier to guess my mental effort.”

Table 15. Subject 5 Answers to The Narrow Research Question regarding Le Chatelier’s Principle.

Question	Claim	Reasoning
What would happen to the system as we increase one of the products concentration?	“To the left.”	“I think it would not be at the equilibrium any more as the concentration changes by adding water. The equilibrium will shift to the left because changing the concentration of one side will affect the system’s state of the equilibrium. And the concentrations will change.”
What would happen to the system as we increase the temperature?	“To the right”	“It is endothermic when the reaction keeps the heat energy inside and exothermic is when the heat goes out.”

Subject 5 Summary

The subject scored nine points out of 14 in the performance quiz with an averaged moderate mental effort. The *subject Cmap* was given the score of 40. The *Cmap* was clear and constructed in a hierarchal fashion with Le Chatelier's principle as a root concept. It included most of the essential concepts. Having the linking words inside the concepts' nodes made it hard to explicitly see how the propositions are formed. Although the subject missed points regarding the effect of manipulating the temperature of a system at the equilibrium in the performance quiz, the interview data revealed that the subject used Le Chatelier's principle as reasoning framework and had a clear understanding of the concepts. Based on the subject interview, mental effort is easier to be subjectively scaled after the subject understands the concepts provided in the questions. Therefore, providing the mental effort scale in the first performance quiz (pre-test) was challenging for the subject to deal with.

Summary of the Subjects' Interviews

The *subject Cmap* projects were descriptive of their understanding of Le Chatelier's principle. Mostly, the *Cmaps* were constructed in a hierarchal fashion with Le Chatelier's principle being the root concept. Propositions in *subject Cmap* projects varied in their clarity. Some propositions were clear as they described the relation between concepts such as subjects 2, 3 and 5's *Cmap* projects, whereas other propositions were not clear and did not provide a clear description, such as the *Cmap* projects of subject 1 and 4. Some important and fundamental concepts regarding Le Chatelier's principle understanding were missing in all *subject Cmaps* such as reaction rate and equilibrium constant. Whereas some projects lacked the concept concentration such as in the projects of subjects 1, 2 and 5. Misconceptions were present in some of the *Cmap* projects such as time being a factor in changing the equilibrium state as in the *Cmap* of subject 2, as well as reaction rate is affected only by concentration of reactant and temperature in the *Cmap* of Subject 3. These two ideas are considered common misconceptions in chemical equilibrium learning literature (Banerjee, 1991; Garnett et al., 1995; Hackling & Garnett, 1985).

Regarding the general question of Le Chatelier's principle, subjects' responses to the question of what Le Chatelier's principle is about were consistent; however, indicating the factors that affect the principle was answered differently by the subjects. Except for subjects 3 and 5, the rest did not explicitly state that temperature, concentration and pressure/volume are the main stressors. For those who did not mention all three stressors, temperature and pressure/volume dominated their answers.

Subjects' answers regarding the narrow questions that focused on the three stressors, namely concentration, temperature and pressure/volume, varied based on the conceptual framework they applied to explain the tasks provided in the interview video. Questions regarding the task of changing the system equilibrium by increasing concentration of one species of the product side were mostly answered correctly through reasoning that was based on Le Chatelier's principle framework by the subjects. Except for subject 4, who tended to apply the collision theory principles framework to explain the task's outcome which also is a common misconception in chemical equilibrium learning (Banerjee, 1991; Gorodetsky & Gussarsky, 1986).

Questions regarding increasing and decreasing the system's temperature were answered differently by subjects. Only subjects 3, 4 and 5 clearly stated that the reaction was endothermic when heat was applied to the system. Although they provided the right answer, it took them a relatively long time to decide whether the reaction was endothermic or exothermic. Also, except for subject 3, it seemed that subjects had some difficulty understanding the fact that the system is endothermic in the forward direction and exothermic in the reverse direction. A notion that is common in collision theory principles is that the direction of the reaction is only forward, so heat as a factor is only thought of in one direction, either endothermic or exothermic (Garnett et al., 1995; Hackling & Garnett, 1985). Differentiating between endothermic and exothermic reactions seemed to be the most challenging concept for the subjects and was reflected in their transfer performance quiz scores as none of the subjects answered the questions correctly.

Questions regarding increasing and decreasing the system's pressure had varied answers. All subjects had some difficulty deciding which side the reaction would shift to as a result of increasing pressure on the system. For all interviews, the researcher asked the subjects to consider the moles number of each side of the system. Subjects then provided answers to the question. Although they were provided with a hint for the answer, subject 2 provided a wrong answer that showed a fallacy in applying the principle, whereas subject 4 could not provide an answer to the question.

The subjects' responses regarding the broad questions that center on their experience with the *performance quiz* (pre-test and post-test) were consistent. Regarding the pre-test, subjects 1, 2, 3 and 5 indicated that the quiz was very hard to think about. The common rationale among the subjects was that they did not have anything to draw upon for the topic, therefore answering the questions was challenging for them. Their responses concerning the post-test were also consistent. All subjects perceived that the post-test was challenging but easier than the pre-test. Their justification showed that as they had learned about the subject matter, the questions seemed relatively easier to think about as the concepts provided in the quiz made sense to them comparing to the pre-test, although the questions were hard to think about in general.

Students' responses regarding subjectively scaling their mental effort in the pre-test and post-test were also consistent. With respect to the pre-test, subjects' responses showed that scaling their mental effort was relatively unachievable. Subjects' justification was that they could not solve the problems in the pre-test, because they had no mental effort to scale as they were not equipped with concepts that would support them to think about the answers. Regarding scaling their mental effort in the post-test, subjects' responses were also consistent as they mentioned that their mental effort was easier to be subjectively scaled since they had a relative understanding of the meaning that the concepts provided in the questions.

Mixed Method Results

Fourth Research Question

How does the qualitative data analysis explain the relationship between the subjects' perceived mental effort scores and subjects' generated concept maps scores on chemical equilibrium?

A Pearson correlation test was conducted to investigate the relationship between the two numerical variables (Table 4). Based on Pearson's correlation results, there was a strong negative relationship between subjects' mental effort scores and subjects' concept mapping scores with a correlation coefficient of (-0.78). Therefore, we accept the hypothesis that the more complex the concept map generated by the subjects, the less mental effort they would invest to solve chemical equilibrium problems.

