COGNITIVE DISEQUILIBRIUM AND SITUATIONAL INTEREST IN A MIDDLE SCHOOL ACTIVITY ON COMPUTATIONAL MODELING IN PALEONTOLOGY

By

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To my Family
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To my family: Thank you for always being there for me. To my husband: Thank you for your patience and unremitting support no matter how stressed I feel. To my daughter: Thank you for bringing so much joy to our lives.
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By

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In 2019, the U.S. is still facing a shortage of science, technology, engineering and mathematics (STEM) workforce that is capable of solving social and economic challenges in 21st century worldwide. Numerous studies have explored the influence of integrative STEM approaches on developing student interest and career aspiration in STEM. Building on this work, this study explored how cognitive disequilibrium (CD) influenced students' triggered situational interest as the proximal outcome and their views of the nature of science, science content learning, and maintained situational interest as distal outcomes. This study used a concurrent embedded mixed method design. Four existing classes of eighth-grade students (n = 88) were randomly assigned to either the treatment or control group as existing intact classes. The lesson "How Big Was Megalodon?" was implemented by the same science teacher in both the treatment and control group. Students in both groups experienced the same lesson except for the CD treatment, which was implemented to trigger an uncomfortable state of uncertainty as a result of students obtaining anomalous data on Megalodon size. Students self-reported their CD, SI, individual interest in science and views of the nature of science using robust, previously validated measures. Their science content knowledge was
assessed using Megalodon activity worksheets. Classroom observations and student interviews were conducted to further explore students’ CD experience and perceptions of the learning activity.

Results revealed that CD was a source for triggering and maintaining students’ situational interest in science. Students’ reappraisal of CD was found to positively predict their triggered situational interest and the feeling components of their maintained situational interest. Anxiety positively predicted the value components of maintained situational interest. For CD-based instructional strategy to be effective in improving students’ views of the nature of science and science content knowledge, the CD experience should be scaffolded to allow students to discover and externalize the misconceptions and gaps in their existing knowledge, and encourage them to resolve CD by seeking new and relevant information. Further implications for educational researchers include a) exploring conceptual and procedural scaffolds for designing a meaningful CD experience, b) determining how individual differences in cognition and affect mediate interactions and learning with CD, and c) investigating how CD affects learning for students from diverse socio-cultural backgrounds.
CHAPTER 1
INTRODUCTION

Context for the Study

There is a rapidly increasing need for qualified science, technology, engineering, and mathematics (STEM) workforce capable of solving social and economic challenges in 21st century worldwide (e.g. Caprile, Palmen, Sanz, & Dente, 2015; Honey, Pearson, & Schweingruber, 2014). The U.S. Bureau of Labor Statistics projects that the employment in STEM occupations will grow by 18.7% compared to 14.3% for all occupations during the period 2010-2020. Efforts have been taken in education and reform policies to ensure that there is an adequate number of students who pursue careers in STEM (e.g. Osborne & Dillon, 2008; Tytler, Osborne, Williams, Tytler, & Cripps Clark, 2008). However, the growth of STEM workforce is still not keeping pace with the overall needs of the labor market in the U.S. (Lowell & Regets, 2006). According to U.S. News and World Report (2018), the shortage of STEM workforce still affects various industries and up to two million of these positions might go unfilled due to the difficulty of finding qualified workers.

There is growing evidence to support the notion that STEM interest plays an important role in STEM persistence and career aspiration (e.g. Beggs, Bantham, & Taylor, 2008; Maltese & Tai, 2011; Tai, Liu, Maltese, & Fan, 2006). STEM interest encompasses an individual’s curiosity, excitement, and enjoyment of learning about a certain STEM topic or field, leading to more sustained focus on STEM content and skills, followed by a desire to seek out more opportunities to interact with STEM in the future (Hidi & Renninger, 2006). Beggs and colleagues (2008) implemented a survey with 852 college students and identified interest as the most influential factor in choice
of major, given they have knowledge of the relevant area. Likewise, Hall, Dickerson, Battts, Kauffmann, and Bosse (2011) conducted a survey study with both high school and college students and found out that personal interest was the top factor influencing students’ career choice. Maltese and Tai’s (2010) study with graduate students and scientists revealed that the interest of the majority of participants was triggered in early childhood or elementary school. The result was confirmed by Dabney, Chakraverty, and Tai (2013) who investigated the survey data from a completely different sample of individuals and found that about 41% of respondents became initially interested in STEM early in elementary school. In contrast, the Royal Society (2004) found out 63% of their participants decided on their career path at the age of 14 by surveying 1,100 scientists and engineers. According to Tai, Liu, Maltese and Fan (2006), eighth-graders with a self-reported interest in science subjects had a higher chance of majoring in STEM-related fields, proving the connection between early interest and future career choice. The same result was found in Dabney and associates’ (2012) study which demonstrated that interest in science and mathematics during middle school was associated with a higher probability of choosing a STEM career. Taken together, these findings suggest that many who pursue STEM career make up their minds to do so before high school. If that is the case, students’ educational experiences aimed at STEM interest development before high school play a critical role in determining whether their will consider a STEM degree and career and whether and how their STEM interest could be nurtured and sustained.

The meaningful integration of STEM disciplines in K-12 education (NRC, 2012) holds the promise to support student development of STEM interest and increase the
number of students pursuing STEM fields. As boundary crossing is a primary feature of integrated STEM perspective, STEM integration has been defined variously ranging from disciplinary, multidisciplinary, interdisciplinary to transdisciplinary. In recent years, more focus has been spent on the interdisciplinary and transdisciplinary STEM integration because STEM education is not a "convenient integration" of its four disciplines, but a combination of “real-world, problem-based learning that links the disciplines through cohesive and active teaching and learning approaches” (English, 2016, p. 9). Advocates for the integrated approaches assert that teaching STEM subjects in a more connected manner will improve the relevance of the subjects, student interest, achievement, and persistence, and increase the number of students who pursue careers in a STEM-related field (NRC, 2014). Research on integrated STEM programs has provided some preliminary evidence to support that. Monterastelli, Bayles, and Ross (2008) evaluated an enrichment program that integrated engineering with biology concepts for gifted and talented high school students from the Baltimore/Washington DC areas and documented that student interest in science, engineering, math, and team problem solving was significantly improved as a result of integrated engineering and biology learning experiences. Burghardt, Hecht, Russo, Lauckhardt, and Hacker (2016) implemented a study to examine the impact of a mathematics infused engineering and technology education curriculum on students’ mathematics content knowledge and attitudes toward mathematics and their survey results showed that infusion students demonstrated stronger interest in math than control students. Nevertheless, although the preliminary research findings about the effectiveness of STEM integration on developing students’ interest in STEM are
promising, their quality varies since researchers still have vastly different interpretations of STEM integration, adopt measures of interest based on different constructs, and do not take into account different phases of interest development (NRC, 2014). Therefore, more research investigating the relationship between STEM interest and STEM integration is needed to inform both educational practice and educational policy.

This study is designed and conducted within a project founded by National Science Foundation (NSF) to explore the influence of the innovative approaches to STEM integration on student interest and learning in K-12 schools. Engaging K-12 Students in Integrated STEM via 3D Digitization, Printing and Exploration of Fossils (iDigFossils), is a NSF-founded project aimed to expand and extend our understanding of integrated STEM learning by designing and testing a model for K-12 STEM engagement using 3D scanning and printing technologies in the context of paleontology, a highly relevant but unexplored educational pathway to STEM in K-12 education. The primary purpose of the iDigFossils project is to develop a transferable model, activities, professional development materials, and novel interactive 3D visualization tools and computational modeling applications to engage K-12 students in hands-on minds-on learning in a way that organically integrates STEM and addresses the three dimensions of the K-12 science education framework-a) science and engineering practices, b) crosscutting concepts, and c) core ideas (NRC, 2012). This project addresses the critical need to engage K-12 students in rigorous and meaningful integrated STEM learning experiences that are aligned with the Next Generation Science Standards (NGSS) and study the effective conditions for scaffolding integrated STEM activities to help students develop interest and identity in STEM.
The present study is a component of the iDigFossils project designed to investigate a specific learning condition scaffolded by the technology integrated in science and mathematics focused learning activity in the 8th grade science classroom. This activity is entitled “How Big Was the Megalodon?” and it uses 3D scanning, printing, and measurement of teeth of the Neogene shark Carcharocles megalodon to demonstrate the potential of paleontology to integrate STEM disciplines and to help develop student interest and motivation in STEM (Grant, MacFadden, Antonenko, & Perez, 2017). The study specifically focused on exploring how cognitive disequilibrium (CD) induced by students’ experience with computational modeling software influenced their situational interest (SI) as the proximal outcome and affected their views of the nature of science (NOS), science content learning, and overall learning experience as the distal outcomes.

**Statement of Problem**

Students’ interest in science plays a critical role in influencing the outcomes of science education (Hong, Lin, & Lawrenz, 2012). However, interest in science has been reported to decline in recent years (Ayotte-Beaudet, Potvin, & Riopel, 2019; Barmby, Kind, & Jones, 2008; Bennett & Hogarth, 2009; Potvin & Hasni, 2014; Turner & Ireson, 2010). Christidou (2011) reviewed more than 100 references and argued that students rapidly lose their interest in science and stop seeing it as a potential career option for their future as they advance from elementary to secondary education. Likewise, Barmby and colleagues (2008) studied the evolution of science interest over school years and concluded that students’ attitudes toward learning science declined the fastest among other attitudes. Therefore, an increasing amount of efforts have been initiated to
increase students’ interest in science, yet the mechanism of arousing student interest in learning science still remains poorly understood.

Situational interest (SI) plays an important role in learning, especially for learners who don’t have pre-existing interest in content areas, certain academic activities, or topics (Hidi & Harackiewicz, 2000). It uses features in the environment (Hidi & Anderson, 1992; Hidi & Renninger, 2006) to initiate interest and is a precursor to the development of sustained interest (Renninger & Hidi, 2011). SI is beneficial for performing cognitive activities, working with computers, narrowing inferencing, focusing attention, integrating information with prior knowledge, and enhancing learning (Hidi & Renninger, 2006). However, the research of SI has been primarily focused on text-based learning (Hidi, 1990), which mainly deals with how characteristics of text segments affect students’ interest in reading tasks. There is still limited research exploring strategies or sources to generate SI in an inquiry-based science classroom (Hidi & Harackiewicz, 2000). As the choice of activities and contents may relate to the development of students’ SI and cause possible changes at both the cognitive and emotional levels, efforts to develop activities that improve students’ SI are worth undertaking (Loukomies, Juuti, & Lavonen, 2015).

Because SI is thought to be associated with factors such as novelty, uncertainty, and complexity (Silvia, 2010), the concept of cognitive disequilibrium, or a psychological state of uncertainty, is of particular relevance to the study of SI. Cognitive disequilibrium (CD) is defined as uncertainty that occurs when students are confronted with stimuli, problems, or situations that present obstacles to goals, anomalous events, impasses, contradictions, incongruities, unexpected feedback, novelty, expectation violations, and
obvious gaps in knowledge (D'Mello & Graesser, 2012; Graesser, Lu, Olde, Cooper-Pye, & Whitten, 2005). Due to the fact that scientists constantly deal with uncertainty (Chinn & Brewer, 1993), CD-based activities can be designed in an inquiry-based science learning environment that have the potential to trigger students’ SI (Chinn & Brewer, 1993; Yarlas & Gelman, 1998). CD is thought to be an uncomfortable psychological state that necessarily prompts questions and inquiry to find answers in order to restore cognitive equilibrium, a state of psychological comfort. Moreover, CD facilitates students’ learning and problem solving through eliciting curiosity (D'Mello & Graesser, 2012). For example, Graesser and colleagues (2005) discovered that CD encouraged learners to ask better questions that were more likely to solve the problem. However, failure to restore CD through thought, reflection, and problem solving may also lead to negative impacts on students’ affective states and learning (D'Mello & Graesser, 2011).

CD-based activities also have great potential to improve students’ understanding of nature of science (NOS). NOS has been advocated as a critical educational outcome by various science education reform documents worldwide (e.g. Australia, South Africa, United States) and is an important component of scientific literacy for 21st century citizens (Lederman, 2013). Previously, situating students’ understanding of NOS within a context of inquiry has been advocated as a solution to improve this outcome, but challenges still exist before the solution can be effective (Lederman, 2006). For example, many studies have advocated a narrow and distorted view of scientific inquiry and often failed to adequately reflect authentic scientific inquiry enacted by scientists in the real world (Burgin & Sadler, 2016; Chinn & Malhotra, 2002; Hogan, 2000;
Lederman, 2006; Sandoval, 2005). CD-based activities can improve this outcome by 1) bringing what scientists experience in real-life (e.g., uncertainty) into classroom instruction; 2) engaging students in practicing inquiry that reflect actual scientific practice; 3) improving students ability of transferring skills they learn in science classroom into solving problems in other contexts and 4) promoting students’ conceptual change (Limón, 2001). The cultivation of NOS through CD-based activities will also help to achieve the ultimate goal of scientific literacy, which is to improve “the utility and relevance of the subject matter included in K-12 science curriculum and students’ ability to apply their science knowledge to make informed decisions regarding personal and societal problems” (Lederman, 2006, p. 301). However, the existing research explicitly investigating the influence of CD-based activities on NOS is rare. Schwartz and Lederman (2002) suggests that generating cognitive dissonance is an important first step to enable the development of learners’ NOS views regardless of their confidence in pre-existing NOS views, but provides no empirical evidence to support that. Following this suggestion, McDonald (2010) implemented an empirical study to evaluate the influence of explicit NOS and argument instruction on preservice primary teachers’ views of NOS and found that the more CD generated at the beginning of the study, the more informed views of NOS conceived at the end of the study.

To summarize, CD-based instruction has been designed and studied primarily to understand: 1) CD’s influence on academic emotion and cognitive processing in virtual learning environments (e.g. Graesser et al., 2005); and 2) CD’s impact in promoting conceptual change (e.g. Hewson & Hewson, 1984). Limited research has been implemented to understand its effects on cultivating SI, improving NOS, and promoting
science content learning in a science classroom setting. Rotgans and Schmidt (2014) have successfully designed three studies to demonstrate that knowledge deficit will increase SI; however, they did not explicitly investigate the function of CD and focused primarily on the relationship between triggered SI and knowledge acquisition. Therefore, more research is needed to explore the effects of CD-based activities on cultivating SI and, in the long term, improving students’ views of NOS, increasing their science content knowledge, and developing their long-term science interest.

**Statement of the Purpose**

The purpose of this dissertation study was to explore the potential of CD to influence students’ triggered SI in a middle school learning activity on computational modeling in paleontology (proximal outcome), as well as their (a) views of the NOS, (b) science content knowledge, and (c) maintained SI as the distal outcomes. Investigating the presence and impact of CD on students’ science learning could provide implications for how to incorporate CD-based instruction to enhance students’ learning experience in the science classroom and their learning outcomes. Narrowing the lens of the study to the context of a middle school learning activity on computational modeling in paleontology could contribute insights on the effectiveness of incorporating CD-based scientific inquiry into K-12 science classroom, especially with regards to affecting students’ SI, views of the NOS, and science content knowledge. Specifically, this research is seeking to answer the following research questions:

1. To what extent does the cognitive disequilibrium generated in a middle school science computational modeling activity influence students’ triggered situational interest, controlling for the effects of individual interest in science?

2. (a) How does the cognitive disequilibrium generated in a middle school science computational modeling activity influence students’ views of the nature of science?
(b) How does the cognitive disequilibrium generated in a middle school science troubleshooting activity impact students’ science content knowledge?

(c) How does the cognitive disequilibrium generated in a middle school science computational modeling activity influence students’ maintained situational interest, controlling for the effects of individual interest in science?

3. What strategies do students negotiate and use when resolving cognitive disequilibrium in a middle school science classroom?

4. What are middle school students’ perceptions of the science computational modeling activity incorporating cognitive disequilibrium?

**Significance of the Study**

The current study was designed to generate evidence exploring the efficacy of CD in triggering students’ SI, improving their views of NOS and science content knowledge, and maintaining their SI in a middle school science classroom. Findings from this study can advance our understanding of how CD affects student interest development and science learning. Furthermore, the study will generate practical implications for science educators on how to implement CD-based activity to generate student interest in science and promote their science learning.

**Definition of Terms**

- **Cognitive Disequilibrium.** A state of uncertainty that occurs when an individual is confronted with obstacles to goals, interruptions of organized action sequence, impasses, contradictions, anomalous events, dissonance, incongruities, unexpected feedback, uncertainty, deviations from norms, and novelty (D’Mello & Graesser, 2011, p. 146).

- **Maintained Situational Interest.** A deeper form of SI in which individuals start to realize the personal value of the content, build meaningful connections with it, and feel empowered by the knowledge in the situation (Hidi, 2001; Mitchell, 1993).

- **Nature of Science.** An understanding of science as a way of knowing, including the values and beliefs fundamental to the development of scientific knowledge (Lederman, 1998).
• **Scientific Inquiry.** The process by which scientific knowledge is developed and, by virtue of the conventions and assumptions of this process, the knowledge produced necessarily has certain unavoidable characteristics (Lederman, 2006, p. 308).

• **Situational Interest.** An affective response to features in the environment (Hidi, 2016) and characterized by focused and effortless attention accompanied by a positive emotion tone (Krapp et al., 2014; Schiefele, 2009).

• **Triggered Situational Interest.** A psychological state of interest resulted from the affective experience individuals associate with the environment (Linnenbrink-Garcia, Durik, Conley, Barron, Tauer, Karabenick & Harackiewicz, 2010, p. 649).
Cognitive Disequilibrium

Cognitive disequilibrium (CD), or an uncomfortable state of uncertainty, is an important impetus to learning (Hewson & Hewson, 1984). Researchers have employed a number of terms based on their research concerns to explain CD in different contexts. Generally, scholars agree that CD refers to “a state of uncertainty that occurs when an individual is confronted with obstacles to goals, interruptions of organized action sequence, impasses, contradictions, anomalous events, dissonance, incongruities, unexpected feedback, uncertainty, deviations from norms, and novelty” (Graesser et al., 2011, p. 146). Piaget (1977) suggested that the development of human beings is governed by CD, which is a driving source to propel the learning processes and maintain a functional order in an open system. In addition, CD is a psychological state that is frequently experienced by scientists (Chinn & Brewer, 1993) and serves to facilitate conceptual change in the field of science (Hewson & Hewson, 1984). Therefore, CD is of particular relevance to the study of science learning in K-12 classroom, the ultimate goal of which is to help students develop understanding of 1) authentic STEM practices (e.g., developing and using models, etc.), 2) disciplinary core ideas (e.g., in Biology, Physics, etc.), and 3) crosscutting STEM concepts (e.g., patterns, adaptation, structure and function, etc.; NRC, 2012). In this study, I am particularly interested in investigating the manifestation of CD in a middle school learning activity on computational modeling in paleontology and its effect on triggering situational interest, and influencing middle-schoolers’ views of nature of science, science content knowledge, and maintaining situational interest. First, I will review the
literature on relevant concepts on CD, relationship between CD and learning, benefits and limitations of CD-based strategies, and influence of CD on science learning to explain my rationale for focusing my research on CD.

**Equilibration of Cognitive Structures**

Piaget (1977) contends that the development of child is governed not only by maturation and under pressure of environmental events but also by a class of factors called “cognitive equilibration (CE)”, which refers to “a class of hitherto overlooked sources of drive and reward propelling the learning processes that give rise to generalized habits of perception and thought” and is “capable of building and maintaining a functional and structural order in an open system” (Berlyne, 1960, p. 302). He proposes three types of equilibrium (Piaget, 1977). The first type is concerned with the relationship between assimilation and accommodation. Assimilation refers to the “collecting and classifying of new information” (Bormanaki & Khoshhal, 2017, p. 998) while accommodation refers to the “process of changing internal structures of knowledge in order to have consistency with external reality” (Yang, 2010, p. 203). Given there is a balance between the cognitive structures of the subjects and the objects, this type of equilibrium can be attained once the subjects’ cognitive structures accommodate to the new objects being presented as well as assimilate the objects into their cognitive structures. The second type of CE pertains to the equilibrium among the subsystems of the subject’s schema and refers to the assimilation of partial systems into the totality of the subject’s knowledge. Finally, CE is also determined by the balance between the parts of subject’s knowledge and the totality of his or her knowledge at any given moment. This third type of CE is the most fundamental type as
it drives the construction process upon which new problems lead to new actions and new actions lead to new knowledge (Bormanaki & Khoshhal, 2017).

Human mind is constantly seeking CE and trying to find the balance between what is known (i.e. the current schemata) and what is currently being experienced (Bormanaki & Khoshhal, 2017). However, sometimes CE cannot be achieved when their schemata do not produce a satisfying result, leading to the uncomfortable situation of cognitive disequilibrium (CD). This triggers actions to remove or reduce disequilibrium (Piaget, 1977) by searching for a solution through assimilation and accommodation of new information until cognitive balance can be re-established (Woolfolk, Winne, & Perry, 2003). Therefore, CE is regarded as an active and dynamic self-regulation process through which learners combat CD and achieve progressively better equilibrium relative to the subject matter. As the nervous system develops and earlier and cruder ways frequently lead to surprises, frustrations, and errors, the learner has the tendency to improve the ways of perceiving and thinking in order to have greater confidence in judgments and to make predictions in more contexts. To summarize, equilibration is the “dynamic process of moving between the states of CD and CE as we assimilate new experiences and accommodate schemes” (Cook & Cook, 2005, p. 8) and the need to reduce CD is a powerful motivator for learning (Piaget, 1977; Piaget, 2018).

**Cognitive Conflict**

Cognitive conflict is a relevant construct that is described as a perceptual state in which there is a discrepancy between one’s cognitive structure and the external environment, or among the different components (e.g. the conceptions, beliefs, substructures, etc.) of one’s cognitive structure (Lee & Kwon, 2001). Berlyne (1960) has laid the groundwork for explaining how cognitive conflict results in the acquisition of
knowledge from the perspective of behavior theory. Behavior theory focuses on understanding the effects of stimulus selection on responses. It asserts that when two or more incompatible responses are evoked simultaneously by one or more stimulus in an organism, it is in conflict (Berlyne, 1960). The stimulus usually has the quality of novelty, uncertainty, conflict, and complexity to cause cognitive conflict. The conflict usually leads to increased arousal and exploratory behavior, which results in learning if the conflict can be resolved (Berlyne, 1978). The conflict is advantageous as it might prevent immature decision making until more information is collected. However, it can sometimes be harmful if the conflict stays for too long and cannot be resolved. Overall, cognitive conflict has "high arousal potential, motivating the learner to attempt to resolve it by seeking new information or by trying to reorganize the knowledge he or she already has" (Lee, Kwon, Park, Kim, Kwon, & Park, 2003, p. 586).

Conceptual Conflict

Hewson and Hewson (1984) prefer using the term "conceptual conflict" to "cognitive conflict" as the former reflects the epistemological point of view about learning more adequately than the latter. Conceptual conflict mainly happens when the learner tries to relate the new idea to his or her current concepts in learning. It is beneficial for learning as children can see inadequacies in their existing knowledge and find resolutions to bridge the knowledge gap (Siegler, 1983). It is closely related to controversy, which refers to the situation when two persons disagree with each other on ideas, information, theories, or opinions and seek to reach an agreement.

Cognitive Dissonance

Another relevant term found in literature on the psychological underpinnings of learning is cognitive dissonance. Festinger (1962) defined cognitive dissonance in terms
of a logical contradiction between two cognitive elements (e.g. beliefs, perceptions) or between a cognitive element and an overt action. For example, Mark is in cognitive dissonance when he chooses to buy Chevrolet although he thinks that Ford is of better quality than Chevrolet. It is the “activated state of a person who experiences different or contradicting cognitions, beliefs, attitudes and behaviors” (Badke-Schaub & Goldschmidt, 2010, p. 121). Cognitive dissonance leads to activities oriented toward dissonance reduction just as hunger leads to activities oriented toward hunger reduction (Festinger, 1962). As cognitive dissonance causes discomfort, people strive to eliminate or reduce it by adjusting evaluations of conflicting elements, reducing the importance attached to them, and seeking social support from other persons who share them. It will help to determine stimulus selection, favoring those that will moderate dissonance and avoiding those that will aggravate it.

Cognitive Imbalance

Abelson’s (1959) theory of cognitive imbalance focuses more on discrepancies among evaluations. Imbalance happens when two positively or two negatively valued elements are dissociatively linked (i.e. “avoids,” “hates”) or a positively valued and negatively valued element are associatively linked (i.e. “has,” “likes”), thus, attainment of cognitive balance is impossible to achieve. For example, one is in cognitive imbalance when he or she likes both to be slim and to eat sugar-rich food but realizes that it is impossible to satisfy both likes. Imbalance can be reduced in four ways: 1) denial: changing one element involved in the evaluation; 2) bolstering: linking one of the elements with other ideas that are associated with opposite belief or evaluation; 3) differentiation: making a distinction within one of the conflicting elements; 4) transcendence: combining conflicting elements into some larger unit.
Berlyne (1960) summarized some other concepts that are pertinent to CD (Table 2-1).

**The Conception of Cognitive Disequilibrium for This Study**

This study employed D'Mello and Graesser’s (2011)'s and Lee, Kwon, Park, Kim, Kwon, and Park (2003)'s conception of CD to inform research design, implementation, and interpretation of results. D'Mello and Graesser (2011) synthesized the conceptual frameworks on CD theorized by major scholars such as Piaget (1977), Berlyne (1960), and Festinger (1962), and defined CD as “a state of uncertainty that occurs when an individual is confronted with obstacles to goals, interruptions of organized action sequence, impasses, contradictions, anomalous events, dissonance, incongruities, unexpected feedback, uncertainty, deviations from norms, and novelty” (D'Mello & Graesser, 2011, p. 146). They validated a model of affective dynamics during complex learning and predicted that CD usually happens when learners are confronted with impasses, such as a contradiction, anomaly, system breakdown, or error, and are unsure about what to do next (Graesser et al., 2005). According to this model (D'Mello & Graesser, 2011), CE is restored once those impasses are resolved.

Lee et al. (2003) refined the concept of CD by including more detailed psychological states and behaviors in an ordered procedure. When learners recognize that a situation is incongruous with their conceptions, they will experience a psychological state of uncertainty (D'Mello et al., 2011) or anxiety or interest (Lee et al. 2003). According to Lee et al. (2003), a student interested in the CD situation would exhibit responses such as heightened interest, curiosity, and focused attention. Or a student anxious about the CD situation would show such responses as confusion, discomfort, and a feeling of oppression. Both interest and anxiety were indications of
CD argued by Berlyne (1960). After experiencing interest or anxiety, or both, learners would reappraise the CD situation to decide whether to resolve or dismiss it by exhibiting response latency, which is another indication of CD proposed by Zimmerman and Blom (1983). Therefore, Lee et al. (2003) viewed CD as consisting of uncertainty, interest, anxiety, and response latency.

**Rationale for Studying Cognitive Disequilibrium in Learning and Instruction**

To illustrate the potential of CD to improve learning, Johnson and Johnson (2018) proposed an evidence-based model of the process of controversy that can be used by teachers to “increase student motivation, creative insight, cognitive development, and learning” (p. 51). The process starts with a student realizing some different opinions, theories, concepts that challenge his or her existing conceptions, leading to a state of CD. To resolve CD, students will take actions for knowledge acquisition, such as searching for more information, engaging in new experiences, and involving in other social activities, in order to adapt to the new cognitive perspective and reasoning process. Other conditions, such as the context within which the controversy occurs, the relevant information students possess, and students’ perspective-taking abilities, will also affect the process. If all other conditions are being met, students will enrich their cognitive perspective, improve their reasoning skills, and increase their accuracy of cognitive perspective-taking, cognitive and moral reasoning skills, problem-solving abilities, and creativeness.

Rotgans and Schmidt (2014) implemented three consecutive studies to demonstrate the influence of CD on situational interest and knowledge development. In the first study, they manipulated secondary-school students’ prior knowledge about reasons for the conquest of Singapore by the Japanese during the Second World War.
Students in the control group were provided with correct information that explained the conquest. In contrast, students in the treatment group were given inaccurate information about the conquest and experienced CD. A six-item measure of situational interest was implemented before, during, and after the activity. The results revealed that students who experienced CD showed significantly more interest in understanding the problem than the students who did not experience CD.

In the second study, Rotgans and Schmidt (2014) examined the extent to which situational interest increases as students became aware of their CD. Secondary school students were enrolled in a problem-based Geography class. Measures of situational interest and self-reported CD were administered before and after the class. The results indicated that the more students were aware of their CD, the higher their situational interest toward the content.

They implemented the third study in a secondary school classroom to examine the extent to which CD triggers situational interest. A problem-based instructional approach was used in a history class. Students worked together in small groups to solve their CD, induced by the inaccurate explanation for the conquest of Singapore by the Japanese, under the guidance of the teacher. Their situational interest and CD were measured before, during, and after the lesson. The results indicated that CD triggered situational interest, which was a driving force aimed at reducing the knowledge deficit through knowledge acquisition. Their studies, therefore, support Johnson and Johnson’s (1978) conjecture that CD motivates the action for knowledge acquisition and triggers situational interest. However, their results also demonstrated that once the CD has been
resolved, students’ situational interest decreases, affecting the future knowledge acquisition process.

Several studies have been conducted to explore the effectiveness of CD in encouraging problem solving and inquiry. Graesser and McMahen (1993) conducted a study to test whether CD induced by anomalous information would cause an increase in questions generated by college students while they solve quantitative problems or while they comprehend stories. The transformations of mathematical word problems and of simple stories through contradictions, irrelevant information, and deletions of critical information were expected to trigger CD. Their results indicated that the CD increased the number of “good” questions that would help students to solve the problem. Grasser, Lu, Olde, Cooper-Pye, and Whitten (2005) conducted a study to investigate eye-movement behavior when college students were confronted with breakdown scenarios and when they asked questions. Participants read illustrated texts about everyday devices (e.g., a cylinder lock) and then were placed in CD through a breakdown scenario (e.g., the key turns but the bolt does not move). They asked questions during the breakdown scenarios, and an eyetracker recorded their eye fixations. The breakdown scenarios were expected to put the participants in a state of CD. Their eye-tracking results supported the prediction that good comprehenders would show a significant tendency to fixate on appropriate defective components when they were in the state of CD. The same results also demonstrated that CD triggered questions that helped them solve the problem.

Cognitive Disequilibrium and Conceptual Change

CD-based instruction has been employed in many studies that investigated students’ conceptual change (Chan, Burtis, & Bereiter, 1997; Limón, 2001; Posner,
Strike, Hewson, & Gertzog, 1982). A CD-based conceptual change model of learning was proposed by Posner, Strike, Hewson, and Gertzog (1982). This model assumes that the fundamental change in an individual’s learning is similar to the nature of change in scientific paradigms proposed by philosophers of science (Pintrich, Marx, & Boyle, 1993). This model predicts that learning happens when there is a discrepancy between an individual’s experiences and his or her current conceptions and ideas (Posner et al., 1982), leading to the uncomfortable state of CD. CD plays a key role in promoting conceptual change by “destabilizing students’ confidence in their existing conceptions through contradictory experiences such as discrepant events and then enabling students to replace their inaccurate preconceptions with scientifically accepted conceptions” (Kang et al., 2010, p. 383). Contradictory information is usually presented through “texts, hands-on activities, experiments, simulations, and/or the opposing views of peers during group discussion” (Kang et al., 2010, p. 383) in the learning environment.

The use of CD in promoting conceptual change has been supported by Piaget (1977), who focuses on the broader use of CD in human development (e.g., assimilation vs. accommodation) and proposes two primary responses to contradictory information - adapted and unadapted. Unadapted responses refer to those situations when individuals are not aware of the CD. Adapted responses are divided into three types: a) alpha: individuals ignore or do not take into account the conflicting data; b) beta: individuals modify part of their existing theories through generalization and differentiation; c) gamma: individuals modify their central core of theories (Limón, 2001). Similarly, Posner and colleagues (1982) considered CD as an important step in the
process of conceptual change. Compared to Piaget (1977), they focused more on fundamental changes in a person’s central, organizing concepts from one set of concepts to another set incompatible with the first, or what Piaget (1977) refers to as accommodation. Their model also considers cognitive conflict generated by anomalies – that is, when students fail to assimilate an experience or a new conception into her or his existing network of conceptions, a first step to prepare their conceptual ecology for conceptual change.

The function of CD to promote conceptual change has been explored in several empirical studies. Posner and colleagues (1982) conducted interviews in a noncalculus, self-study, self-paced introductory physics course with undergraduate students who had completed a unit on special relativity to study their attempts in coming to terms with the special theory. They documented in the study that cognitive conflict generated by anomalies prepared student’s conceptual ecology for conceptual change. Specifically, their interview data indicated that “the more students consider the anomaly to be serious, the more dissatisfied they will be with their current concepts, and the more likely they may be ready ultimate to accommodate new ones” (Posner et al., 1982, p. 224). Hewson (1992) taught the concepts of mass, volume, and density to two groups of 10th-grade students. The control group was to use integration strategies during learning, which involved the integration of new non-conflict content with a student’s existing conceptions. In contrast, the treatment group used exchange strategies, which aimed to create conceptual conflict between a student’s conception and the new content. A pre- and a post-test of conceptual understanding were used to measure students’ conceptual change in those concepts. The results indicated that the treatment group
that used CD-based strategies achieved better acquisition of desired conceptions than the control group. A similar result was obtained in another study Hewson (1992) study on speed. Trowbridge and McDermott (1980) proposed that a significant proportion of college students held the alternative conception that two balls were moving at the same speed when one was next to the other while passing it, rather than when they maintained a constant separation (the “position” criterion). Hewson (1992) designed a microcomputer program to diagnose when a student held the alternative conception. In the first part, the program showed the alternative conception held by students. In the second part, she used the exchange strategy, in which students were shown two objects which were at the same position for an instant but were obviously not moving with the same speed (the desired conception), to produce a conceptual conflict for students. The results indicated that a significant portion of students who learned with the second part of the treatment changed from using the “position” criterion to using the desired conception. They concluded that it was the CD produced by the exchange strategy that was responsible for the conceptual change that occurred.