To explain the quantitative analysis result of the first research question, the qualitative data analysis was used. The qualitative analysis of *subject Cmap* projects as well as the subjects' responses in the interview will be the focus of the explanation process. The qualitative analysis of *subject Cmap* projects showed that subjects whose *Cmap* was more complex, contained more accurate descriptive propositions, had a hierarchical fashion of knowledge representation that was generated under the question of "how does Le Chatelier's principle work?" They invested less mental effort while solving the performance quiz, regardless of their performance scores. For example, subjects 2, 3 and 5 had high scores on their *Cmap* projects and reported less mental effort on the mental effort scale as compared with subjects 1 and 4.

Moreover, data from the *subject interviews* showed that subjects' answers varied in their reasoning framework. Some subjects leaned more towards the framework of the Le Chatelier's principle while others used the collision theory principles in their explanations for the narrow questions. Subjects who could explain the tasks' outcomes used in the narrow questions relying more on Le Chatelier's principle as a conceptual framework for their reasoning scored higher in their *Cmap* projects and lower on the mental effort scale while solving the *performance quiz*. This could indicate that subjects who had relatively more conceptual understanding of Le Chatelier's principle tend to reflect that the *performance quiz* was less mentally challenging for subjects 2, 3 and 5 regardless of their scores on the *performance quiz*. Also, subjects who had more conceptual understanding of Le Chatelier's principle could generate more complex *Cmaps* that represent their conceptual understanding of the topic. However, subjects who were leaning more towards the collision theory as a framework for their reasoning were less likely to express their understanding during the interview and their *Cmap* projects were not as developed and complex as those who used Le Chatelier's principle as a reasoning framework. Therefore, *subject Cmap* projects and subjects' reasoning framework generated from the narrow questions might explain the reason behind the strong negative correlation between concept mapping scores and mental effort scores showed in the quantitative results of this study.

Fifth Research Question

How does the qualitative data analysis explain the relationship between subjects' concept mapping scores and subjects' score on the performance quiz?

A Pearson correlation test was conducted to investigate the relationship between the two numerical variables (Table 6). Based on Pearson's correlation results, there was a strong negative relationship between subjects' concept mapping scores and subjects' performance scores with a correlation coefficient of (- 0.64). Therefore, we reject the hypothesis that there is a positive relationship between *subject Cmap* scores and subjects' *performance quiz* scores, as a strong negative correlation (-0.64) was found.

The qualitative analysis for describing the quantitative results of the fifth research question will be centered on the nature of the two variables: students' concept maps and performance quiz. With respect to the *student Cmap* projects, they were generated under the question of "how does Le Chatelier's principle work" and students were encouraged to represent their knowledge by constructing a hierarchical concept map. The hierarchical fashion of concept mapping is widely accepted in the concept mapping literature to be a valuable tool to describe, define and graphically organize and share knowledge in science education (Novak & Gowin, 1984; Novak & Tyler, 1977). The students' constructed *Cmaps* were then analyzed and scored based on scoring criteria suggested by Novak and Gowin (1984).

However, in the *performance quiz,* the questions were designed in a manner that tests the subjects' deep understanding of Le Chatelier's principle as well as the rationale which is related to the cognitive load theory point of view. Each question of the quiz was designed in a manner that represents a closed system, and only one variable (concept) was being manipulated. Based on the manipulated concept, the students were questioned to predict what would happen to the interrelated concepts or variables. For example, in question seven, both temperature and pressure were being kept constant and only concentration was being decreased. The student was then asked what would happen to the other interrelated variables which was the mass of one of the reactants, the equilibrium constant and the rate in which one of the reactants is being formed. To answer the question the student would think about the concepts in their dynamic state based on tension that had happened to the system due to concentration reduction. The student then was given a point for each correct predicted result in question seven and the rest of the questions were constructed in the same manner.

Consequently, the Pearson analysis between *student Cmap* scores and *performance quiz* scores showed no positive relationship. The first variable, *student Cmap* scores were generated based on students' static knowledge of Le Chatelier's principle, students' definitions and conceptual description in a hierarchical fashion. The proposition among concepts only described the static relations among concepts. The functional relationship among concepts was absent in the *student Cmap* projects and present in the *performance quiz*. How changing in one concept would affect the other interrelated concepts in each system was not shown in the *student Cmap* projects. Whereas, the questions in the *performance quiz* were focused on these interrelation dynamic changes that would result from altering one concept in a system. Therefore, to have a positive relationship between *student Cmap* scores and students' *performance quiz* scores in this study, the concept maps should have the same nature of the *performance quiz*, dynamic and functional. Therefore, we reject the hypothesis that student static concept map scores will positively correlate with students' scores on the *performance* *quiz*. Alternately, we hypothesize that students' dynamic concept map scores would have a potential to positively correlate with students' scores on the *performance quiz*.

CHAPTER FIVE

CONCLUSION

Chemical equilibrium is a complex subject matter in the chemistry domain of knowledge. The complexity associated with learning chemical equilibrium, Le Chatelier's principle, could be understood from the cognitive point of view, the cognitive load theory (CLT), and by Novak and Tyler (1977) theory of education frameworks. In educational settings, cognitive load theory measures mental load objectively and subjectively through problem solving and mental effort. These two instruments were used in this study; however, we included concept mapping as a mean of instrumentation to better understand the complexity phenomena of learning about Le Chatelier's principle. Concept mapping helps in externalizing students' understanding in any subject matter and is widely used in science classrooms. Students' interviews were also utilized as qualitative data to better explain the quantitative part of the study through better understanding of students reasoning framework while solving problems regarding Le Chatelier's principle. We hypothesized that there would be a negative correlation between students' *mental effort* scores and students' *concept map* scores as well as a positive correlation between students' *performance quiz* scores and *concept map* scores.

To achieve that, we used a mixed method explanatory sequential multiple case study design to understand the cognitive load phenomena subjects experience while learning about Le Chatelier's principle in a high school chemistry classroom. This is an epistemological constructive study that seeks subjective responses from the participants regarding their experience in the study (Creswell, 2013). The explanatory sequential design is one of the mixed method research designs that helps in utilizing qualitative data to explain quantitative findings (Creswell, 2015).

The study took four weeks and was conducted in a chemistry classroom where the flipped classroom model, 5E teaching and learning design, was utilized as a teaching strategy. Data for the study was gathered at the end of the learning cycle then analyzed by the researcher.

The descriptive results showed that out of 14 points the mean number on the performance quiz was 7 (SD= 1.79). This could be because the performance quiz questions were intentionally designed in a manner that tests students' deep understanding of the subject matter. The questions required a deep understanding of the concepts in their dynamic nature, that is, a chain of interrelated relationships among the concepts. Although there are three main stressors in Le Chatelier's principle, the reasoning of the functional properties of each concept is unique (Hackling & Garnett, 1985). The effect of those stressors on the reaction rate, equilibrium constant and concentrations after reestablishing the equilibrium is the core concept for deep understanding (Banerjee, 1991; Hackling & Garnett, 1985).

The results showed that students who isolated the essential concepts and constructed *concept maps* that contained differentiated and descriptive concepts in a hierarchal manner invested less *mental effort* while solving the transfer *performance quiz* based on the Pearson correlation test. Also, the qualitative analysis showed that students who were leaning toward Le Chatelier's principle framework reasoning had more complex *concept maps* and invested less *mental effort* while solving the transfer *performance quiz*.

In addition, a qualitative analysis of the students' concept maps and students' performance test showed that students who constructed more holistic and complex *concept maps* such as subjects 3 and 5 scored higher on the transfer *performance quiz* than their counterparts who had less-developed *concept maps*. However, the quantitative analysis performed to investigate the relationship between students' *concept map* scores and students' transfer *performance quiz* scores showed no positive significant relationship between the variables. This could be due to the fact that the sample was too small for the analysis, that is, any outliers could have a significant effect on the statistical analysis applied. For example, subject 2 had the highest *concept map* score even though the *concept map* was focused only on the pressure aspect of Le Chatelier's principle. Whereas, subjects 3 and 5 had more holistic *concept maps* that contained most of the essential concepts and scored lower than subject 2. Conducting a Pearson correlation test after eliminating subject 2's data points showed a high positive correlation between concept mapping and transfer test scores (0.60). Therefore, in this analysis the factor "holistic map" in a concept mapping scoring is important when it comes to correlation with performance.

Value of the Study

Curriculum

Science curriculums is well-constructed valid knowledge claims of previous scientific inquiry (Gowin, 1981; Gowin & Alvarez, 2005; Novak & Gowin, 1984). The primary objective for this scientific inquiry was to understand a world phenomenon and not to teach a phenomenon. Those understandings are determined by the knowledge ceiling that is constantly increasing. Converting the knowledge claims of previous scientific inquiry to an educational pedagogical curriculum is not an easy task for science curriculum builders. The main objective of a science curriculum builder is to select, organize and share what is culturally worth knowing in a specific domain of knowledge (Gowin, 1981; Gowin & Alvarez, 2005). Therefore, what is worth knowing is governed by pedagogical curriculum builders.

Science classroom curriculum (books, educative videos, educational articles, etc.) are examples of pedagogical curriculum builders' works that are intently and logically constructed for sharing valid meaning with teachers and learners in all levels. Most of them contain specific concepts, propositions, activities and examples, needed educative materials and criteria of excellence essential for meaningful learning to occur.

Managing the valid meaning of the curriculum (subject matter content) to fit with the learner's previous knowledge, curriculum builders should consider the limitation of the learner's working memory and learner's cognitive structure (long-term memory). That is, the curriculum should be constructed and arranged in advance before actual teaching and learning take place. Concepts (topics) in a curriculum should be chosen carefully to enrich the learner as they proceed in learning using such a curriculum.

A successful use of mastery leaning or flipped classroom learning depends on initial consideration of the curriculum. This kind of teaching and learning environment requires a systematic curriculum development, active learners and facilitator-teachers. Systematic curriculum requires a deliberate consideration of each part in the curriculum. Each step in the curriculum requires specific valid conceptual and procedural skills to be mastered at the end of the learning loop. Meaningful understanding of the previous loops is crucial for the leaner to proceed in such a systematic environment and can be considered as a pre-training for the following loops. This requires the learner to be actively engaged and responsible for their learning, a principle that is not fully supported by passive learners as well as students less familiar with the classroom organization. These kinds of classrooms are designed to hold both novice and expert students as leaners and are not required to be at the same level at the same time. Students can proceed in a well-designed curriculum as they express learning mastery.

Teachers' awareness of the whole systematic curriculum and mastery of all subject matter contents that includes concepts, facts, value and criteria of excellence, enables them to guide students leaning through utilizing just-in-time teaching and providing help for students who need support with their learning. Therefore, chunking, ordering, and organizing the curriculum can be conceptualized as governing the meaning of each step in the systematic curriculum. This in turn governs the effort to grasp the meaning which should enrich the learner's knowledge structure (long-term memory) that is governed by a limited working memory capacity.

Teaching

Considering teaching as the sharing of meaning (Gowin, 1981; Gowin & Alvarez, 2005), the value derived from the results focus around the notion of element interactivity. A complex subject matter content, that has a high level of element interactivity, requires a careful estimation by the teacher because reaching the overall meaning requires high cognitive demands that have to be achieved within the leaner's working memory limitation. Considering the working memory limitation, this could be attained by optimizing (governing) the intrinsic cognitive load through utilizing methods of chunking and scaffolding information through guided inquiry. Since the meaning is the most important aspect of any educational event, deliberate governing segmenting of the content (curriculum) should not be compensated for the overall meaning. Each chunk of information should have its own meaning, a holistic temporary meaning. Whereas the holistic overall meaning should be constructed by merging and combining the temporary meanings. This could happen with the learner's awareness of the learning process and the use of advanced organizers and concept mapping could help to that end. A deliberate and clear advanced organizer created by the teacher of the curriculum could reduce the time and effort of the teacher to teach and leaners to grasp the intended meaning intrinsic to the curriculum.

For instance, in teaching about the chemical equilibrium, teaching three stressors together in one learning event could generate a cognitive load that could hinder the meaning of each concept. Each stressor (concentration, temperature or pressure) could be taught solely in one learning event as a chain of reactions with emphasizing the effects it generates to each interrelated concept (reaction rate, equilibrium constant and concentrations after equilibrium is reestablished). As Le Chatelier's principle is internationally considered hard to grasp, the teaching governance over the shared meaning, regardless of the means in which the concept is being faced, is crucial for a deeper learning of the concept (Gowin, 1981; Gowin & Alvarez, 2005).