However, presenting CD alone does not guarantee the conceptual change to happen. According to Siegler (1983), facilitating conceptual change is most efficient when children can see the conflict between their existing and new knowledge and find a resolution to resolve the conflict. Nussbaum and Novick (1982) conducted a case study of an actual classroom event and proposed a set of guidelines for the design of instructional sequences that can use CD to promote conceptual change successfully. They suggested that students should first be presented with an “exposing event” which they could interpret by using their conceptions, then with a “discrepant event” which
caused CD between their previous conceptions and the new phenomenon, and finally with a resolution phase in which they would be encouraged to articulate and elaborate the desired conception. To summarize, conceptual change requires a conceptual ecology comprised of many different kinds of knowledge and epistemic events, such as anomalies, analogies and past experiences, to create a new conception that is intelligible, plausible, and meaningful enough to learners, put them in CD, and provide opportunities to resolve the CD.

**Triggers of Cognitive Disequilibrium in Learning**

A key strategy to introduce CD in learning is to present students with “a puzzling situation which is counter-intuitive” (Appleton, 1993, p. 1) based on the assumption that the resolution of the disharmony will result in meaningful understanding (Baddock & Bucat, 2008). The puzzling situation usually contradicts students’ ideas, beliefs, or theories (Limón, 2001) and has demonstrated significant effects on promoting conceptual change (Guzzetti et al., 2006). However, presenting the contradictory data is not enough to lead to meaningful CD, which only happens when students consciously experience it and spend great efforts in alleviating it through meaningful cognitive restructuring. Kuhn, Amsel, and O'Loughlin’s (1988) demonstrated that most people of different ages persisted with their existing beliefs in the face of the CD. Vosniadou (1994) arrived at a similar conclusion when students often treated local inconsistencies superficially without reaching conceptual change. Therefore, Limón (2001) suggested that in order to achieve meaningful CD in learning, the contradictory information should be relevant for students. That is, students need to experience curiosity and motivation regarding the learning activities, have a certain amount of prior knowledge to be able to understand the new information, have relevant learning strategies to process the new
information, have positive attitudes and epistemological beliefs about learning and teaching, and discuss and work with their peers to integrate the new information.

**Resolution of Cognitive Disequilibrium**

In learning situations, disequilibrium must be kept “just right” to encourage conceptual change. Failure to restore CE through thought, reflection, and problem solving may lead to negative impacts on students’ affective states and learning (Bormanaaki & Khoshhal, 2017; D’Mello & Graesser, 2011). In classroom settings, CD is often set in motion naturally such as when the teacher or another student suggests a new way of defining or solving a problem. Students receive surprising results that go against their expectations and obstruct their goals. Different strategies need to be utilized to help learners to manage CD. Concrete experiences can provide raw material for thinking while communication and interaction make students use, evaluate and finally improve their thinking abilities to accommodate the situation (Woolfolk et al., 2003). VanLehn, Siler, Murray, Yamauchi, and Baggett (2018) explored whether learning was more probable when the students reached an impasse in a computer-based tutoring setting. Impasses occur “when a student realizes that he or she lacks a complete understanding of a specific piece of knowledge” (p. 220), thus, experiencing a state of uncertainty. These researchers asked tutees to solve five problems in a computer-based tutoring setting with the assistance of the tutors. Their results suggested that learning was more common at impasses than when the tutor helped a student to perform the action correctly or when the student did the action without signs of an impasse. As a result, they proposed a strategy, which is to a) use impasse to cause CD in students, b) let students try to perform an action to resolve CD, and c) prompt students to reason and arrive at a solution with appropriate scaffolding.
However, D'Mello & Graesser (2011) argue that this strategy might not work for everyone as learners might have varying levels of domain knowledge, capacity for coping with CD, and ability to self-regulate their learning activities. They suggest that interventions incorporating the VanLehn strategy should be tailored to the individual learners and to scaffold them out of the CD state before they get too frustrated or even disengaged.

**Measurement of Cognitive Disequilibrium**

Zimmerman and Blom (1983) assessed CD by focusing on two topics: degree of uncertainty and response latency. First, they measured the degree of uncertainty (self-report, subjective measure) as an indicator of the level of cognitive conflict since relieving uncertainty was a result of cognitive conflict. Then, they measured response latency (objective measure) as a second measure of cognitive conflict since “hesitation, looking back and forth, and signs of uneasiness and tension” (Zimmerman & Blom, 1983, p. 22) were evidence of cognitive conflict.

Lee (1998) measured levels of CD by conducting individual interviews. Students were presented with anomalous situations in mechanics and electricity. Then, Lee and two other panel members rated the levels of CD using a rating scale while replaying the videotaped individual interviews. After that, the levels of CD were member checked by students.

Kang, Scharmann, and Noh (2004) used the Test of Responses to a Discrepant Event (TRDE) to examine students’ cognitive reactions to a discrepant event. TRDE is a self-report questionnaire appropriate for measuring middle schoolers’ cognitive responses to a discrepant event. It consists of three phases: initial explanation, discrepant event, and students’ rating. In the initial explanation phase, students read a
text passage predicting the result of the problem in the test and write whether they believe the initial explanation. Then, they read another text passage with a discrepant event that contradicted the initial explanation but is consistent with an accurate scientific one and rate the believability of the discrepant event on a scale of 1 (believe) to 3 (do not believe). They also rate the extent of consistency between the initial explanation and the discrepant event on a scale of 1 (consistent) to 3 (inconsistent). Finally, students report on conceptual change after experiencing the discrepant event and explain their reasons for each rating.

The CD measurement methods described above are all time-consuming, difficult to apply with a large number of participants and constrained to a specific content area and learning context. To overcome those difficulties, Lee et al. (2003) developed a Cognitive Conflict Levels Test (CCLT) to measure CD and is appropriate for students who are learning science. It is a self-report questionnaire to examine students’ cognitive conflict levels. It measures not only cognitive factors but also affective factors during CD. CCLT consists of four factors: a) recognition of contradiction, b) interest, c) anxiety, and d) cognitive reappraisal of situation that are based on Lee and colleagues’ (2003) cognitive conflict process model. CCLT is comprised of general statement-type items that are content-free and can be applied to any learning situation (e.g., the result confuses me, I would like to ascertain further whether my idea is incorrect, etc.). The measure was shown to produce good validity and high reliability scores (Lee et al., 2003).

**Pegagogical Implications of Cognitive Disequilibrium**

Learning environments that challenge students through CD are expected to elicit critical thought and deep inquiry. Based on D’Mello & Graesser’s (2011) model of
affective dynamics during complex learning, students experience the uncomfortable state of CD after encountering impasses, which encourages increased cognitive activity such as impasse resolution, problem solving, causal reasoning and critical thinking in order to restore CE. In contrast, students will only be in the state of CE when they learn in comfortable learning environments with predictable strategies and outcomes, thus, yielding limited cognitive engagement.

Teachers play a key role in implementing CD-based strategies successfully. To be effective, teachers should be provided with training to improve their ability of facilitating discussions on the implications of conflicting data and the generation and management of CD. According to Pintrich and colleagues (1993), since motivational constructs such as interest, goals, values, and self-efficacy are potential mediators in the process of resolving CD, teachers should not leave students entirely to their own devices to resolve CD, but instead, must create tasks that increase the opportunities for CD and help students resolve CD by modeling and scaffolding. Akpinar and colleagues (2009) proposed that teachers should provide students with the opportunity to explain a concept, help them establish the relationship between new concepts and previous concepts, and test their ideas regarding the concept. Palmer (2004) suggested that teachers should control the difficulty level of the experience so that students can maintain curiosity and continue to engage in the activity after encountering the CD.

Although CD-based strategies have been frequently investigated and produced positive outcomes in a number of studies (e.g., Guzzetti, Snyder, Glass, & Gamas, 2006), there are still a number of challenges associated with their application in the classroom. Most of these challenges have to do with the complexity of factors
intervening in the context of classroom learning. Chan, Burtis, and Bereiter (1997) have argued that CD-based strategies do not always work to the extent expected. Some have further reported that merely presenting discrepant events such as contradictions, impasses, or anomalous events to students does not consistently cause CD (Chan et al., 1997; Chinn & Brewer, 1998; Lin, 2007). Limón (2001) further explained that CD-based strategies focus exclusively on the individual’s cognitive processes, neglecting many other individual’s characteristics, such as interest, motivation, attitudes, that influence students’ learning in the school setting.

CD-based strategies also do not always lead to conceptual change (Dekkers & Thijs, 1998; Limón, 2001). For example, Kang and colleagues (2010) explored CD with a group of Korean 7th graders and concluded that although students experienced cognitive conflict and SI was triggered by the use of the discrepant event, the influence was too minimal to affect students’ conceptual understanding and the retention of important conceptions. Many students processed the contradictory events in a superficial way without reaching conceptual change. Overall, the general trend with most studies using CD-based strategies is that there is often a “lack of efficacy for students to achieve a strong restructuring and, consequently, a deep understanding of the new information” (Limón, 2001, p. 364).

**Cognitive Disequilibrium in Science Learning**

The concept of CD has had significant influence on science education research (Posner et al., 1982). Akpınar, Erol, and Aydoğdu (2009) conducted a study with the participation of 10 volunteer science teachers and concluded that activities based on cognitive conflict would capture students’ attention in the lesson, provide them with the ownership of the problem, let them be more eager to solve the problems, and increase
their persistence of learning the topic. Madu and Orji (2015) investigated the efficacy of cognitive-conflict-based physics education over the traditionally designed physics instruction and found the students taught with cognitive-conflict-based strategy experienced more conceptual shift that those with traditional method. CD-based instruction aligns with the major principles of how students learn science synthesized by Bransford, Brown, and Cocking (1999). “Students build their scientific understanding on what they already know and believe, and formulate new scientific knowledge by modifying and refining their current concepts and adding new concepts to what they already know” (Bybee, 2006, p. 6). CD-based instruction emphasizes the importance of recognizing students’ current conceptions (and misconceptions) about science and improving their science learning by challenging their existing conceptions. Therefore, CD-based instruction may serve as a valuable tool for science learning.

**Anomalous Data**

CD is often triggered by presenting students with anomalous data, - that is, data that contradict a hypothesis. Anomalous data are often used by scientists to promote deep conceptual change and are important for the revolution of scientific theories and the progress of science (Kuhn, 1970; Limón & Carretero, 2009). Popper (2009) suggested that anomalous data promote scientific revolutions by refuting old hypotheses or theories and facilitating conceptual change. Lakatos (as cited in Nussbaum, 1989) further clarifies Popper’s view that anomalous data do not reject theory directly, but predict new data that could falsify the old hypothesis or theory. Kuhn (1970) asserted that anomalous data alone cannot lead to conceptual change without other urgent necessity. Many models in cognitive science predict that learning usually happens when questions are triggered by anomalous information that need to be solved
(Graesser, Person, & Huber, 1992). Thagard (2012) noted that anomalous data make it possible for learners to develop a more elaborate and sophisticated understanding of science concepts as they have the chance to “integrate new data into their prior knowledge, contextualize them historically, discriminate levels of analysis, and use the dimension of time to give an account of the conflicting information” (Limón, 2001, p. 363).

**Anomalous Data and Cognitive Disequilibrium**

Posner and colleagues (1982) first proposed that one of the conditions to achieve a radical conceptual change was to become dissatisfied with existing conceptions. According to this proposition, use of anomalous data would be a potential strategy to induce CD directly by challenging students’ existing mental models and prior knowledge and prepare them for radical conceptual change in an inquiry-based science learning environment (Chinn & Brewer, 1993; D'Mello & Graesser, 2011). They are intended to draw students’ attention, cause discrepancies in students’ existing conceptions, and encourage them using different strategies to explain the data (Posner et al., 1982).

Many empirical studies have been conducted to demonstrate the influence of anomalous data on students’ cognitive processing. Graesser and McMahen (1993) explored whether anomalous information could cause an increase in questions generated by college students while they solve quantitative problems or comprehend stories. Participants were presented with different versions of each problem or story: a) complete original, b) deletion of critical information, c) addition of contradictory information, and d) addition of salient or subtle irrelevancies. They were encouraged to generate as many questions as they could. The time course of generating the questions and solving the problems was monitored by the experimenter. The results showed that
some types of anomalies such as deletion versions elicited more questions than others (e.g., complete version, contradictory information, and irrelevancy version). Although the authors did not specifically hypothesize how anomalous information would affect participants’ CD experience, their findings implied that anomalous data caused deficiencies in participants’ knowledge, leading them to CD and as a result, triggering their desire for reconciling CD and understanding anomalies by asking questions and using other problem-solving skills.

Limón and Carretero (1997) implemented a study to explore novice students’ responses to anomalous data. They recruited high school students and divided them into two conditions. In condition “A”, only anomalous data were presented. In condition “A+B”, both anomalous and confirmatory data were presented. Students were asked to participate in a paper and pencil task about the origin of life. Results indicated that anomalous data put students in a state of CD and facilitated their awareness of contradiction between their pre-existing conceptions on the origin of life and the new conceptions. Introducing anomalous data was a good start point to promote students’ reflection on the problem presented and their thinking about it, and motivate them to get more domain-specific knowledge about the topic, leading to a deeper degree of conceptual change about science. Although there was not a significant change in their ideas about how life appeared on the earth, Limón (2001) later argued that anomalous data helped establish the foundations for later changes to take place.

People may react to anomalous data in different ways. Piaget (1977) distinguished between adapted and unadapted responses to anomalous data. Unadapted responses refer to those when individuals do not recognize the conflict.
Adapted responses refer to those when individuals recognize the conflict but take it into account to different extent. In order to further understand how individuals respond to anomalous data differently, Chan, Burtis, and Bereiter (1997) implemented a study to examine how individuals and peers process scientific information that contradicts what they believe. They recruited high school students and randomly assigned them to four conditions: a) individual conflict, b) peer conflict, c) individual assimilation, and d) peer assimilation. Students were asked to think aloud or discuss with their peers eight scientifically valid statements that were presented in an order that either maximized or minimized the conflict between new information and existing beliefs. Student verbalizations were tape-recorded and coded for five levels of knowledge-processing activity. Two major approaches to processing of the anomalous data were identified: 1) direct assimilation, which refers to fitting new information into what was already known, and knowledge building, which refers to treating new information as something problematic that needed to be explained.

Chinn and Brewer (1993) proposed a more detailed classification of individuals’ reactions to contradictory information or anomalous data in their theoretical framework for understanding how students respond to contradictory data and why they respond as they do. They classified individuals’ reactions to contradictory data into seven categories, 1) ignoring, 2) rejecting, 3) excluding, 4) holding the anomalous data in abeyance, 5) reinterpreting, 6) peripheral change, and 7) change of theory. The choice of each reaction is influenced by individuals’ existing conceptions, new theory, the anomalous data, and processing strategies. Depending on these variables, the use of anomalous data may or may not lead to CD.
Graesser and colleagues (1993) conducted five studies with college students and found that the anomalous data strategy works best if the learner is able to 1) detect the anomaly, 2) articulate and refer to the anomaly in words, and 3) address the anomaly in the form of a question to overcome CD. Furthermore, Chan et al. (1997) suggested that it is necessary to distinguish between external and internal conflict. External conflict could lead students to treat new concepts as something problematic that needs an explanation, while internal conflict could only lead students to fit the new information into the one they already have without achieving any desirable conceptual change.

**Situational Interest**

As all behavior has both cognitive and affective components (Piaget, 2018) and because interest in science has been declining (Potvin & Hasni, 2014), this section focuses on situational interest (SI), an important affective outcome that is associated with CD. A person’s interest has a powerful influence on learning (Ainley, Hidi, & Berndorff, 2002; Harackiewicz, Barron, Tauer, Carter, & Elliot, 2000; Renninger & Hidi, 2002). As a motivational variable, interest refers to “the psychological state of engaging or the predisposition to reengage with particular classes of objects, events, or ideas over time” (Hidi & Renninger, 2006, p. 112), and this is a particularly relevant variable for improving educational practice. It is inherently dynamic and can be influenced (Hidi & Harackiewicz, 2000). Therefore, learning content and environment can be manipulated to influence the direction of interest and contribute to the development of interest (Renninger, 2000; Renninger & Hidi, 2002). Findings from studies of interest (e.g., Harackiewica, Barron, Tauer, & Elliot, 2000) suggest that educators can trigger and maintain students’ interest by a) providing support or engaging them in personally relevant events; b) empowering students to express curiosity and ask questions; and c)
selecting or creating contexts that encourage problem-solving and strategy generation. Interest is generally conceptualized as individual interest and situational interest (Krapp et al., 1992). Individual interest refers to “a person’s relatively enduring predisposition to reengage particular content over time as well as to the immediate psychological state when this predisposition has been activated” (Hidi & Renninger, 2006, p. 113).

Situational interest refers to “the appealing effect of an activity or learning task on an individual” (Chen, Darst, & Pangrazi, 2001, p. 384). Rather than being narrowly focused and difficult to change as the individual interest, situational interest is known to be more malleable and manipulable by using the instructional materials under the direct control of educators in the school (Hidi & Renninger, 2006). This study will specifically focus on situational interest by reviewing relevant literature and investigating the possibility of triggering it through CD-based approaches.

**The Concept of Situational Interest**

Situational interest (SI) is defined as an affective response to features in the environment (Hidi & Anderson, 1992; Hidi & Renninger, 2006) and characterized by focused and effortless attention accompanied by a positive emotion tone (Krapp et al., 2014; Schiefele, 2009). It is considered to be an interactive construct because it “flows from a person’s relationship with a particular activity” (Reeve, 1996, p. 170). In learning, SI originates from learners’ affective response toward the appealing features associated with a specific learning situation (Mitchell, 1993). The SI fluctuates as a response to the characteristics of the situational factors (Hidi & Renninger, 2006; Krapp, 2007) and may influence subsequent performance (Rotgans & Schmidt, 2011).