Learning

Learning is the grasp of meaning of the curriculum that is facilitated by teaching (Gowin, 1981; Gowin & Alvarez, 2005; Novak & Gowin, 1984). A teacher can facilitate and guide learning in meaningful ways but cannot cause learning. Leaners cause learning by actively participating in grasping the curriculum meaning. Complex subject matter learning requires identifying and isolating the essential concepts and demands, deliberate deep considering of the inner connections of meaning in order for meaningful understanding. From the cognitive load perspective, the inner connections among concepts, intrinsic cognitive load, are considered complex by the level of the concepts' interactivity; therefore, deliberately looking for connections among concepts is germane for meaningful learning. More proficient leaners have a more elaborated schema of a subject matter content; therefore, they experience lower intrinsic cognitive load than their counterparts who have less-developed schema. Students who are able to extract the inner meaning can govern their learning. Concept mapping could be utilized as tool for looking at the inner connections among concepts as well as helping students to learn.

Discussion

Cognitive Load and Cognitive theory of multimedia learning are two instructional theories that suggest several teaching principles that provide better learning outcomes for learners based on empirical outcomes (Mayer, 2014; Sweller et al., 2011). The theories provided three main principles with regards to high complex subject matter teaching: segmenting, pre-training and modality principles. Research studies in light of the two theories are being done mostly by comparing a principle with the absence of the principle. Measuring the learner's outcome is centered on complex problem solving and subjective rating of mental effort. The supporting results of the theories shows a significant statistical difference of students' performance scores between two groups as well as mental effort between the same two groups utilizing one of the principles with its absence. The research conducted in the framework of these theories lacks the explanation of the relationship between *performance* and *mental effort*. We think other learning indicators should be utilized at least on the teachers' part. In this study, we used *concept mapping* and students' reasoning as two main indicators of students' cognitive load while learning in a chemistry classroom.

We found a strong negative relationship between students' *metal effort* while solving the post-test scores and students' scores on *concept mapping*. The qualitative data explained that *subject Cmap* projects and their reasoning framework generated from the interview's narrow questions could be a reason behind the strong negative correlation between *concept maps* scores and *mental effort* scores showed in the quantitative results of this study. Relating *mental effort* to students' reasoning framework is not mentioned in cognitive load literature as a technique to measure students' mental effort. However, there is a growing part of research that aims to investigate behavioral aspects of the relationships between speech features and cognitive load (Khawaja, Chen, & Marcus, 2013). In the context of science education, we utilized students reasoning suggested by Mintzes et al. (2005) and Novak and Gowin (1984) as a possible indictor of students' *mental effort* as they learn about Le Chatelier's principle. We found that through students' reasoning framework, subjects who had more conceptual understanding of Le Chatelier's principle could generate more complex *Cmaps* that represent their conceptual understanding of the topic. However, subjects who were leaning more towards the collision theory as a framework for their reasoning were less likely to express their understanding during the interview and their *Cmap* projects were not as developed and complex as those who used Le Chatelier's principle as a reasoning framework.

A previous study was conducted in the context of teaching Le Chatelier's principle. With regards to problem solving and mental effort relationship, an empirical research study was conducted by Musallam (2010) to investigate the effect of the pre-training principle. Results showed that the treatment group experienced significantly less *mental effort* and scored on average significantly higher than the control group. However, the correlational analysis between *mental effort* and *performance* showed no relationships within or between groups. We think dynamic *concept mapping* as a means to measure students' understanding could fit to better understand this gap with more graphical results.

Reflection

Concept mapping was utilized in this study to be better understand student cognitive load while learning a complex subject matter content: Le Chatelier's principle. Our research understanding of concept mapping as a knowledge representation tool was consistent with Novak and Gowin (1984) description of concept mapping: hierarchical static concept mapping. However, an emerging type of concept mapping, cyclic dynamic concept mapping, that has been suggested by Safayeni, Derbentseva, and Cañas (2005) might provide deeper understanding of students cognitive load and transfer problem solving while learning a complex topic.

Both static and dynamic concept mapping are unique in their knowledge representation. Static concept map normally answers a focus question that concerns with what something is. To answer such a question, static concept mapping is normally used for representing one's knowledge in a hierarchical fashion, in which more general concepts are represented upper in the map and progressively differentiated into less general more specific concepts. That is, static concept mapping contains independent propositions that show relative position of two concepts that represent a static thinking of the concepts in the map (Safayeni et al., 2005).

On the other hand, dynamic concept maps generally tend to respond to a process-oriented question that requires representing the interdependence among concepts due to change of a quantified concept in systematic fashion. Answering a dynamic question requires dynamic thinking that could be externalized using a dynamic relationships representation tool. This require utilizing interdependent propositions that are capable of displaying functional interdependency among concepts, covariation. Unlike static concept maps, dynamic concept maps tend to have a cyclic fashion for showing how a change in one concept would attribute to changes in other correlated concepts in systemic fashion(Safayeni, Derbentseva, & Cañas, 2007). Therefore, both static and dynamic maps are knowledge representation tools, but each represent different types of knowledge: hierarchical static or cyclic dynamic.

In our study, we accommodated and utilized the hierarchical static concept mapping technique as a knowledge representation tool. This required us to pre-train our students about the static concept mapping and how to use them for sharing knowledge. All the quantitative results obtained in this study were based on the hierarchical static nature of the students' concept maps projects. Our results showed that there is a strong negative correlation between students' hierarchical static maps scores and students' mental effort invested to solve the transfer performance problems; no significant correlations between students' performance quiz scores and students' mental effort scores invested while solving the transfer quiz were detected. Also, no significant correlation between students' concept map scores and students' performance quiz scores was found. However, reflecting back to the nature of the transfer problem solving quiz, we believe that the cyclic dynamic concept mapping would better explain the students' performance scores than the obtained hierarchical static maps.

This classification of concept mapping is considered novel in the concept mapping literature. Safayeni et al. (2005) indicated that "The difference between static and dynamic relationships has not been recognized in the CMap literature, which has led to the false assumption that Cmaps are capable of representing all forms of knowledge." Regarding the hierarchical ordering of the concepts in the static Cmaps, Safayeni et al. (2007) critiqued the representation limitation of the CMap and added that "Although they are robust in representing static relationships between concepts, Cmaps are seldom used for representing dynamic relationships among concepts. This deficiency may be attributed to the hierarchical nature of CMaps." Figure 13 below shows how our thinking has changed due to the explicit distinction between the two types of concept maps and their potential use to understand cognitive load. Concepts that are connected with a solid line represent our results from this study whereas, concepts that are linked with cut lines represent our future hypotheses that need to be tested.

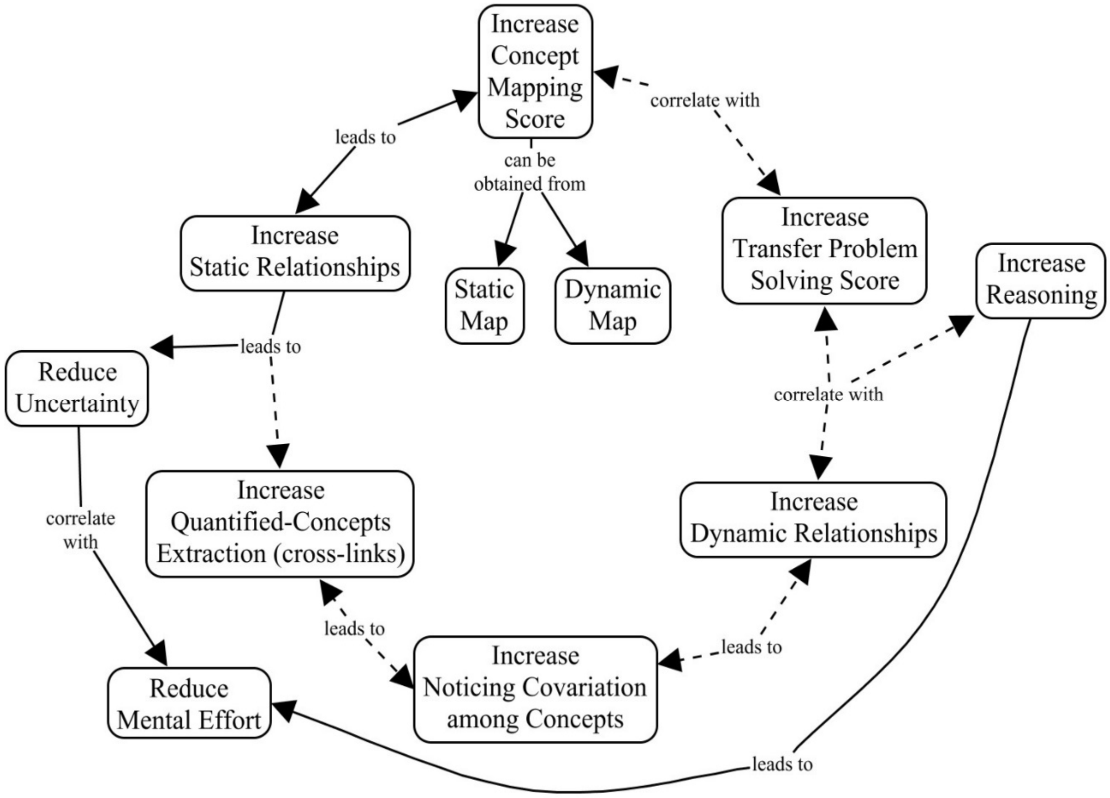

Figure 13. How concept mapping would help us predict students' mental effort and transfer problem solving?

The mapping requires the user to connect a concept with the interrelated concepts in a chain or functional fashion based on cause and effect and/or increase and decease manner (Safayeni et al., 2005, 2007). Considering utilizing this tool as students' knowledge representation of Le Chatelier's principle could open a novel avenue of measuring *mental effort*, *performance*, reasoning and decision making simultaneously. We think utilizing dynamic concept maps will bring measuring mental effort and performance to a more applicable and realistic manner.

Complex Problem solving (transfer) is an indirect measure of cognitive load (mental effort). Both a long time on task and a lack of accuracy are considered indications of high mental effort used in the working memory. They reflect a problem-solving search that the learner's working memory experiences while solving a problem or a task at hand (Ayres, 2006; Leppink & van den Heuvel, 2015; Sweller et al., 2011). This also could be attributed to less-developed schema the learner possesses in order to overcome a problem at hand. A learner with a more-developed schema could solve problems faster with high accuracy; whereas, a learner with a less-developed schema would take a longer time to solve a problem or with higher error rates compared to expert learners. Therefore, to better visualize this process, a dynamic *concept map* can be utilized as a technique to assess a learner's inner selection of concepts, ordering the concept, as well as the learner's decisions taken to reach a desired outcome. Systematic problem solving requires a very precise decision for a precise outcome in a chain-like structure that can be depicted in a dynamic map.

Evaluating a principle of cognitive load theory (Sweller et al., 2011) or cognitive load of multimedia learning (e.g. pre-training) in a complex systematic subject matter, Novak's theory of learning could be utilized to provide more realistic results (Cañas & Novak, 2006). Dynamic concept mapping could be used as an instrument. The number of concepts considered in the map creation could refer to the student's mental effort, while the propositions' validity could refer to student's performance that depends on their reasoning and decision making in explaining how a system operates based on tension that occurs. This could provide the teacher or researcher with overall performance as well as the mental effort sources.

In this exploratory study, we investigated the idea that concept mapping could be a useful technique in assessing student cognitive load and mental effort in complex problem solving. Based on results, we believe that concept mapping may be a useful way to assess student mental effort and complex problem solving. In the five cases of this study, we believe that static concept mapping was a valid way to understand cognitive load of the five students who participated in this study as it relates to their *mental effort* and understanding of equilibrium problem solving.

In the future, we expect to explore the idea that the relationship between *concept maps* and *mental effort* may be content specific. In this case, a better equilibrium map may be related to lower effort on equilibrium problems. The alternative is that the ability to create better concept maps (following extensive training) on any subject is in general related to lower mental effort in problem solving across knowledge domains.

It is clear that this model needs to be tested in a larger sample. We expect to continue the study of concept mapping and cognitive load in the future. We welcome partnerships in diverse settings where the relationships of mental effort, student knowledge, concept mapping and cognitive load can be further explored.

Limitation of the Study

The study was focused on understanding the cognitive load phenomena students experience while learning a complex subject matter, Le Chatelier's principle, in a high school chemistry classroom. Although the *performance quiz* and *mental effort* scale was previously used in different empirical research, the concept mapping scoring system and the interview was designed by the researcher to better understand the phenomena. The concept mapping scoring system was adopted from guidelines provided by Novak and Gowin (1984) and the clinical interview questions were generated through guidelines adopted from Mintzes et al. (2005) and Novak and Gowin (1984). Also, no pilot study was conducted to test the interview questions as well as the interview video. The sample size was small for conducting an empirical study or to generalize the results; however, the qualitative data provided a clear descriptive understanding of the phenomena.