Situational interest is theorized to consist of two main forms - a) triggered SI and b) maintained SI (Hidi & Harackiewicz, 2000). These are the first two phases in Hidi and
Renninger (2006)’s four-phase model of interest development (see Table 2-2) that described levels of interest in terms of both affective and cognitive processes as well as characteristics, such as differing levels of effort, self-efficacy, goal setting, ability to self-regulate behavior, that are associated with each phase. Triggered SI (T-SI), which is similar to Mitchell’s (1993) conceptualization of a “catch”, refers to a psychological state of interest that results from the affective experience individuals associate with the environment (Linnenbrink-Garcia, Durik, Conley, Barron, Tauer, Karabenick & Harackiewicz, 2010, p. 649). It is sparked by environmental or text features such as incongruity momentarily and will trigger engagement and attention, but it does not lead to prolonged engagement with the content. The affective responses to the context likely emerge from the form of instruction itself, rather than the content of the course (Linnenbrink-Garcia et al., 2010). Triggered SI is often short-lived but may be a precursor to the more developed phases of interest (Hidi & Renninger, 2006; Renninger et al., 2004; Renninger & Hidi, 2002).

Maintained SI (M-SI), which is similar to Mitchell’s (1993) conceptualization of a “hold”, refers to a deeper form of SI in which individuals start to realize the personal value of the content, build meaningful connections with it, and feel empowered by the knowledge in the situation (Hidi, 2001; Mitchell, 1993). M-SI always involves focused attention and persistence over an extended time (Hidi & Renninger, 2006). It is different from T-SI as it is held and sustained through the context that supports enjoyment, involvement, and persistence (Schiefele, 2009) to help students experience positive feelings and develop value for the content (Renninger, 2009). M-SI is precursory to an
emerging, more stable, personalized interest in the learner (Harackiewicz et al., 2000; Mitchell, 1993).

Both T-SI and M-SI are associated with feelings emerging from the situation. However, T-SI is more associated with feelings that result from the form of instruction, whereas M-SI is more closely related to feelings based on the content of the instruction (Linnenbrink-Garcia, Patall, & Messersmith, 2013). That is, T-SI is an affective response to the way the materials are presented or experienced, whereas M-SI is an affective response to the topic itself. These two phases are “sequential and distinct and represent a form of cumulative and progressive development” (Lin, Hong, & Chen, 2013, p. 2154). Moreover, the length and characteristics of triggered SI and maintained SI are influenced by individual experience and genetic predisposition (Hidi & Renninger, 2006).

Three-factor model of SI. To further understand the concept of SI, Linnenbrink-Garcia et al. (2010) conducted three studies to develop and validate scores on a new measure appropriate for assessing adolescents’ SI across various academic settings. They proposed a three-factor model that divided SI into a) T-SI, b) M-SI-feeling, and c) M-SI-value with empirical evidence from three studies implemented with three different groups of students. Their conceptualization of T-SI was similar to those proposed by other scholars (Hidi & Renninger, 2006; Mitchell, 1993) reviewed above. With regard to the concept of M-SI, they proposed that it can be further decomposed into two components, M-SI-feeling and M-SI-value. This proposition was based upon both theoretical and empirical evidence. The theoretical evidence revealed that SI can grow into individual interest (Hidi & Renninger, 2006; Krapp, 2002) by using the M-SI as the link. Therefore, it was possible that M-SI was structured similarly to individual interest by
having the feeling related components, which characterize “individuals’ affective experiences while engaging with domain content” (Linnenbrink-Garcia et al., 2010, p. 649), and value-related components, which “emerge as individuals come to believe a domain is important and meaningful” (Linnenbrink-Garcia et al., 2010, p. 649). Their empirical evidence justified this proposition by showing that the CFA model with the best fit split the M-SI items into M-SI-feeling and M-SI-value. Therefore, they proposed this three-factor model as it had theoretical accounts closer to individual interest (Schiefele, 2001) and provides “a more nuanced picture regarding the mechanisms for supporting SI” (Linnenbrink-Garcia et al., 2013, p. 611).

Relationship Between Situational Interest and Individual Interest. Interest is typically divided into two kinds: individual interest (II) and SI (Ainley, 2006; Hidi, 2000). II is defined as “a person’s relatively enduring predisposition to reengage particular content over time as well as the immediate psychological state when this predisposition has been activated” (Hidi & Renninger, 2006, p. 113). According to Ainley et al. (2002), students can have II in one or more specific domains or a network of IIIs. Students with II tend to respond positively to stimuli across situations, channel energy into exploring the domain of the stimuli, and expanding their knowledge of it (Durik & Harackiewicz, 2007). Hidi (1990) reported that II is beneficial for cognitive functioning and performance, as students who have interest in a domain or task tend to pay more attention, persist for longer periods of time, enjoy their involvement and acquire more qualitatively different knowledge than individuals without such interest. Similarly, Alexander and Jetton (1996) found that II stimulates deeper processing of knowledge and thus enhances positive subject matter learning. Linnenbrink-Garcia et al. (2013) concluded that II resulted in
enduring conceptual change when it supported self-efficacy and basic prior knowledge. Comparing the characteristics of SI and II, SI is dependent on the features in the environment, yet II has a dispositional quality and resides in the person across situations (Renninger, Hidi, & Krapp, 1992; Schiefele, 1991). Moreover, SI is transitory and context-dependent, whereas II is stable and persistent (Kang et al., 2010).

SI is a precursor to the development of II and can grow into II (Renninger & Hidi, 2011). According to Linnenbrink-Garcia and colleagues (2010), T-SI initiates this process by attracting students’ attention to the material, followed by M-SI that establishes the importance of the material for students, and over time transitioning to the development of II once the connection between students and the material becomes strong. However, SI may or may not evolve into II. Krapp (1999) proposed a multi-stage process depicting the transition from SI to II (see Figure 2-1). First, the occurrence of SI is always a result of an interaction between personal and situational factors (Hidi & Baird, 1986; Bergin, 1999). Second, the T-SI has to be maintained for stability in order to stimulate a long-lasting state of interest. Whether M-SI can be ultimately developed into II depends on a lot of factors. For example, the people-object interaction model (Hidi, 2000) proposes a dual regulation system that can be used to explain the transition. The dual regulation system consists of two systems. The first system deals with a person’s feeling related experiences, such as emotional and motivational dynamics. The second system deals with a person’s cognitively related factors, such as values and goals. The development of II will only occur if a person has developed positive feelings and established meaningful values and goals toward the object. In
other words, M-SI can only be developed into II if it fits into both the existing feeling and value systems of the person.

Pre-existing II also has the potential to influence learners’ approach to situations, thus affecting their experience of SI (Durik et al., 2007; Krapp, 2002; Schiefele, 2009; Tapola, Veermans, & Niemivirta, 2013). Not surprisingly, individuals care about and devote more energy to the topics in which they are personally interested (Renninger, 2000). They feel excited about exploring the domain and establish a solidified link between the person and the domain or activity (Krapp, 2002). According to Durik and Harackiewicz (2007), individuals who enter learning situations with high levels of II are more receptive to the information and eager to engage in the learning activity. In contrast, individuals with low II in the topic are unlikely to become engaged in the activity or to establish a meaningful relationship with the material that is being taught. These two groups of individuals have very different orientations to the material.

Research investigating the influence of II on SI during learning has produced mixed results. Ainley, Hillman, and Hidi (2002) found that II made a relatively small contribution to arousing SI, yet Tsai, Kunter, Lüdtke, Trautwein, and Ryan (2008) revealed that II for the subject was significantly associated with SI. Rotgans and Schmidt (2017) found that only the first measure of SI, taken before the problem was introduced, was highly correlated with II. They concluded that the influence of II on SI was limited, by only having this effect in the absence of a situationally arousing event. Therefore, the result indicates that a certain degree of II students bring with them to class could only determine the starting level of SI. Contrary to Rotgan and colleagues’ (2017) result, Harackiewicz, Durik, Barron, Linnenbrink-Garcia and Tauer (2008) found
that II was not only significantly correlated with SI at the beginning of the course ($r = .32$) but also towards the end ($r = .28$).

**Significance of Situational Interest in Educational Settings**

Research on SI has primarily focused on one of two general topics: 1) the role of seductive details in increasing SI in text-based learning (e.g., Hidi & Baird, 1988; List, Stephens, & Alexander, 2019; Schraw, 1997) and 2) environmental factors that contribute to the development of SI. The first strand of research focuses on examining the impact of features of instructional texts, such as surprising, incongruent, and unexpected information, on SI. In contrast, the second strand of research explores task conditions that are conducive for SI to emerge. Significant findings are identified in these two strands of research and lend support for the important role of SI in educational settings (Hidi, 1990; Renninger, Hidi, & Krapp, 1992; Tapola et al., 2013; Høgheim & Reber, 2015).

As SI is malleable and can be partially manipulated by educators through task design and teaching strategies, it plays an important role in the educational process, especially in engaging learners who don’t have pre-existing interest in content areas, certain academic activities, or topics (Hidi & Harackiewicz, 2000; Kang, Scharmnn, Kang, & Noh, 2010). Palmer (2009) implemented a study to investigate SI and its sources by working with 9th-graders participating in a science lesson focused on inquiry skills. The lesson was designed to facilitate students’ inquiry skills by using a structured sequence which consisted of four main phases: Demonstration, Proposal, Experiment and Report. Students’ self-reported SI scores revealed that students from both low and high achievement groups exhibited the same high level of SI after the lesson and demonstrated the potential of inquiry and hands-on activities in creating SI for the
majority of students, irrespective of their achievement level or previous interest in science. Similar to Palmer's (2009) result, Rotgans et al. (2017) worked with students who had reported low interest in science and found their SI scores increased after a problem-based lesson, indicating that thought-provoking problems were capable of increasing SI for students who lack prior interest in science. In other words, a lack of II can be counteracted by purposeful instructional design.

The benefits of SI for performing cognitive activities have been demonstrated mostly in research using text-based instructional materials (Hidi, 1990). Anderson (1982) conducted a study to investigate whether an interesting text segments might increase learning by affecting the depth of children’s processing, just as meaning emphasis instruction does. Their results suggested that since meaning emphasis instruction and interest affect different underlying facets of the reading process, the extra attention given to interesting text segments might cause the increased learning. Same evidence was found in Anderson’s (1982) and Shirey and Reynolds’s (1988) studies that used identical research procedures and lent support for the effectiveness of SI in facilitating cognitive activities. Both studies were implemented to examine students' text processing. Anderson (1982) focused on fourth-grade students, whereas Shirey and Reynolds (1988) focused on college students. Students first read a series of unrelated sentences that had been previously rated for interest by a peer group. Then, they were asked to respond to a tone while reading. Both reading and reaction time were measured. Their results indicated that longer reading and reaction time were associated with the more interesting sentences, which were also recalled better by students.
Research has also demonstrated the effectiveness of SI in influencing students’ engagement with learning task. Sun and Rueda (2012) conducted a study to investigate possible relationship among motivational and learning variables (interest, self-efficacy, and self-regulation) and three types of student engagement (behavioral engagement, emotional engagement, and cognitive engagement) in a distance education setting. Participants were 203 students enrolled in online classes, who completed an online survey assessing their levels of SI, computer self-efficacy, self-regulation and engagement in distance education. Their results indicated that SI was significantly correlated with the three types of engagement, suggesting that online activities and tools such as multimedia and discussion boards may serve as the situational stimuli to increase students’ engagement in online learning.

Although SI is a transient phenomenon, SI may contribute to the development of long-term II in learners (Alexander & Jetton, 1996; Hidi & Anderson, 1992). Mitchell (1993) found that mathematics classes that were high in SI were particularly effective for students with low II in mathematics. Linnenbrink-Garcia et al. (2010) conducted a series of studies to develop and validate scores on a new measure for assessing adolescents’ SI across various academic settings. They found that the level of SI measured at the beginning of a course predicts the level of II at the end of that course, indicating that SI served as the first important step in developing students’ II. Rotgans and Schmidt (2017) conducted two studies with elementary school science students to explore how II in a subject develops in learners. The results of latent growth curve modeling revealed that the arousal of SI had a positive effect on the development of II and engaging students with interest-provoking didactic stimuli, such as problems, was
critical to triggering SI and increasing II. Bernacki and Walkington (2018) found that students’ II in mathematics could be changed through the triggering of SI by personalizing math problems in an intelligent tutoring system. Likewise, Rodríguez-Aflecht et al. (2018) found that students whose SI was successfully triggered by the game-based learning environment improved their II in science as well.

SI has also been found to affect academic performance. Rotgans and Schmidt (2011) implemented a study to investigate how SI develops over time and how it is related to academic achievement in an active-learning classroom. Sixty-nine undergraduate students worked in small teams on a problem related to their studies (i.e., “market failure”) in a one-day, problem-based learning session. Five measures of SI were administered at critical points in time. A measure of prior knowledge, achievement-related classroom behaviors, and academic achievement were also collected. Results revealed that SI was significantly increased after the problem stimulus was presented. Their path model analysis indicated that SI was highly predictive for observed achievement-related behaviors, such as participation, teamwork, presentation skills, and self-directed learning, which later proved to be significant predictors for academic achievement. Bernacki et al. (2018) found that T-SI – induced by context personalization – predicted students’ performance on math exams administered by teachers in the classrooms.

The relationship between SI and knowledge acquisition was explored by Rotgans et al. (2017) who found SI was a significant predictor of knowledge acquisition by working with both primary and secondary school students in two separate studies. They argued that the more students were aroused by the thought-provoking problem, the
more and better knowledge they acquired. This result was achieved by other studies (e.g. Schmidt et al., 2011), which suggest that more highly aroused students are aware of the gap between what they know and what they need to know to a higher extent and thus spend more effort on the materials to be studied.

**Conditions Influencing the Development of Situational Interest**

Research into SI has identified both triggering and maintaining conditions under which SI can be developed (Schiefele, 1991; Schraw, 1997). Triggering conditions are effective for triggering students’ SI, whereas maintaining conditions are effective in maintaining SI over a period of time. T-SI is the first phase in the four-phase model of interest development (Hidi & Renninger, 2006) and is related to stimulation and focused attention (Hidi & Baird, 1986). M-SI is the second phase in the model and occurs when individuals bring meaning and importance to the material (Mitchell, 1993).

Tapola, Jaakkola, and Niemivirta (2014) implemented a study to examine how elementary school students’ goal orientation profiles and task characteristics influence their SI development. SI was measured in three different phases in two simulated science learning task conditions (i.e., concrete condition and concreteness fading condition) that differed in the concreteness of the task elements. Three achievement goal orientation groups were identified: success-oriented, mastery-oriented, and avoidance-oriented. The results revealed that the condition did not have an effect on the average level of students’ SI. However, students’ goal orientation group partly determined the patterns of changes in SI. Mastery-oriented students’ level of SI was either held constant (concrete condition) or slightly increased (concreteness fading condition) during the task. As mastery-oriented students always aimed for learning and self-improvement, this result indicates that any task that affords an opportunity for
increasing one’s knowledge is likely to trigger SI for mastery-oriented students. The developmental trend of SI was more descending in the concreteness fading condition than that in the concrete condition for the success-oriented students. This result indicates that the novelty effect was able to trigger SI for success-oriented students at first. However, extrinsic features, such as the possibility for demonstrating superior competence, are needed in order to maintain their SI for them. Avoidance-oriented students’ level of SI was the lowest among the three groups and relatively stable in both conditions as expected. As avoidance-oriented students focus on avoiding effort-demanding activities, this result indicates that it was difficult to trigger SI solely by means of situational or task characteristics for avoidance-oriented students.

Situated in a similar science learning environment as Tapola et al. (2014), Rotgans and Schmidt (2017) implemented another study with elementary school science students to investigate whether interest-provoking didactic stimuli, such as problems, is critical to triggering SI and increasing individual interest. Four classes of elementary school students (N=129) were randomly assigned to two conditions in a quasi-experimental setup. The treatment condition received four SI-inducing science problems as part of a course whereas the control condition did not. The results revealed that SI-inducing science problems were effective in triggering SI and were related to growth in II.

Palmer (2009) also investigated SI and its sources by working with small groups of middle school students in a science class. Each group of about eight students participated in a single, 40-minute inquiry skills lesson which consisted of four main phases: Demonstration, Proposal, Experiment and Report. Students’ SI was measured
by only one item immediately after each phase. An audiotaped group interview was carried out at the end of each lesson for students to reflect on the lesson such as stating whether they had been interested and describing what it interested them. Despite students’ lack of inquiry skills, the quantitative data from the one-item survey revealed that science inquiry tasks did generate SI, which fluctuated frequently between phases. There was high interest in the Demonstration, moderate interest in the Proposal, very high interest in the Experiment, and moderate interest in the Report. The audiotaped student interview identified that novelty (i.e. suspense, surprise, novelty) was the most important source of SI, especially in triggering SI in spite of students’ prior interest in science. Learning was also identified the most common source of SI. As learning was consistently reported as the main source of interest in three out of the four phases throughout the lesson, it was therefore more likely to be the source that maintained students’ SI. Choice, physical activity, variety, and social involvement were also identified as the sources of SI with less importance.