REFERENCES CITED

Abeysekera, L., & Dawson, P. (2015). Motivation and cognitive load in the flipped classroom: definition, rationale and a call for research. *Higher Education Research & Development, 34*(1), 1-14. doi:10.1080/07294360.2014.934336

Andrew, S. T., & Mayer, R. E. (2007). Learning by Doing Versus Learning by Viewing: Three Experimental Comparisons of Learner-Generated Versus Author-Provided Graphic Organizers. *Journal of Educational Psychology, 99*(4), 808-820. doi:10.1037/0022-0663.99.4.808

Ausubel, D. P. (1977). The facilitation of meaningful verbal learning in the classroom. *Educational Psychologist, 12*(2), 162-178. doi:10.1080/00461527709529171

Ayres, P. (2006). Using Subjective Measures to Detect Variations of Intrinsic Cognitive Load within Problems. *16*(5), 389–400. doi:10.1016/j.learninstruc.2006.09.001

Banerjee, A. C. (1991). Misconceptions of students and teachers in chemical equilibrium. *International Journal of Science Education, 13*(4), 487-494. doi:http://dx.doi.org/10.1080/0950069910130411

Bergmann, J., & Sams, A. (2014). *Flipped Learning: Gateway to Student Engagement*. International Society for Technology in Education.

Bergmann, J., & Sams, A. (2015). *Flipped Learning for Science Instruction (The Flipped Learning Series)*. International Society for Technology in Education.

Bishop, J., & Verleger, M. (2013). *The Flipped Classroom- A Survey of the Research*. Paper presented at the 120th ASEE Annual Conference & Exposition.

Cañas, A. J., & Novak, J. D. (2006). *Re-examining the Foundations for Effective Use of Concept Maps*. Paper presented at the The Second International Conference on Concept Mapping, San José, Costa Rica.

Cañas, A. J., & Novak, J. D. (2009). What is a Concept Map?   Retrieved from https://cmap.ihmc.us/docs/conceptmap.php

Clark, R. C., Nguyen, F., & Sweller, J. (2005). *Efficiency in Learning: Evidence-Based Guidelines to Manage Cognitive Load*. Pfeiffer.

Cook, A. E., Zheng, R. Z., & Blaz, J. W. (2009). *Measurement of Cognitive Load During Multimedia Learning Activities*: Cognitive effects of multimedia learning.

Creswell, J. W. (2013). *Qulaitative Inquiry and Research Design: Chosing Among Five Approaches*. SAGE.

Creswell, J. W. (2015). *A Concise Introduction to Mixed Methods Research*. SAGE Publications.

DeLozier, S. J., & Rhodes, M. G. (2017). Flipped Classrooms: a Review of Key Ideas and Recommendations for Practice. *Springer, 29*(1), 141-151. doi:10.1007/s10648-015-9356-9

Gabel, D. (1999). Improving Teaching and Learning through Chemistry Education Research: A Look to the Future. *Chemical Education*. doi:10.1021/ed076p548

Garnett, P. J., Garnett, P. J., & Hackling, M. W. (1995). Students' Alternative Conceptions in Chemistry: A Review of Research and Implications for Teaching and Learning. *Studies in Science Education, 25*(1), 69-95. doi:http://dx.doi.org/10.1080/03057269508560050

Gorodetsky, M., & Gussarsky, E. (1986). Misconceptualization of the chemical equilibrium concept as revealed by different evaluation methods. *European Journal of Science Education, 8*(4), 427-441. doi:http://dx.doi.org/10.1080/0140528860080409

Gowin, B. D. (1981). *Educating*. Cornell University Press.
Gowin, B. D., & Alvarez, M. C. (2005). *The Art of Educating with V Diagrams*. Cambridge University Press.

Hackling, M. W., & Garnett, P. J. (1985). Misconceptions of chemical equilibrium. *The European Journal of Science Education, 7*(2), 205-214. doi:http://dx.doi.org/10.1080/0140528850070211

Kaya, E. (2013). Argumentation Practices in Classroom: Pre-service teachers' conceptual understanding of chemical equilibrium. *International Journal of Science Education, 35*(7), 1139–1158. doi:http://dx.doi.org/10.1080/09500693.2013.770935

Khawaja, M. A., Chen, F., & Marcus, N. (2013). Measuring Cognitive Load Using Linguistic Features: Implications for Usability Evaluation and Adaptive Interaction Design. *International Journal of Human-Computer Interaxtion*. doi:10.1080/10447318.2013.860579

Knaus, K. J., Murphy, K. L., & Holme, T. A. (2009). Designing Chemistry Practice Exams for Enhanced Benefits. An Instrument for Comparing Performance and Mental Effort Measures. *Jornal of Chemical Education, 86*(7), 827-832. doi:10.1021/ed086p827

Leppink, J., & van den Heuvel, A. (2015). The evolution of cognitive load theory and its application to medical education. *Perspect Med Educ, 4*(3), 119-127. doi:10.1007/s40037-015-0192-x

Mayer, R. E. (2014). *The Cambridge Handbook of Multimedia Learning* Cambridge University Press.

Milman, N. B. (2012). The flipped classroom strategy: what is it and how can it best be used? *Distance Learning, 9*(3), 85-88.

Mintzes, J. J., Wandersee, J. H., & Novak, J. D. (2005). *Assessing Science Understanding: A human Constructivist View*. Elsevier Academic Press.

Musallam, R. (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*. San Francisco: University of San Francisco.

Niaz, M. (2007). Relationship between student performance on conceptual and computational problems of chemical equilibrium. *International Journal of Science Education, 17*(3), 343-355. doi:http://dx.doi.org/10.1080/0950069950170306

Novak, J. D., & Gowin, B. D. (1984). *Learning How to Learn*. Cambridage University Press.

Novak, J. D., & Tyler, R. (1977). *A Theory of Education*. Cornell University Press.

Paas, F. G. W. C., & Van Merriënboer, J. J. G. (1993). The Efficiency of Instructional Conditions: An Approach to Combine Mental Effort and Performance Measures. doi:10.1177/001872089303500412

Rickey, D., & Stacy, A. M. (2000). The Role of Metacognition in Learning Chemistry. *Journal of Chemical Education, 77*(7), 915-920. doi:10.1021/ed077p915

Safayeni, F., Derbentseva, N., & Cañas, A. J. (2005). A Theoretical Note on Concepts and the Need for Cyclic Concept Maps. *Journal of Research in Science Teaching, 42*(7), 741-766. doi:10.1002/tea.20074

Safayeni, F., Derbentseva, N., & Cañas, A. J. (2007). Concept Maps: Experiments on Dynamic Thinking. *Journal of Research in Science Teaching, 44*(3), 448-465.

Seery, M. K. (2015). Flipped learning in higher education chemistry: emerging trends and potential directions. *Chemistry Education Research and Practice*. doi:10.1039/C5RP00136F

Stacy, A. M. (2010). *Living By Chemistry* (First ed.). Key Curriculum Press.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive Load Theory*. Springer Science and Business Media.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn (Vol. 12, pp. 185-233).

Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296. doi:10.1023/A:1022193728205

Tawfik, A. A., & Lilly, C. (2015). Using a Flipped Classroom Approach to Support Problem-Based Learning. *Technology, Knowledge and Learning, 20*(3), 299-315. doi:10.1007/s10758-015-9262-8

APPENDICES

APPENDIX A

IRB APPROVAL AND STUDENT ASSENT FORM

MONTANA STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

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MEMORANDUM

TO: Ahmed Shawli and Michael Brody

FROM: Mark Quinn *Mark Quinn cj*
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: February 16, 2017

SUBJECT: *"Relationships between Mental Effort Invested in Solving Complex Chemical Equilibrium Problems and Students' Concept Mapping"* [AS021617]

The above proposal was reviewed by expedited review by the Institutional Review Board. This proposal is now approved for a period of one-year.

Please keep track of the number of subjects who participate in the study and of any unexpected or adverse consequences of the research. If there are any adverse consequences, please report them to the committee as soon as possible. If there are serious adverse consequences, please suspend the research until the situation has been reviewed by the Institutional Review Board.

Any changes in the human subjects' aspects of the research should be approved by the committee before they are implemented.

It is the investigator's responsibility to inform subjects about the risks and benefits of the research. Although the subject's signing of the consent form, documents this process, you, as the investigator should be sure that the subject understands it. Please remember that subjects should receive a copy of the consent form and that you should keep a signed copy for your records.

In one year, you will be sent a questionnaire asking for information about the progress of the research. The information that you provide will be used to determine whether the committee will give continuing approval for another year. If the research is still in progress in 5 years, a complete new application will be required.

SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN RESEARCH
AT MONTANA STATE UNIVERSITY

Student Assent Form

My Name is Ahmed Shawli and I am a doctoral student at Montana State University. You have been invited to join a research study to look at the relationships between concept mapping, performance and mental effort invested in solving problems regarding understanding Le Chatelier's Principle. The purpose of the study is to determine the relationships between students' conceptual understanding of Le Chatelier's Principle, performance and mental effort.

You will complete a pre-test and a posttest on Le Chatelier's Principle science content coupled with a self-report of mental effort invested in solving problems. The pre-test will be taken two weeks before the introduction to the subject. The post-test will be taken after the completion of the unit. You will also be invited to an interview with the researcher to talk about your experience with learning about Le Chatelier's Principle concepts.

All the above activities will be taken in the classroom during the normal class time. There are no foreseeable risks to the students involved. In addition, students can stop participation at any time; the parents or researcher may also remove the student from the study at any time. Specific information about the individual student will be kept strictly confidential and will be obtainable from the school principal if desired. The results that are published publicly will not reference any individual student since the study will only analyze relationship among group of data. Students who chose not to participate or stop participating at any time, or were removed by their parents or the researcher will be provided with alternate activity by the teacher.

The purpose of this form is to allow you to participate in the study, and to allow the researcher to use the information obtained from the actual study to analyze the outcomes of the study. Student Assent for this study is strictly voluntary. Participation or nonparticipation will not affect your grade or class standing. Your signature below assumes that you understand and agrees to participate cooperatively.

If you have additional questions regarding the study, the rights of subjects, or potential problems, please call the class administer or the researcher Mr. Ahmed Shawli (A doctoral student in the Department of Education at Montana State University) on (406) 595-6688 or Dr. John Graves (the classroom teacher) on (406) 581-1253 or the Mark Quinn (the chair of the Montana State University's Institutional Review Board) on (406)-994-4707

Student's Assent Signature: ______________________
Investigator: ______________________
Date: ______________________

APPROVED
MSU IRB
02/16/2017
Date approved

APPENDIX B

CHEMICAL EQUILIBRIUM CONCEPT ASSESSMENT

(Pre-test &Posttest)

Chemical Equilibrium Concept Assessment

(Pre-test &Posttest)

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

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

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

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

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

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

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 CI2 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:

$2CO\ (g) + Cl_2\ (g) \leftarrow\rightarrow COCI2\ (g) + heat$

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

(A) the mass of COCI2 present will be______ ______

Mental Effort: Very Little Little Moderate Large Very Large

(B) the rate at which COCI2 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

$2CO\ (g) + Cl_2\ (g) \leftarrow\rightarrow COCI2\ (g) + heat$

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 COCI2 present will be_____ ______

Mental Effort: Very Little Little Moderate Large Very Large

(B) the concentration of COCI2 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