Compared to the short-term interventions reviewed above, Lin, Hong, and Chen (2013) conducted a quasi-experimental study to explore how students’ cumulative SI can be developed into better II in a semester-long chemistry lesson. They integrated novelty and aesthetic experience into the lesson for the experiment group (n = 64) while did not integrate any of these elements into the lesson for the control group (n = 105). They incorporated discrepant events in the teaching strategy of prediction-observation-explanation (Borges & Gilbert, 1999). Specifically, the instructor started with asking students to predict what would happen if he turned the cup filled with water upside down and removed window screen attached to the mouth of the cup. Then, the instructor
made the demonstration to prove that the water stayed in the cup even after the window screen was removed, which was against the prediction of most students. The instructor then encouraged reasonable explanations for this discrepant even through classroom discussions. The aesthetic experience was created by adding an elegant dancing motion of the strings along with the music to students’ hands-on activities. The analysis of covariance comparing the two group students’ pre- and post-test perceptions of learning science indicated that the experimental group outperformed the comparison group in their perceptions of interest, enjoyment, and aesthetics. The weekly assessment of students’ SI revealed the seven sources that triggered SI and ordered them based on their frequency reported by students. They were 1) interest level of a learning activity; 2) novelty; 3) joy; 4) aesthetics; 5) practicality; 6) challenge; and 7) curiosity. The results also revealed that the experimental group students’ SI was well maintained by two leading learning activities: demonstrations and hands-on experiments with novelty and aesthetic experience.

To extend the research investigating the sources of SI in science learning context, Ayotte-Beaudet et al. (2019) implemented a study aiming at identifying the factors that were most related to middle school students’ SI in outdoor science lessons. The study involved 26 science teachers, who planned and conducted five outdoor lessons for 2007 students from seventh and eighth grades in their school’s immediate surroundings in line with the existing science program. Students were asked to complete a questionnaire to identify factors that triggered and maintained their SI. They also conducted in-depth semi-structured interviews with teachers to find convergences and divergences with the survey data. The results revealed the first outdoor lesson
produced a novelty effect that triggered SI. Students’ level of preparation and students’ opportunity to make choices maintained middle school students’ SI. However, the results also showed a significant negative correlation with SI when the teachers assigned students to work in pairs, which were inconsistent with the results found in other studies (e.g. Ayar, 2015).

Except science learning context, sources of SI have been investigated in other content learning area as well. Chen, Darst, and Pangrazi (1999) conducted a four-stage study in which they empirically examined the multidimensionality of SI in physical education, using an iterative, multi-sample design. Middle school students were asked to either view jogging and gymnastics stunts on video or participate in physical activities before responding to an instrument developed to measure the 7 dimensions of SI suggested by Deci (1992) in each stage. Exploratory and confirmatory factor analyses were employed to examine the dimensionality of SI and revealed 5 dimensions – Novelty, Challenge, Exploration Intention, Instant Enjoyment, and Attention Demand – that can trigger SI in learning physical activity. However, the findings suggested that the five dimensions may not account equally for SI. Exploration Intention and Instant Enjoyment were the two major dimensions that accounted for 14.59% and 13.66% respectively of total variance for the conceptual and physical task in their study. Novelty, Attention Demand, and Challenge each accounted for a lower percentage of variance. This provides empirical evidence to support the notion that an activity needs to have the characteristics that arouse students’ intention and provide instant enjoyment in order to trigger SI. In contrast, Novelty, Attention Demand, and Challenge played a less important role in eliciting exploration behavior and producing instant enjoyment.
Based on the five dimensional sources of SI identified in Chen and associates’ (1999) work above, Chen, Darst, and Pangrazi (2001) implemented another study to further clarify the influence of the sources, examining how they contribute differently to SI and how the influence of a source might be mediated by other sources. Two samples of middle school students were employed in this study. Students in Sample A evaluated SI and the dimensional sources in conceptual tasks of analyzing jogging and gymnastics stunts on video. Students in Sample B evaluated them in physical tasks of learning basketball. The correlation analysis demonstrated that Instant Enjoyment had a stronger correlation with SI than any other sources and mediated the effects from other sources. A regression analysis indicated that SI was the most influential sources among others. The path analysis revealed a mediating effect of Instant Enjoyment on other sources. Instant Enjoyment was a direct source of high SI and resulted from the features of Novelty, Exploration intention, and Attention Demand in the activities. In addition, Novelty, Challenge, and Attention Demand had an equal effect on Exploration Intention in the conceptual task. In contrast, the effect of Challenge on Exploration Intention was diminished in the physical task. Also, Novelty did not have a direct effect on SI in either conceptual and physical learning tasks but showed a high direct effect on Challenge. Since the five dimensional sources of SI have only been verified in the context of physical education, it is worthwhile to apply them into other learning contexts that involve different kinds of learning tasks.

Mitchell (1993) developed a Situational Interest Survey consisting of 45 items to identify factors that could trigger SI in mathematics learning among high school students. The results from correlational analysis and student interviews indicated that
presenting various cognitive and sensory stimuli (e.g. computer, group work, puzzles) were effective tools to trigger SI. For example, using puzzles was effective in getting students’ curiosity about new information and preparing them for further learning. The study also found that involving students in meaningful tasks is effective in maintaining SI. Involvement refers to the degree to which students felt they are active participants in the learning process. Meaningfulness means students perceive the topics under study as meaningful for them in their present lives. For example, collaborative group work (Renninger & Heidi, 2002) is a source of creating involvement while problem-based learning (Deci, 1992) is a source of creating meaningfulness.

To explore sources of SI in text-based research, Schraw (1997) implemented a study to examine relationships between text characteristics and SI by working with undergraduate students. They were asked to read a typed, double-spaced copy of an 870-word story, and then respond to the Sources of Interest Questionnaire (SIQ). Their factor analysis indicated that suspense, coherence, and thematic complexity accounted for approximately 54% of the variance in SI, a finding consistent with a number of previous studies (e.g., Jose & Brewer, 1984).

In addition to the characteristics of the learning activity, teachers’ personal characteristics are also found to be sources of SI. Rotgans and Schmidt (2011) used correlational and path analyses to explore the influence of teacher characteristics on middle school students’ T-SI. Three teacher characteristics, social congruence, subject-matter expertise, and cognitive congruence were investigated. Social congruence refers to a teacher’s personal interest or concern for students. Subject-matter expertise refers to a teacher’s knowledge in a particular subject. Cognitive congruence refers to a
teacher’s ability to express oneself in a language that students can understand. The results revealed that all three played an influential role in triggering students’ SI. Specifically, cognitive congruence was the most important factor in predicting students’ level of SI in the classroom.

Unlike the previously reviewed studies exploring sources that contributed to overall SI, Linnenbrink-Garcia, Patall and Messersmith (2013) implemented a study to examine antecedents and consequences of three forms of SI, triggered-SI, maintained-SI-feeling, and maintained-SI-value, in the context of a three-week summer residential program for talented high school students. Participants completed self-report measures prior to the start of the summer program and at the end of the program. Multiple regression analyses revealed that classroom practices differentially predicted triggered SI, maintained-SI-feeling, and maintained-SI-value. As expected, autonomy support was associated with high levels of triggered-SI and maintained-SI-feeling. Instructor approachability enhanced triggered-SI but was not related to either form of maintained-SI. Course connections to real life were significantly associated with maintained-SI-value, but not with the other two forms of SI. All three forms of SI were associated with increases in individual interest during the course. Contrary to their hypotheses, involvement (i.e. classroom support for involvement or opportunities for group work) was not associated with triggered-SI, maintained-SI-feeling, or maintained-SI-value.

The sources of SI have been studied in game-based learning as well. Rodríguez-Aflecht, Jaakkola, Pongsakdi, Hannula-Sormunen, Brezovszky, and Lehtinen (2018) conducted a study to explore the development of SI during digital game playing and to investigate the relationship between SI and II in math. Two hundred and twelve 5th
graders participated in this study. They were asked to solve arithmetic problems in different sessions by using the Number Navigation Game independently. Their II in math, SI, and game performance were assessed with different instruments. The results showed that SI was triggered for 73.11% of the participants and maintained for 61.30% of the participants. Also, students’ SI within each session remained stable but their overall SI decreased across sessions, indicating that the novelty feature of the game-based learning environment did not last long. Students who had higher prior II in math achieved corresponding higher SI, which would in return contribute to their II later. Students who had lower prior II in math had a lower chance to be situationally triggered or maintained by the game-based learning environment.

To explore how students’ personal characteristics contribute to SI, Hunsu, Adesope, and Van Wie (2017) implemented a study to examine the role of personal interest, students’ perceptions of meaningfulness and the instructional utility of an innovative hands-on learning module in the development of triggered and maintained SI in an engineering classroom that used hands-on learning modules. Participants were undergraduate students enrolled in a fluid mechanics course at a large public university. They attended two 50-min sessions on heat transfer each week. Heat transfer concepts were taught in lecture-only format and using desktop learning modules as hands-on instructional aid. The stepwise multiple regression analyses revealed that the novelty factor of the innovative instructional method was the most influential in triggering students’ SI. Also, meaningfulness played a more substantive role in predicting maintained SI than in predicting triggered SI. The authors suggested that novelty was a
strong factor to trigger SI while task value and the relevance of content matter were efficient in maintaining SI.

Except for the personal characteristics, instructional elements were found to be related to SI as well. Dorfner, Fortsch, and Neuhaus (2018) examined the effects of three basic dimensions of instructional quality, classroom management, supportive climate, and cognitive activation, on students’ SI in videotaped biology instruction from German sixth-grade classes. They also used multilevel analyses to evaluate the mediating effects of cognitive activation on classroom management and supportive climate. Twenty-eight biology classes were videotaped for three lessons on the topic of botany. The three basic dimensions of instructional quality were separately examined using respective rating manuals. The results revealed that all three basic dimensions were effective in triggering students’ SI and cognitive activation was the only predictor of students’ SI. Also, cognitive activation mediated the effects of classroom management and supportive climate on students’ SI although the latter two dimensions also had direct positive effects on SI.

To explore how students’ out-of-school interests affect SI, Bernacki and Walkington (2018) conducted an experimental study to examine whether context personalization – the incorporation of students’ out-of-school interest into learning tasks – contributes to students’ SI, II, performance, and learning in mathematics. High school students (N=150) participated in this study by solving four personalized units of algebra problems in an intelligent tutoring system. Their SI, II, performance, and learning were assessed by separate instruments. The results revealed that context personalization had a significant impact on triggered SI and indirect effects on maintained SI related to
enjoyment and value. Positive predictive relationships were also observed from triggered SI to maintained SI and from maintained SI to II, controlling for initial II. The study indicated that math problems, which were adapted to reflect students’ interests, were effective in triggering their affective response toward the personalized math problems, which would then contribute to students’ enjoyment of solving math problems and develop their understanding of the value of the math problems. However, types of context personalization approach need to be taken into consideration with regard to the effectiveness of context personalization on improving SI. For example, Hogheim and Reber (2015) reported a higher increased SI by personalizing the surface features of problems, such as names of music artists and locations, than that reported by Bernacki et al. (2018), which personalized the problem by developing a story around the students’ prior interests. In addition, whether students take part in personalizing the problem also affects their SI and learning experience (Walkington & Bernacki, 2014). Besides, the study demonstrated the possibility of changing students’ II in math through the triggering of SI as a result of longitudinal intervention.

Some research has identified conditions that increase SI without differentiating between “triggering” and “maintaining” perspectives. Bergin’s (1999) suggests that instructional aspects such as hands-on activities, discrepancy, novelty of learning stimuli, social interaction by means of group work, modeling experts, using games and puzzles, using fantasy to learn relevant content, humor, using narrative to keep interest can increase students’ SI. The effectiveness of each instructional factor was supported by empirical evidence except that of discrepancy. The discrepancy approach focused on presenting contradictory information to defeat misconception and was frequently
used to facilitate conceptual change. Bergin (1999) argued that people often manifest interest in resolving the discrepancy but the research on conceptual change typically measured understanding rather than interest as the outcome variable.

Berlyne (1960) provided some empirical evidence regarding the effectiveness of discrepancy in increasing SI. Although the term SI was not used, this research focused on environment-based causes of interest, which could be interpreted as the external factors that trigger SI. Berlyne (1960) studied how stimulus characteristics affected perceptual processing of and response to visual and auditory patterns. It was found that interest was a function of collative variables, such as familiar-novel, simple-complex, expected-surprising, clear-ambiguous, and stable-variable, whose underlying characteristics were that they created conflict and uncertainty.

To further explore the relationship between discrepancy-based approach and SI, Kang, Scharmann, Kang, and Noh (2010) conducted a study to investigate the relationships between cognitive conflict and SI induced by a discrepant event. 183 middle school students who had misconception toward weight-density concept were enrolled in this study. They were assigned to work individually on a computer assisted instruction programme as a conceptual change intervention. An animation showing that weight was not a criterion for solving a “sink or float” problem was presented and intended to cause cognitive conflict to them during the intervention. Cognitive conflict, SI, attention, effort, and conceptual change were measured. The results revealed that all students experienced cognitive conflict and SI provoked from the use of the discrepant event. However, cognitive conflict and SI were not directly correlated but all contributed to conceptual change mediated by attention and effort.
To summarize, only four out of 17 studies reviewed above explored how discrepancy approach contributed to the development of SI. Among the four studies, Lin et al. (2013) demonstrated a discrepant event in a physical science classroom and investigated its contribution to SI. However, Lin et al. (2013) was implemented on college students and did not measure CD resulting from the discrepant event. Kang et al. (2010) measured cognitive conflict and explored its relationship with SI. However, their study was situated in a computer-based learning environment and did not include any collaborative learning activities. In contrast, Berlyne (1960) and Bergin (1993) focused primarily on exploring how text elements of opposite meaning contributed to SI during reading tasks and did not provide implications for authentic classroom instruction. Overall, there is still lack of empirical evidence to support the role of CD-based instruction in triggering and maintaining SI in middle school classrooms.

Measurement of Situational Interest

As SI is temporal and context-specific, it is challenging to measure its dynamics over time. There are plenty of strategies, such as short-answer measures, interviews, and free recall questions to measure SI in text-based learning, but there are fewer tools available to assess middle schoolers’ SI in authentic classroom environment. Most of the tools developed for assessing students’ SI in a classroom setting use the self-report format. Mitchell (1993) developed a self-reported scale separating “catch” (triggered SI) from “hold” (maintained SI) to measure SI in secondary math classrooms. However, questions in this instrument are relevant to specific instructional strategies and tools instructors use to engage students in math (e.g., puzzles, computers, and group work), and are mostly irrelevant to classrooms that use other techniques (i.e., CD-based strategies). In contrast, Chen, Darst, & Pangrazi (2001) developed a scale to measure
SI that does not focus on any particular instructional techniques or content area. It was used in Chen and Darst’s (2001) study to measure the SI of four basketball learning tasks with various cognitive and physical demands. They asked students to complete the scale (Chen et al., 2001) in a paper-pencil format, immediately after they interacted with each task since the shorter the time between an event and participants’ reporting of SI, the more accurate and reliable the measurement is supposed to be. This scale measured SI based on five dimensions, Novelty, Challenge, Attention Demand, Exploration Intention, and Instant Enjoyment, each of which was represented by four items. All items possessed the capability to distinguish between high- and low-interest activities. However, this measure focuses solely on the feeling-related beliefs without considering the value-related aspects of SI.

Gungor, Eryilmaz, and Fakioglu (2007) developed an affective characteristics questionnaire that consists of 53 items and used it with 890 freshmen physics students to determine the best-fitting structural equation model between the freshmen’s physics achievement and selected affective characteristics related to physics. The 53 items were divided into 12 subdimensions. The characteristics of students’ SI in physics was one of them. The results indicated that the SI related items had both high reliability and validity scores, but they had been only applied to undergraduate students involved in physics classes and did not differentiate between T-SI and M-SI (Gungor, Eryilmaz, & Fakioglu, 2007).

Rotgans and Schmidt (2011) administered a measure of SI revised from Hidi and Renninger (2006), which explored focused attention and affective reaction five times during crucial points in time with 69 undergraduate students in a one-day, problem-
based learning session. The measure was administered multiple times to monitor students’ change in SI throughout the learning session since aggregating SI over the day would lead to less accurate predictions of achievement-related classroom behaviors and academic achievement. By using the multiple measurements, they found some fluctuations of SI throughout the learning session, but other measures such as the level of active engagement were needed to validate their explanation of these changes. This limitation seemed to be solved in Sun and Rueda (2011)’s study, in which they investigated the relationships among motivational and learning variables (interest, self-efficacy, and self-regulation) and three types of student engagement (behavioral engagement, emotional engagement and cognitive engagement) in a distance education setting. They not only used the Chen and colleagues’ (2001) scale to measure students’ SI involved in an online learning environment, but also correlated the SI scores with their self-reported engagement levels, in order to find explanations for the variations of SI scores.

Lin et al. (2013) conducted a quasi-experimental study to explore how student cumulative SI can be developed into II. Similar to Rotgans and Schmidt (2011), Lin et al. (2013) measured college students’ SI every week from week 2 to week 15 during the semester-long intervention. The questionnaire was composed of both multiple choice and open-ended questions. It was designed to assess students’ SI towards each week’s learning activities. The repeated measures of students’ weekly SI over a total of 11 weeks enabled the researchers to better understand how students responded to different learning activities and to observe fluctuations in students’ interest level towards a specific learning activity. However, the repeated measures also posed other threats to
the internal validity of the design. For instance, students’ scores tend to regress toward the mean if they are assessed several times.

To address the shortcomings of the instruments for measuring SI reviewed above, Linnenbrink-Garcia et al. (2010) developed and validated the Situational Interest Scale (SIS) across various academic settings. The SIS scale was validated with undergraduate students in psychology and middle and high school students in mathematics in three studies. In Study 1, the SIS was administered to undergraduates in introductory psychology. A three-factor model was confirmed by confirmatory factor analyses. In Study 2, the SIS scale was validated with middle and high school students. Items used in Study 1 were further refined to be applicable for middle and high school students who had various prior learning experiences. In Study 3, the SIS scale was implemented with another sample of middle and high school students. The three-factor model was tested with newly revised items. All three studies demonstrated high validity and reliability scores of the SIS scale and supported the three-factor model that appeared to be robust across different educational contexts. The SIS scale is designed to measure students’ overall experience of SI, rather than any specific techniques instructors use to engage students. Moreover, the three-factor model can be used measure T-SI, M-SI-feeling, and M-SI-value respectively and can be used to predict how SI develops into II. It is easy to be implemented with students from elementary to undergraduate levels.

**Using Cognitive Disequilibrium to Trigger and Maintain Situational Interest**

Employing CD to trigger and maintain SI is supported by both theoretical and empirical evidence (Berlyne, 1960; Hidi, 2006; Hidi & Baird, 1986). Behavior theory asserts that “responses depend jointly on external stimuli and on factors within the
organism” (Berlyne, 1960, p. 2). In other words, even if SI is capable of evoking responses from individual, CD may determine whether those responses will eventually occur and their sequence. It was also reported that students demonstrated more curiosity or interest when they encountered an unconventional experience because it was unexpected or surprising (Yarlas & Gelman, 1998). Furthermore, Rotgans and Schmidt (2014) proposed a knowledge-deprivation framework which suggests that SI arises if the learner experiences knowledge deficit (i.e., does not have sufficient knowledge to understand the problem) and becomes acutely aware of the knowledge deficit. Here, the uncomfortable psychological state of CD will trigger learners’ SI as they notice the knowledge gap between what they know and what they don’t know and take actions to bridge the gap. Lee et al. (2003) found students were situationally interested in discrepant events from problems associated with the use of a pulley and the workings of electric bulbs, which caused them to be confused. The finding indicates that CD might play an important role in stimulating SI.

Learning requires a complex coordination between cognitive processes and affective states (D’Mello & Graesser, 2011). Cognitive processes, such as troubleshooting an anomaly, are likely to be affected by CD and accompanied by negative affective states such as irritation, frustration, anger, and rage. Once the CD is reduced/resolved, positive affective states such as content, delight, excitement, and flow will be experienced. According to Mandler (1999), both positive and negative states are systematically affected by the state of knowledge and cognitive processes, and vice versa. Similarly, Sinatra and Pintrich (2003) argued that conceptual change depends not only on CD, but also on affective, metacognitive, and/or motivational factors, which
may stimulate or inhibit the conceptual change process. Kang and associates (2010)
found that students can engage in deeper processing of anomalous data if they have a
higher degree of individual interest in the subject matter. Likewise, Moreno’s cognitive-
 affective theory of learning with media (CATLM) proposes that motivational factors such
as interest, activation, and persistence influence learning by increasing or decreasing
cognitive, emotional and behavior engagement in multimedia learning environments
(Moreno, 2006). That is to say, students with higher CD, interest, self-awareness, and
deliberate goal orientation toward learning would be more likely to actively and
positively engage in conceptual change and deep learning (Kang et al., 2010).
Moreover, cognitive processes such as reducing CD would help students to reflect more
on their learning and this reflection could activate or deepen their interest in the
phenomenon being studied (Limón, 2001). Overall, it seems clear that both cognitive
and affective factors are beneficial for personalizing learning experience and improving
learning outcomes (Walkington & Bernacki, 2014).

SI has a great potential to regulate CD. According to D’Mello and Graesser’s
(2011) model of affective states during complex learning, if the state of CD cannot be
appropriately addressed, it will lead to some negative states such as frustration and
boredom. Once the negative states are detected, pedagogical interventions, such as
providing options of solutions, introducing new activities, and showing support for
exploration, can be implemented to increase SI, thus, alleviating the negative states
(Csikzentmihalyi, 1975; Lepper & Woolverton, 2002; Pekrun, Goetz, Daniels, Stupnisky,
& Perry, 2010).
CD and SI can assist in promoting students' conceptual change. Limón (2001) argues the CD is the first step for any change or restructuring of students’ beliefs, concepts or ideas, but in order to achieve the CD meaningfully, motivational and affective factors, students’ epistemological beliefs, and prior knowledge should also be taken into account. According to Pintrich and colleagues (1993), although motivational factors may not have a direct influence on conceptual change, they may indirectly influence the process of belief formation that takes place when students are experiencing CD and the degree of cognitive engagement students may reach. For example, sometimes anomalous data are not sufficient enough to change students’ concepts since affective variables are intervening with cognitive variables in students’ learning (Lee et al., 2003). In other words, anomalous data might contribute to the triggering of SI, which has the potential to draw students’ attention, increase their persistence over tasks, and elicit more effort in processing the content to facilitate conceptual change. Furthermore, Limón (2001) proposes that motivational factors are dependent on the classroom context, rather than on individual traits only, and it is necessary to conduct research to clarify the relationship between CD and motivational factors like SI in order to design learning environments in which CD-based strategies can be successful.

**Scientific Inquiry and Nature of Science**

As CD-based strategy has been shown to be effective in preparing for conceptual change, it is reasonable to expect that CD may also play an important role in promoting students’ views of nature of science (NOS) and science content knowledge as distal outcomes. This dissertation study took place in the context of a middle school learning activity that employed computational modeling in paleontology to engage students in
estimating the length of the Megalodon. Students measured 3-D printed Megalodon teeth and then used a custom-designed R Shiny Megalodon Body Size App to estimate the size of Megalodon. The entire experience was designed to scaffold student inquiry based on the authentic practices of paleontologists. The critical aspects of NOS in the activity were explicitly discussed with students by the teacher. Authentic scientific inquiry and explicit teaching of NOS were the instrumental treatments for my study and provided rich discursive resources for identifying appropriate science learning contexts. Below I review relevant literature on conceptual change, scientific inquiry, NOS, and the explicit and reflective approach to promote NOS in the classroom to inform this study design.

**Conceptual Change**

According to Westbrook and Rogers (1992), conceptual change is a process that uses instructional strategies to bring children’s thinking in line with that of scientists. It is also a social process by which students make sense of their experience in terms of extant knowledge. Conceptual change is an intentional act done by the learner to change, modify, or reject one’ conceptual beliefs when presented with an anomalous situation (Hewson, 1992).

Conceptual change is the most significant learning model that evolved from the “alternative conceptions movement” in science education (Kang et al., 2005). It posits that learning involves iterative interactions between students’ existing conceptions and their new experiences. Concept confusions may negatively affect the learning of the new topic, lead to misinterpretation of the new concepts, and cause invalid solutions or no solution at all when learners encounter problem situations (Akgun & Deryakulu, 2007). Therefore, teachers need to take into students’ prior knowledge and conceptions
consideration and build new knowledge upon them (Limón, 2001). In science, there are three different conditions of prior knowledge that require different types of learning (Chi, 2008). First, a student may have no prior knowledge and need to learn new knowledge. Second, a student may have some incomplete prior knowledge and need to learn more to fill the gap. Third, a student may have prior knowledge from school or everyday experience that is in conflict with the to-be-learned concepts (Vosniadou, 1994). Posner et al. (1982) also developed a Conceptual Change Model to explain two conditions for conceptual change. The first is the condition (dissatisfaction, intelligible, plausible, and fruitfulness) to be met for a learner to replace non-scientific conceptions with scientific ones. The second is the person’s conceptual ecology, such as previous knowledge and alternative cognition of the learner, that influences the conceptual change. Thus, having a solid base of knowledge about students’ prior knowledge/conceptions and existing conceptual ecology are instrumental to designing instructions to facilitate the conceptual change.

The cognitive conflict strategy has demonstrated its effectiveness in promoting conceptual change in science education. Its newest application was found in Helmers, Youngquist and Grudens-Schuck (2019), in which a brief, focused video aimed to dispel a misconception was designed by following Strike and Posner’s (1992) conceptual change framework and found to be effective in changing farmers, landowners, and their advisors’ understanding of prairie strips. Similarly, Madu and Orji (2015) found students taught with cognitive conflict strategy experienced more conceptual shift in physics learning than those taught with traditional lecture-based approach. They suggested that the difference could be attributed to the presentation of the anomalous situation that
could not be explained with existing concepts, students’ active role in dealing with the cognitive conflict, and their interaction with each other to share ideas and find solutions.

Kang et al. (2010) investigated the relationship between cognitive conflict and students’ conceptual change in learning the concept of density and found cognitive conflict had an indirect effect on students’ conceptual understanding. The indirect effect was mediated by attention and effort allocated to conceptual learning. It is in line with Limón and Carretero’s (2009) earlier discovery, which revealed that even when anomalous data were unable to directly produce conceptual change, almost all students recognized the presence of a contradiction on the topic of the origin of organic life on Earth. That means the acceptance of anomalous data that created cognitive conflict played an important role in conceptual change (Mason, 2000). Even when cognitive conflict does not lead to conceptual change directly, students’ responses to cognitive conflict could mediate their belief changes.

However, some questions have been raised regarding the role of the cognitive conflict strategy in facilitating conceptual change. Kuhn, Amsel, O’Loughlin, Schauble, Leadbeater and Yotive (1988) indicated that most people preferred to adhere to their existing beliefs even in the face of contradictions in the area of scientific thinking. Vosniadou (1993) suggested that students often resolve the contradictions in a superficial way without reaching conceptual change. Furthermore, Chinn and Brewer (1998) argued that merely presenting contradictory information to students is not sufficient enough to induce cognitive conflict. There are many factors, such as an individual’s prior knowledge, the characteristics of the anomalous data, the processing strategy, motivation, that will determine how people respond to cognitive conflict.
According to Kang and colleagues (2005), students’ ability to effectively select necessary information from a contradictory event might play an important role in their response to cognitive conflict. Klaczynski (1997) found that adolescents treated the contradictions on a moment-to-moment basis to suit their existing beliefs. They may not be fully aware of the differences between their existing conceptions and given contradictory data and should be assisted by the teacher who could highlight the cognitive conflict as suggested by Limón (2001).

To understand the challenges associated with the cognitive conflict strategy, Pintrich, Marx and Boyle (1993) proposed that non-cognitive elements, such as emotions, motivational beliefs, and metacognitive factors, should also have to be considered as they may have a mediating effect of students’ conceptual change. Theoretical models proposed after 1993 started to pay attention to the role of affective constructs on student learning. Dole and Sinatra (2005) proposed the Cognitive Reconstruction of Knowledge Model (CRKM), which describes how learner and features of instructional content interact with each other, leading to a degree of engagement with the new concept. The CRKM describes how learner characteristics, such as background knowledge, interest, emotional involvement, and self-efficacy, are implicated in the change process. In line with the CRKM, Gregoire’s (2003) Cognitive Affective Model of Conceptual Change (CAMCC) describes how cognitive and motivational factors interact with features of instructional content that influence learners’ conceptual change. In addition, the CAMCC includes more emotional influences, such as stress, threat appraisals, and goals, on engagement with the instructional content. Both models view conceptual change as a complex process in which cognitive,
affective, and motivational constructs interact in ways that either facilitate or inhibit change (Pintrich et al., 1993).

To summarize the theoretical research on conceptual change, several assertions can be made. First, cognitive conflict can be used to prepare students for the process of conceptual change. Second, cognitive conflict has an important role in facilitating conceptual change, even though its presence does not guarantee the conceptual change. Third, there are many cognitive and non-cognitive factors that influence the effectiveness of cognitive conflict in promoting conceptual change.

**Scientific Inquiry**

Scientific inquiry is conceptualized as “the process by which scientific knowledge is developed and, by virtue of the conventions and assumptions of this process, the knowledge produced necessarily has certain unavoidable characteristics” (Lederman, 2006, p. 308). It refers to the systematic approaches used by scientists to seek solutions to their questions of interest in the real-world setting. It includes traditional science processes, such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analyzing data, as well as scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge (Lederman, 2006). Scientists construct scientific knowledge of the natural world through scientific inquiry (Bybee, 2006).

Scientific inquiry is interpreted in three different ways in science education reforms (Lederman, 2013). First, it can be simply viewed as a set of skills acquired by students and performed in scientific investigations. Second, it can be considered as a learning outcome for students to achieve. Specifically, the newest vision of scientific inquiry has made a clear distinction between performance of inquiry (i.e., what students
will be able to do) and knowledge of inquiry (i.e., what students should know; NRC, 2012). Performance of inquiry refers to engaging learners in designing and conducting investigations that reflects the work of professional scientists and engineers while knowledge of inquiry focuses on their understanding on how scientific knowledge develops (NRC, 2012).

Finally, scientific inquiry can relate strictly to pedagogy. This pedagogical sense of scientific inquiry can be mostly seen in an inquiry-based teaching approach, where scientific inquiry is used as a teaching approach to allow students to construct their own knowledge. It engages students in scientific practices that are defined by the following five essential features: 1) engaging in scientifically oriented questions; 2) giving priority to evidence; 3) formulating explanations from evidence to address scientifically oriented questions; 4) evaluating their explanations in light of alternative explanations, particularly those reflecting scientific understanding; and 5) communicating and justifying their proposed explanations (NRC, 2012).

In this study, scientific inquiry was used as a pedagogical approach to guide both my research and instructional design of the inquiry-based learning activity on estimating Megalodon body size. It involved engaging students in a project to conduct scientific inquiry in an applied, hands-on manner, and construct meaning with teacher guidance to “develop an understanding of the defining qualities of science as a way of knowing and explaining the natural world” (Bybee, 2006, p. 5), “develop some cognitive abilities and manipulative skills associated with scientific inquiry” (Bybee, 2006, p. 5), and “achieve meaningful understanding of scientifically accepted ideas targeted by the
curriculum” (Schwartz et al., 2004, p. 612) and “an appreciation of inquiry and the nature of science” (Bybee, 2006, p. 5).

**Nature of Science**

As a core component of scientific literacy, developing students’ views of NOS is consistent with current scientific practices and science education as well as constructivist perspectives on learning and instruction (AAAS, 1993). “Students should develop an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture” (NRC, 2014, p. 21). Learners with no understanding of the assumptions and values of the scientific knowledge and the scientific process by which that knowledge is created cannot construct a comprehensive picture of science and make the knowledge relevant and applicable (Lederman, 1998). Although the importance of students’ views of NOS is clear, the means to achieve this are not satisfying as many students lack a very basic, baseline understanding of NOS (Schwartz, Lederman, & Crawford, 2004).

Even though NOS is discussed extensively in well-known reform documents (e.g. NRC, 2012), disagreements about the definition and meaning of NOS still exist among philosophers of science, historians of science, scientists, and science educators. However, there is an acceptable level of generality of NOS that is relevant to K-12 students and their daily lives as summarized succinctly by Lederman, Antink, and Bartos (2014). Scientific knowledge has the following characteristics:

1. Tentative (subject to change).
2. Empirically-based (based on and/or derived at least partially from observations of the natural world).
3. Subjective (theory-laden, involves individual or group interpretation) and necessarily involves human inference.
4. Involves imagination.
5. Involves creativity (e.g., the invention of explanations).
6. Socially and culturally embedded (influenced by the society and in which science is practiced).
7. Highlights differences between observation and inference.
8. Highlights differences between scientific theories and laws.

This summarization of NOS is useful for this study because the perspective is primarily focused on “learning outcomes that are developmentally appropriate, have empirical support for learning, and are arguably important for all students to learn so they can achieve the goal of scientific literacy” (p. 291). Lederman and colleagues’ (2014) vision of science education, which is to “develop informed citizens so decisions can be made concerning personal and societal issues that are scientifically-based” (Lederman 2014, p. 291), is aligned with my intention of doing this study and serves as an inspiration for me to design my study. Thereafter, the eight aspects included in Lederman and associates’ (2014) definition were targeted in this study. Specifically, they were incorporated into the instructional design and students’ views of NOS were assessed as a distal learning outcome.

**The Relationship between NOS and Scientific Inquiry**

As students’ naïve NOS views are partly due to their lack of experience conducting scientific investigations, the use of scientific inquiry is strongly recommended to improve learners’ conceptions of NOS (AAAS, 1993; NRC, 1996). Learners who engage in scientific inquiry have a better chance to improve their conceptions of NOS (AAAS, 1993; NRC, 2012). This view is supported in Taking Science to School (NRC, 2007), which suggests that “with appropriate supports for
learning strategies of investigation, children can engage in designing and conducting investigations that enable them to understand science as a way of knowing" (p. 182).
Both NOS and scientific inquiry provide a meaningful context for the subject matter (Lederman, 2006). Moreover, NOS is a significant component of the discipline-specific standards. Students’ experiences in doing science in the context of scientific inquiry provide them with an experiential base upon which to reflect about the process and NOS (e.g., what procedures they used, why they used them, what implications this had for the knowledge produced; Lederman, 2006). For teachers, it is suggested to integrate NOS into the scientific inquiry activities they already do to facilitate students’ understandings of the subject matter.