$$\mathbf{2CO\ (g) + Cl_2\ (g) \leftarrow\rightarrow COCI2\ (g) + heat}$$

7. Some Cl_2 is removed from 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

APPENDIX C

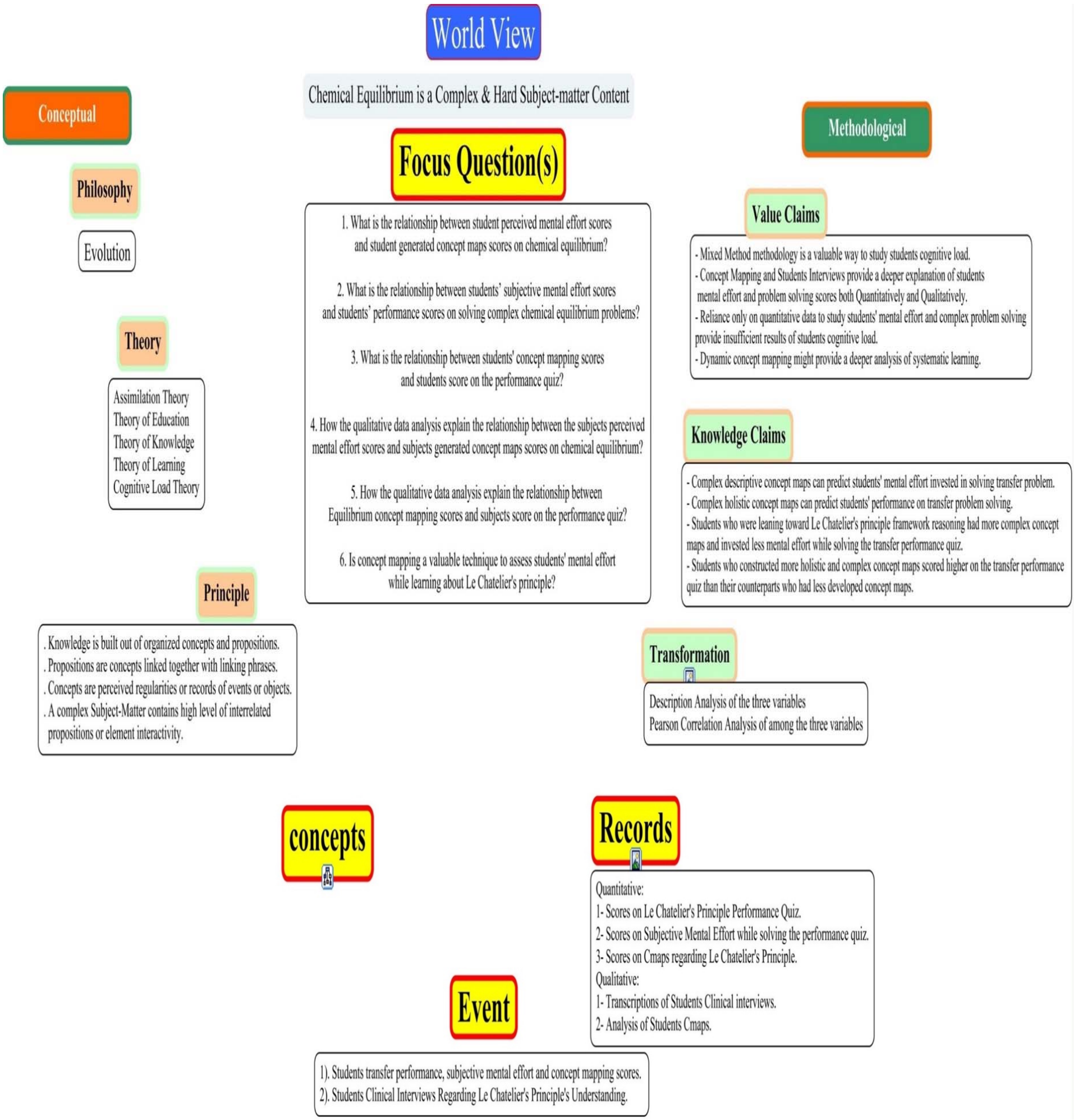
INTERVIEW QUESTIONS

Specification	Interview Questions	Justification
Overall Experience	1. We are going to talk about the last 4 weeks experience. How did you find it? 2. From you CM walk me through the content.	• These questions open the conversation with the subject to talk about the overall experience.
LCP Broad Question	1. Tell me about LCP? 2. What is it about? 3. What are the main stressors?	• Seeking overall understanding of the concept.
LCP Narrow Questions (With the use of the interview video).	1. What would happen if we increase the concentration? 2. Why did that happen? 3. What happened when we increased the temperature? 4. Why did that happen? 5. What happened when we increased pressure on the system? 6. Why did that happen?	• Seeking deeper understanding of how the LCP operates. • Seeking knowledge claims from students in form of claims and reasoning of the phenomena at hand. • Seeking connections between mental effort and performance.
Concept Mapping Questions	1. How did you find the concept mapping experience? 2. How easy or hard was it to use the tool? 3. Which verging did you prefer? Why?	• Seeking realistic data from the subject.
Performance Quiz Questions	1. Tell about your experience with the pretest? posttest?	• Seeking realistic data from the subject.
Mental Effort Questions	1. Tell about your experience with	• Seeking realistic

	scaling your mental effort in the pretest? Posttest?	data from the subject.

APPENDIX D

A VEE DIAGRAM OF THE DISSERTAION



World View
Chemical Equilibrium is a Complex & Hard Subject-matter Content
Conceptual
Methodological
Focus Question(s)
1. What is the relationship between student perceived mental effort scores and student generated concept maps scores on chemical equilibrium?
2. What is the relationship between students' subjective mental effort scores and students' performance scores on solving complex chemical equilibrium problems?
3. What is the relationship between students' concept mapping scores and students score on the performance quiz?
4. How the qualitative data analysis explain the relationship between the subjects perceived mental effort scores and subjects generated concept maps scores on chemical equilibrium?
5. How the qualitative data analysis explain the relationship between Equilibrium concept mapping scores and subjects score on the performance quiz?
6. Is concept mapping a valuable technique to assess students' mental effort while learning about Le Chatelier's principle?
Philosophy
Evolution
Theory
Assimilation Theory
Theory of Education
Theory of Knowledge
Theory of Learning
Cognitive Load Theory
Principle
. Knowledge is built out of organized concepts and propositions.
. Propositions are concepts linked together with linking phrases.
. Concepts are perceived regularities or records of events or objects.
. A complex Subject-Matter contains high level of interrelated propositions or element interactivity.
Value Claims
- Mixed Method methodology is a valuable way to study students cognitive load.
- Concept Mapping and Students Interviews provide a deeper explanation of students mental effort and problem solving scores both Quantitatively and Qualitatively.
- Reliance only on quantitative data to study students' mental effort and complex problem solving provide insufficient results of students cognitive load.
- Dynamic concept mapping might provide a deeper analysis of systematic learning.
Knowledge Claims
- Complex descriptive concept maps can predict students' mental effort invested in solving transfer problem.
- Complex holistic concept maps can predict students' performance on transfer problem solving.
- Students who were leaning toward Le Chatelier's principle framework reasoning had more complex concept maps and invested less mental effort while solving the transfer performance quiz.
- Students who constructed more holistic and complex concept maps scored higher on the transfer performance quiz than their counterparts who had less developed concept maps.
Transformation
Description Analysis of the three variables
Pearson Correlation Analysis of among the three variables
concepts
Records
Quantitative:
1- Scores on Le Chatelier's Principle Performance Quiz.
2- Scores on Subjective Mental Effort while solving the performance quiz.
3- Scores on Cmaps regarding Le Chatelier's Principle.
Qualitative:
1- Transcriptions of Students Clinical interviews.
2- Analysis of Students Cmaps.
Event
1). Students transfer performance, subjective mental effort and concept mapping scores.
2). Students Clinical Interviews Regarding Le Chatelier's Principle's Understanding.