Despite recent efforts to integrate NOS in science instruction, using scientific inquiry to improve students’ views of NOS has achieved mixed results in K-12 science education research. In Akerson and Abd-El-Khalick’s (2009) study, fourth grade elementary students’ NOS views did not improve after engaging in an inquiry-based science activity. Furthermore, some studies found that while K-1 children were able to improve understanding of NOS (e.g., Akerson & Hanuscin, 2007; Akerson & Volrich, 2006), other studies came to the conclusion that elementary and middle school students were not able to improve their understanding of NOS despite immersion in inquiry science classrooms (Akerson & Abd-El-Khalick, 2009; Meichtry, 1992). Simply situating students in an inquiry-based learning environment, “doing science”, is not sufficient for developing informed views of NOS. Bell, Blair, Crawford and Lederman (2003) investigated the impact of an 8-week science apprenticeship program on understandings of NOS and found that few students changed their conceptions of NOS.
after experiencing scientific inquiry. Their report indicated that no NOS instruction or reflection prompts were used in this program. Schwartz et al. (2004) also found that “doing science” itself did not have an impact on their participants’ conceptions of NOS. Instead, the explicit and guided attention to and reflection on NOS were the critical factors in promoting student views of NOS. An understanding of NOS should be considered as a cognitive learning outcome and taught explicitly rather than “assimilated via a kind of osmotic process during the regular science activities” (Durkee, 1974, p. 352).

**Explicit and reflective instruction.** To tackle the problems associated with scientific inquiry and NOS instruction above, explicit and reflective instruction has been proposed as an effective approach that incorporates instruction specifically focused on various aspects of NOS to improve learners’ views of NOS (Abd-El-Khalick & Lederman, 2000; Bell, Blair, Crawford, & Lederman, 2003; Burgin & Sadler, 2016; Lederman, 2006). The explicit and reflective instruction approach is based on the assumption that “NOS instruction should be planned for and implemented in the science classroom as a central component of learning, not as an auxiliary learning outcome” (McDonald, 2010, p. 1138). This approach emphasizes critical aspects of NOS by means of questioning, discussion, and reflection throughout students’ process of doing scientific inquiry (Schwartz, Lederman, & Crawford, 2004). The explicit aspect refers to giving NOS equal importance as any other cognitive learning outcome (Schwartz & Lederman, 2002). The reflective aspect emphasizes the role of learner reflection on their experience of practicing science, its connection to NOS (Lederman, 2006), and its application “in the context of activities, investigations, and historical examples used in
daily science instruction” (Schwartz & Lederman, 2002, p. 207). It is also associated with instructional elements, such as encouraging students to analyze the activities in which they are engaged from various NOS perspectives, compare their activities with those undertaken by scientists, and draw generalizations about a domain of knowledge, all of which are designed to imitate the activities of scientists in order to understand the workings of science (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002). Overall, the explicit and reflective instruction approach “emphasizes student awareness of certain NOS aspects in relation to the science-based activities in which they are engaged, and student reflection on these activities from within a framework comprising these NOS aspects” (Khishfe & Abd-El-Khalick, 2002, p. 555).

**Relevant Empirical Findings on NOS and Scientific Inquiry**

A number of empirical studies have documented the effectiveness of explicit and reflective instruction in developing learners’ views of NOS (e.g. Khishfe & Abd-El-Khalick, 2002), while some other studies continue to show that the implementation of the explicit and reflective approach does not always lead to improved NOS views for all learners (e.g. Abd-El-Khalick & Akerson, 2004). Since it is impossible to review all studies conducted on NOS and scientific inquiry within the scope of this dissertation, I only focused on reviewing those studies that used the explicit and reflective approach to teach NOS in the context of scientific inquiry.

Adopting an explicit and reflective approach to teach NOS in an inquiry-based learning environment typically improves students’ views of NOS. For example, Richmond and Kurth (1999) investigated the impact of a research apprenticeship on high school students’ understanding of NOS and reported that reflective journals, interviews, and group discussions about NOS helped students improve conceptions of
NOS. Smith, Maclin, Houghton and Hennessey (2018) conducted a longitudinal study in a middle-school inquiry classroom for six years and found that an inquiry classroom for science instruction gave students a more intense inquiry experience and the explicit approach to teaching NOS allowed students to better negotiate understanding of NOS. In Khishfe and Abd-El-Khalick (2002)’s study, sixth-grade students improved their view of NOS by participating in the explicit inquiry group and the explicit reflective instruction was effective at promoting more informed views of NOS.

Abd-El-Khalick (2005) conducted a study to investigate the effectiveness of using philosophy of science to teach the knowledge of NOS with a sample of 56 undergraduate and graduate preservice secondary science teachers. All participants received the explicit, reflective NOS instruction and ten of them were also enrolled in a graduate philosophy of science course. Results indicated that students who were enrolled in the philosophy of science course developed a deeper understanding of NOS than those who did not. Instead of taking the position that the philosophy of science course led to the deeper understanding of NOS, the author claimed that the explicit, reflective approach to NOS provided a framework from which the 10 students enrolled in the philosophy of science course could benefit, thus, maximizing their learning outcomes of NOS.

Similarly, McDonald (2010) conducted a study to assess the influence of a science content course incorporating explicit NOS and argumentation instruction in an inquiry-based learning context on five preservice primary teachers’ views of NOS using multiple sources of data. Results demonstrated that participants had improved views of NOS at the end of the study and provided some evidence to support the claim that
integrating explicit NOS into a science content course based on a scientific inquiry format would lead to desirable developments in participants’ NOS views. In addition, providing opportunities to generate CD early to let learners to recognize the deficiencies in their NOS views enabled them to seek alternative and better views, which informed the design of my dissertation study. Likewise, both Akerson and Volrich (2006) and Akerson and Hanuscin (2007) illustrated the benefits of the professional development stressing the importance of explicitly teaching NOS by engaging pre-service teachers in scientific inquiry in improving their views of NOS.

To summarize, there are more studies focusing on teachers’ views of NOS than those on students’ NOS views and we still need more empirical evidence on effective strategies that can appropriately support K-12 students’ development of their NOS views. Although there is strong evidence that an explicit and reflective approach to the teaching of NOS is more effective than other approaches, there has been limited research to investigate the influences of explicit and reflective NOS instruction within a CD-based conceptual change framework (Posner et al., 1982) on younger students’ NOS views. According to Khishfe and Abd-El-Khalick (2002), the explicit and reflective approach could be enhanced if implemented within a conceptual change framework. Therefore, my intent was to implement a CD-based activity in an inquiry-based science learning environment coupled with the explicit and reflective approach to teach NOS and investigate these treatment effects on students’ views of NOS and science content learning.

**Conceptual Framework**

The conceptual framework for this study summarizes my literature review and represents my understanding of the relationships between the key constructs I am
interested in (Figure 2). This conceptual framework explicates the relationship between CD and SI and helps to “justify the significance of the problem, define relevant concepts, establish theoretical and empirical rationale, guide selection of appropriate of the methods, and scaffold data analysis and interpretation” (Antonenko, 2015, p. 57).

My conceptual framework rests on the assumption that STEM interest plays a critical role in STEM persistence and career aspiration (Maltese & Tai, 2011) and helps to prepare qualified STEM workforce capable of solving social and economic challenges in 21st century worldwide (Honey et al., 2014). The meaningful integration of STEM disciplines in K-12 education holds the promise to support the development of STEM interest but the associated research varies in quality and does not take into account the different phases of interest development (NRC, 2014). In Hidi and Renninger (2006)’s four-phase model of interest development, four phases are proposed: triggered situational interest (triggered SI), maintained situational interest (maintained SI), emergent individual interest (emergent II), and well-developed individual interest (well-developed II). Each phase is characterized by different affect, knowledge and value and has different requirement for learning environments. Among them, situational interest (SI) defined as an affective response to features in the environment (Hidi & Anderson, 1992; Hidi & Renninger, 2006) is of particular relevance to meaningful STEM integration as it uses features in the learning context (Hidi & Anderson, 1992; Hidi & Renninger, 2006) to initiate interest and plays an important role in determining whether the integrative approach will contribute to the development of sustained, individual STEM interest (Renninger & Hidi, 2011).
Because SI is associated with factors such as novelty, uncertainty, and complexity (Silvia, 2010), cognitive disequilibrium (CD), is a relevant factor for the initiation of SI. CD is defined as uncertainty that occurs when students are confronted with stimuli, problems or situations that present obstacles to goals, anomalous events, impasses, contradictions, incongruities, unexpected feedback, novelty, expectation violations, and obvious gaps in knowledge (D'Mello & Graesser, 2012; Graesser, Lu, Olde, Cooper-Pye, & Whitten, 2005). Human mind is constantly seeking cognitive equilibrium, the balance between what is known (i.e. the current schemata) and what is currently being experienced, the incoming information and new knowledge, to achieve cognitive adaptation (Bormanaki & Khoshhal, 2017). However, imbalance is often inevitable and will lead to the uncomfortable situation of CD. Through an active and dynamic self-regulation process, human beings combat CD to regain cognitive equilibrium, the powerful human motivation to promote learning (Piaget, 1977). As CD always happens to scientists in their real-world practice and has the possibility of affecting student science learning in the classroom (Chinn & Brewer, 1993), it is important to explore the effects of CD-based activities in an inquiry-based science learning environment and understand their potential in initiating students’ SI, which is the foundation for developing their sustained, individual interest in STEM and increasing their chances of pursing STEM careers in the future (Yarlas & Gelman, 1998).

A useful vehicle for inducing CD in inquiry-based science instruction is anomalous data (Chinn & Brewer, 1993; D'Mello & Grasser, 2011). They are intended to draw students’ attention, cause discrepancies in students’ existing mental models and prior knowledge and encourage them using different strategies to explain the data.
(Posner et al., 1982). Most importantly, anomalous data play a key role in promoting conceptual revolutions in science as learners can develop a more elaborate and sophisticated understanding of science concepts by “integrating new data into their prior knowledge, contextualizing them historically, discriminating levels of analysis, and using the dimension of time to give an account of the conflicting information” (Limón, 2001, p. 363).

As CD has been shown to be effective in conceptual change (e.g., Hewson & Hewson, 1984), its potential for improving students’ views of the nature of science (NOS) and science content knowledge is worth investigating in an inquiry-based science learning environment. The conceptual change model predicts that learning consists of iterative interactions between students existing conceptions and their new experiences (Kang, Scharmann, Noh, & Koh, 2005). CD is highly appropriate for creating these interactions in order to destabilize students’ confidence in their previous conceptions by presenting contradictory experiences and substituting them with more scientifically accepted ones (Chan et al., 2009). Therefore, situating a CD-based strategy in an inquiry-based science learning environment offers the potential of influencing students’ views of NOS and improving their science content knowledge by engaging them in scientific investigations to construct their own knowledge. Combining a CD-based strategy with the explicit and reflective approach to teaching NOS should improve learners’ views of NOS (Burgin & Sadler, 2016; Lederman, 2006).

**Connection between my Conceptual Framework and Learning Intervention**

My study used the lesson (see Appendix A) “How Big Was Megalodon?” developed by NSF-funded iDigFossils project as the intervention to investigate role of CD in developing students’ situational interest, views if the nature of science, and
science content knowledge. The lesson used “3-D scanning, printing, and analysis of teeth of the Neogene shark Carcharocles megalodon as an example of how paleontology has the potential to integrate all four STEM disciplines and to help develop student interest and motivation in STEM” (Grant et al., 2017, p. 201). The lesson was aligned with a number of grade-specific Next Generation Science Standards and Common Core State Standards. In the section below, I describe how the key concepts discussed in my literature review come into play in this learning intervention.

**Scientific Inquiry**

The activities in the lesson engaged students in an authentic scientific inquiry simulating one of the processes that scientists use to estimate the body length of extinct animals, in this case Megalodon. The lesson was based on two driving questions:

1. How can scientists determine the total body length of Megalodon using fossil teeth? and
2. How do scientists use modern sharks to help them gain an understanding of fossil sharks?

The inquiry process engaged students in observing, predicting, questioning, scientific reasoning, critical thinking, and collaboration, which were all important components of scientific inquiry. A discussion-oriented presentation on Megalodon was used to stimulate students’ interest in scientific inquiry and keep them focused on the essential inquiry processes. The process of using the Great White Shark as the basis for measuring the body length of Megalodon resembled scientists’ real-world practice in seeking answers to their questions of interest. The inquiry was “an authentic science research experience that is exclusively student driven” (Grant et al., 2017, p. 204).
Nature of Science

Students experienced features of NOS throughout the lesson. Students were introduced to previous estimates for Megalodon body length, which ranged from ~15-20 meters for an average adult and the largest living Great White Shark, which is only over 6 meters in length (Gottfried, Compagno, & Bowman, 1996; Shimada, 2003). This helped students to have a basic idea of the massive size of Megalodon. Also, the teacher emphasized that fact that the size estimation of Megalodon would change as the science surround its evolution progressed. This highlighted the uncertainty of the massive size of Megalodon, one of the most important NOS features. It is crucial for students to understand that scientific knowledge is never absolute or certain and is subject to change as new evidence is made possible through advances in theory and technology (Lederman et al., 2014). Students’ experience in measuring the crown height of a Megalodon tooth and predicting its position on the upper or lower helped them to see the potential for error caused by misidentifying the tooth position, another instance of uncertainty associated with NOS. As part of the lesson, students also discovered that the Great White Shark was not a perfect analog for estimating the body length of Megalodon despite the studies suggesting otherwise (Gottfried et al., 1996; Shimada, 2003), which again reaffirmed the uncertainty aspect of NOS. The features of NOS were explicitly discussed throughout the lesson by following the rules of the explicit and reflective approach to teaching NOS in an inquiry-based learning environment. A guide that explained when and how aspects of NOS were discussed with students was provided to the teacher before the lesson. For example, before asking students to use Shimada’s (2003) equation to estimate the body length of Megalodon, the teacher specifically discussed with students about the subjective nature
of scientific knowledge, such as scientists’ different theoretical commitments affecting their choice of methods when estimating the length of Megalodon.

**Cognitive Disequilibrium**

Students in the treatment group were expected to experience CD after receiving an anomalous result of the body length of Megalodon calculated by a flawed version of the R Shiny Megalodon Body Size App. The CD resulted from the contradiction between previous estimates for Megalodon length students learned about previously in the lesson and the actual results students received using the flawed version of the App. To resolve the CD, students engaged in troubleshooting the anomalous data by diagnosing the fault state. The uncomfortable psychological state was expected to elicit questions from students, stimulate their curiosity for knowledge, and drive their quest for answers to explain the anomalous data. The process of trying to resolve CD was hypothesized to improve students’ views of the nature of science, their science content knowledge, and promote their triggered situational interest in science.

**Situational Interest**

The intervention used for this study was manipulated to examine the potential effectiveness of CD in triggering situational interest. Specifically, the treatment group used a version of the R Shiny Megalodon Body Size App to calculate the body length of the Megalodon with a flawed regression model that had incorrect slope and intercept, to produce an abnormally large or small body length estimates (Chinn & Brewer, 1993). As SI can be sparked by environmental features such as surprising, anomalous, and unexpected data, the CD induced by the anomalous result was supposed to trigger SI and the follow-up procedures of resolving CD were supposed to maintain students’ SI.
The control group engaged in the lesson using a properly functioning version of the R Shiny Megalodon Body Size App.

**Research Questions**

Based on the literature review and conceptual framework outlined above, this study was designed to address the following research questions along with their hypotheses:

**Research Question 1.** To what extent does the cognitive disequilibrium generated in a middle school science troubleshooting activity influence students’ triggered situational interest, controlling for the effects of individual interest in science?

- Hypothesis 1: The treatment group will report higher triggered situational interest than the control group.
- Hypothesis 2: Cognitive disequilibrium, including recognition of anomaly, interest, anxiety, and reappraisal of CD situation, will positively predict students’ triggered situational interest.

**Research Question 2A.** How does the cognitive disequilibrium generated in a middle school science troubleshooting activity influence students’ views of the NOS?

- Hypothesis 1: The treatment group will report more informed views of NOS than the control group.
- Hypothesis 2: Cognitive disequilibrium, including recognition of anomaly, interest, anxiety, and reappraisal of CD situation, will positively predict students’ views of the NOS.

**Research Question 2B.** How does the cognitive disequilibrium generated in a middle school science troubleshooting activity impact students’ science content knowledge?

- Hypothesis 1: The treatment group will exhibit better science content knowledge scores than the control group.
Hypothesis 2: Cognitive disequilibrium, including recognition of anomaly, interest, anxiety, and reappraisal of CD situation, will positively predict students’ science content knowledge.

Research Question 2C. How does the cognitive disequilibrium generated in a middle school science troubleshooting activity influence students’ maintained situational interest, controlling for the effects of individual interest in science?

Hypothesis 1: The treatment group will report higher maintained situational interest than the control group.

Hypothesis 2: Cognitive disequilibrium, including recognition of anomaly, interest, anxiety, and reappraisal of CD situation, will positively predict students’ maintained situational interest.

Research Question 3. What troubleshooting strategies do students negotiate and use when resolving cognitive disequilibrium in a middle school science classroom?

Research Question 4. What are middle school students’ perceptions of the science computational modeling activity incorporating cognitive disequilibrium?
### Table 2-1. Other concepts pertinent to CD (Berlyne, 1960)

<table>
<thead>
<tr>
<th>Concept</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doubt</td>
<td>It refers to the conflict between tendencies to believe and to disbelieve the same statement. It can be classified as both learned antagonism and neural processes with an innate physiological process.</td>
</tr>
<tr>
<td>Perplexity</td>
<td>It refers to the conflict when there are factors connecting the subject with a number of mutually exclusive beliefs.</td>
</tr>
<tr>
<td>Conceptual incongruity</td>
<td>It arises out of learned conflict between symbolic responses.</td>
</tr>
<tr>
<td>Confusion</td>
<td>It happens when stimulus patterns are ambiguous that can be confused with one another.</td>
</tr>
</tbody>
</table>

![Multistage process of transition from SI to II (Krapp, 1999).](image)
Table 2-2. The four-phase model of interest development (Hidi & Renninger, 2006).

<table>
<thead>
<tr>
<th>Phase</th>
<th>Features</th>
<th>Requirements for instructional conditions or learning environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triggered SI</td>
<td>-Sparked by environmental or text features</td>
<td>Group work, puzzles, computers, etc.</td>
</tr>
<tr>
<td></td>
<td>-Typically externally supported</td>
<td></td>
</tr>
<tr>
<td>Maintained SI</td>
<td>-Sustained through meaningfulness of tasks and/or personal involvement</td>
<td>Meaningful and personally involving activities such as problem-based learning, cooperative group work, and one-on-one tutoring</td>
</tr>
<tr>
<td></td>
<td>-Typically externally supported</td>
<td></td>
</tr>
<tr>
<td>Emerging II</td>
<td>-Characterized by positive feelings, stored knowledge, and stored value</td>
<td>Peer support, challenges, modeling</td>
</tr>
<tr>
<td></td>
<td>-Typically self-generated</td>
<td></td>
</tr>
<tr>
<td>Well-developed II</td>
<td>-Characterized by positive feelings, and more stored knowledge and more stored value for particular content</td>
<td>Interaction, challenge, peer and expert support</td>
</tr>
<tr>
<td></td>
<td>-Typically self-generated</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2-2. Conceptual Framework
CHAPTER 3
METHODOLOGY

The study was inspired by a) my past middle school science learning experiences as a student and current research experiences in science classroom as an educational researcher and b) my goal of contributing to conceptual and empirical scholarship on students' interest in science learning. Prior research suggests that cognitive disequilibrium (CD) drive curiosity, questions, and inquiry (Berlyne, 1960; Chinn & Brewer, 1993; Festinger, 1962; Piaget & Cook, 1952), and with this study I sought to examine whether and how a CD-based inquiry science learning activity can trigger science learners’ situational interest. Thus, the purpose of this study was to explore the potential of CD to influence students’ triggered situational interest (T-SI) in a middle-school science classroom as the proximal outcome, as well as their (a) views of the nature of science (NOS), (b) science content knowledge, and (c) maintained situational interest (M-SI) as the distal outcomes. In this chapter, I describe the study design, context, participants, intervention, instrumentation, data collection and analysis procedures of the study in detail.

Study Design

A concurrent embedded mixed method design (Creswell & Clark, 2017) was implemented in this study. The purpose of implementing the concurrent embedded mixed method design was to use both quantitative methods and qualitative methods concurrently to understand the complex problem of learning in a CD-embedded inquiry science learning activity in an authentic classroom context. The integration of quantitative and qualitative methods was implemented at three levels. At the study design level, quantitative methods (i.e., learning tests, surveys) were used to guide the
qualitative methods (i.e., interviews, observations) to provide a supporting role and possible triangulation in the procedures (Creswell, 2009). Both quantitative and qualitative data were collected in the same phase. Learning tests and previously validated surveys were used to collect quantitative data to understand students’ individual interest in science prior to the intervention, investigate the quantifiable effects of a CD-based troubleshooting activity on students’ cognition and SI, views of the NOS and science content learning. Observations and semi-structured interviews were used to collect qualitative data to gain a deeper understanding of the aspects of the science computational modeling activity that might have triggered and maintained SI, the strategies students used to negotiate and resolve CD, students’ perceptions of the science computational modeling activity, and how their overall experience in this activity and perspectives of the NOS influenced each other.

At the methods level, the integration occurred through linking the quantitative and qualitative methods of data collection and analysis in four ways: 1) connecting: the interviewees were a subgroup of the students who responded to the survey; 2) building: the results of student responses to the survey and classroom observations informed the selection of students for interview; 3) merging: after data from individual data sources were analyzed, quantitative and qualitative findings were brought together for analysis and for comparison, and 4) embedding: quantitative and qualitative findings were linked at multiple points to explain each other (Creswell, Klassen, Plano Clark, & Smith, 2011).

At the interpretation and reporting level, quantitative and qualitative findings were integrated through narrative in a single report. Specifically, the weaving approach was
employed which involved writing both qualitative and quantitative findings together on a theme-by-theme basis (Creswell et al., 2011).

**Study Context, Participants and Intervention**

**Study Context**

Data collection took place in 8th-grade classrooms at PK Yonge Developmental Research School (PKYDRS). For generalizability purposes, the student population at PKYDRS is specifically designed to represent the diverse population of the state of Florida, the third largest state in the U.S. Thus, the PKYDRS students participating in this study were representative of the diverse population of middle school students in Florida.

**Participants**

Four existing classes (periods) of 8th-grade students at PKYDRS were randomly assigned to either the treatment or control groups as existing intact classes. The random assignment was performed via a coin flip. Eighty-five students were enrolled in the two conditions for this study (43 in the treatment group and 42 in the control group). The students represented a variety of academic abilities, science interests, races, and genders.

**Intervention**

This study adapted and implemented the lesson “How Big Was Megalodon?” (see Appendix A) developed by the NSF-funded iDigFossils project. The lesson used “3-D scanning, printing, and analysis of teeth of the Neogene shark Carcharocles megalodon as an example of how paleontology had the potential to integrate all four STEM disciplines and to help develop student interest and motivation in STEM” (Grant et al., 2017, p. 201). It was taught by the same 8th-grade science teacher in both
treatment and control groups. The teacher was an iDigFossils project teacher leader who was familiar with the project and the lesson.

The lesson addressed two driving questions:

1. How can scientists determine the total body length of Megalodon using fossil teeth? and
2. How do scientists use modern sharks to help them gain an understanding of fossil sharks?

It engaged students in authentic scientific inquiry to estimate the body length of Megalodon. The goal of the lesson was for students to be able to a) understand how scientists use modern sharks to gain understanding of fossil sharks, and b) estimate the size of Megalodon using the measurements of 3D printed fossil teeth and a R Shiny application that provides a graphical user interface for running a linear regression used in computational modeling to estimate the Megalodon total body length. Both treatment and control groups were instructed with an explicit and reflective NOS instruction approach (Lederman, 2006), in which the teacher 1) made various aspects (e.g., uncertainty, tentativeness) of NOS visible within instruction through reflective discussions with students about the practice of science; 2) discussed with students the implications such aspects of NOS and scientific inquiry have for the way they view scientists, scientific knowledge, and the practice of science; 3) took time and explicitly pointed out to students the aspects of NOS and scientific inquiry at the conclusion of any activity (Lederman, 2006). The overview of the lesson design is presented in Table 3-1.

Both treatment and control groups were instructed for about 60 minutes over the same week during which both groups engaged in the same five phases, review, engage, demonstrate, apply and reflect. The activities targeted eight-grade science
content and were aligned with grade-specific Next Generation Science Standards and Common Core State Standards (Appendix A). Students worked in small groups of four and the group membership remained the same throughout the intervention. Below is a detailed breakdown of the lesson procedure.

**Phase 1: review.** The lesson started with the fossil activity, in which students engaged in reviewing their background knowledge of fossils. The teacher first posed two guiding questions: 1) What is a fossil? and 2) What does a fossil tell scientists about the past? Students first individually answered the questions in Nearpod™, an online interactive learning platform and then shared their prior knowledge about fossils, provided examples of fossils, and discussed the importance of studying fossils as a whole class. The teacher prompted students to talk about what they had learned about fossils in 6th grade and helped them establish the connections between fossils and biodiversity, species origination and extinction, past and present climates, oceans, and atmospheres.

**Phase 2: engage.** Students were introduced to Megalodon by watching a short movie trailer. The teacher first posed three guiding questions for students to think while watching the movie trailer: 1) What is/isn’t true in the movie? 2) Why are we interested in Megalodon? and 3) What is the best way to study Megalodon? Then, students watched the official trailer of the movie “The Meg”. After watching the movie trailer, students used their prior knowledge about Megalodon and the trailer to answer the three guiding questions as a whole class. The teacher reminded students of being critical about the information provided by the movie trailer, such as asking the question “Is Megalodon still alive?”. She also helped students to use the information they had
discussed in Phase 1 to answer the guiding questions in Phase 2. Most importantly, the teacher directed students’ attention to the comparison between the Great White Shark and Megalodon, and the potential of using fossil teeth of Megalodon to estimate their massive body length.

**Phase 3: demonstrate.** Shimada’s (2003) method for predicting the body length of the Megalodon was introduced in this activity. The teacher first gave an overview of Shimada’s method for predicting the length of Megalodon. Shimada (2003) developed a series of linear equations correlating tooth-crown height for each tooth position to body length in the living Great White Shark and proposed that the same linear relationship existed in Megalodon. Then, the teacher gave an interactive presentation on the dentition of Megalodon, measurement of tooth crown height using a ruler, and implementation of Shimada’s (2003) equations in estimating the body length of Megalodon.

**Phase 4: apply.** Students engaged in an authentic research challenge of estimating the body length of Megalodon with the R Shiny Megalodon App (see Figure 3-1). A R Shiny Megalodon App was designed by the iDigFossils project to use a linear regression model to perform the estimation based on the measurement of Megalodon teeth correctly placed on either the upper or lower Megalodon jaw. The estimation activity began with an introduction of the set of 46 3-D printed teeth of a specific Megalodon. Each group was assigned with two specific teeth and each pair used one to estimate the body length of this specific individual. They used what they had learned about the dentition of Megalodon from the previous phase to determine the position of the tooth in the jaw. Then, they measured tooth crown height in millimeters. The teacher
presented several examples of computational modeling tools that scientists used in their real-world practice to accelerate discovery and explained how using the R Shiny Megalodon App helped students to estimate the length of Megalodon.

**Cognitive disequilibrium treatment.** Both treatment and control groups used the R Shiny Megalodon App to estimate the body length of this specific Megalodon. Students completed this activity with their group members. Each pair of students worked on one specific tooth. One student was responsible for putting the data in the R Shiny Megalodon App and the other student was responsible for making sure every step was taken correctly. After opening the App, the student first selected the upper/lower jaw and tooth position represented by their fossil Megalodon specimen via two drop down menus. They then typed the crown height of their fossil tooth into the measurement field. Finally, they clicked on the “Size Comparison” tab to see the results of their calculations, including the numerical value and a graphical comparison between Megalodon and the largest recorded Great White Shark (see Figure 3-2). The treatment group used the app to calculate the body length of the Megalodon with a regression model that did not correspond to the tooth that was assigned to them, and received an anomalous result (that was, the technology and the process did not work as expected; Chinn & Brewer, 1993), which was intended to induce CD in students. This problem represented an actual issue encountered by paleontologists who may misidentify the tooth position on the jaw and apply an incorrect linear equation to predict the length of Megalodon (Shimada, 2003). According to Chinn & Brewer (1993), a potentially useful strategy to trigger SI and infuse CD in an inquiry-based science classroom is to present students with unexpected or anomalous data and scaffold troubleshooting activities to
explore the possible causes of such an anomaly. Therefore, students in the treatment group were expected to experience CD induced by an anomalous result – the animal appeared much larger or smaller than the literature suggested regarding the maximum length of Megalodon. Then, they engaged in a troubleshooting activity to solve this issue (Jonassen, 2000). The troubleshooting activity was implemented with the explicit and reflective approach. Students were presented with a guide for troubleshooting the anomalous result, which listed three potential errors that might have caused the anomaly. The three potential errors were a) misidentifying the tooth position, b) making a measurement error, and c) a problem with the R Shiny App. Each pair of students was to check for each potential error one by one and discuss with other teammates about their troubleshooting results. After troubleshooting each potential error, the teacher reviewed the correct answer with students and discussed how each type of error might have occurred in scientists’ real-world practice. In the end, the students found out that the R Shiny Megalodon App did not function properly and led to the anomalous result.
After the troubleshooting activity, each student finished the Megalodon Total Length Activity Worksheet (see Appendix E).

**Control group.** The control group used the same app to calculate the body length of the Megalodon except the app used a regression model that accurately corresponded to the tooth that was assigned to them and provided a realistic total of Megalodon body length (that was, the technology and the process worked as expected). After that, they engaged in a reflective activity to review the process for estimating Megalodon size, discussed how scientists used similar inquiry-based practice to solve real-world problems, and explored the differences between science and other
disciplines with the explicit and reflective approach. They also worked in groups and received the guidance from the teacher. After that, each student finished the Megalodon Total Length Activity Worksheet (see Appendix F).

**Phase 5: reflect.** The lesson was concluded with an activity focusing on students’ overall experience with the lesson. It was be guided by four questions:

1. These teeth all came from one shark, but why do you think we obtained different estimates from different parts of the jaw?
2. Where do you see the “nature of science” in this lesson”?
3. Was scientific inquiry as you expected? Why or why not? and
4. How do you think this lesson will affect your future science learning?

Students discussed their perceptions and experiences as a whole class. In order to facilitate the implementation of this lesson, a teacher guide was collaboratively designed with the teacher. Each phase of the lesson was clearly described in the guide. Learning objective, learning format, student activities, major discussion questions along with the answer keys, essential aspects of VNOS, and when and how the teacher can support students were discussed for each lesson phase.

**Instrumentation**

**Quantitative Instruments**

**Cognitive disequilibrium.** Cognitive disequilibrium was the independent variable manipulated in this study design (see Table 3-2). Only students in the treatment group were assessed on CD since they were exposed to CD. CD was measured by using the Cognitive Conflict Levels test (CCLT; Appendix B) developed by Lee, Kwon, Park, Kim, Kwon, and Park (2003). It is a self-report questionnaire appropriate for measuring middle students’ cognitive conflict levels as they learn science. CCLT is
based on Lee and Kwon’s (2001) cognitive conflict process model and designed to measure students’ levels of cognitive conflict. The measure assesses four major psychological constructs: recognition of contradiction, interest, anxiety, and cognitive reappraisal of situation. Each construct is represented by 3 items in the measure for a total of 12 items. All items use a 5-point Likert scale ranging from 0 (not at all true) to 4 (very true). Example items are “When I saw the result, I had doubts about the reasons”, “When I saw the result, I was surprised by it”, and “The difference between the result and my expectation made me felt strange”. The content validity coefficients rated by experts ranged from .85 to .97. The Cronbach’s alpha for this scale ranged from .86 to .91 as reported by Lee et al. (2003). In the present study, the Cronbach’s alpha of the total and each individual factor scores ranged from .69 to .74. Students in the treatment group completed the CCLT after receiving the anomalous data provided by the Megalodon Body Size App. Analyses were conducted at the aggregate summed score level.

**Situational interest.** Situational interest was a dependent variable in this study design (see Table 3-2). It was expected to be influenced by whether students experience CD or not. It was measured by using the Situational Interest Scale (SIS) (Appendix C) developed by Linnenbrink-Garcia and colleagues (2010). Students in both treatment and control groups completed the SIS before and after the lesson in the pretest-posttest format. SIS is a self-report questionnaire appropriate for assessing adolescents’ SI across three levels of schooling (middle school, high school, and college) in a broad range of academic contexts. There are 12 items which are rated on a 5-point Likert scale ranging from 1 (not at all true) to 5 (very true). Example items are
“This troubleshooting activity is entertaining”, “I like what we are doing in this activity”, and “We are learning valuable things in science”. The Cronbach’s alpha for this scale demonstrates a high degree of internal consistency reliability at $\alpha = .95$ as reported by Linnenbrink-Garcia et al. (2010). In this study, the Cronbach’s alpha of the total and each individual factor scores ranged from .92 to .94. It employs a three-factor model of SI, and yields separate measures for a) triggered SI, b) maintained-feeling SI, and c) maintained-value SI. Analyses were conducted at both the individual factor level and aggregate summed score level.

**Individual interest.** Individual interest was a moderator variable (see Table 3-2) in this study design. It reflected students’ existing interest in science prior to this study’s intervention. Students in both treatment and control groups completed the S-STEM Science attitudes subscale before the lesson. Individual interest was measured using science-related items in student attitudes toward science, technology, engineering, and math (S-STEM) survey (Appendix D) developed by Unfried, Faber, Stanhope, & Wiebe (2015). The Middle/High S-STEM survey is specifically designed to measure middle and high school students’ attitudes toward STEM and interest in STEM careers. The S-STEM survey was used to measure students’ II because its constructs of attitudes corresponded to the definition of II proposed by Hidi & Renninger (2006). There are 9 science-related items which are rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Example items are “I am sure of myself when I do science”, “I expect to use science when I get out of school”, and “Science will be important to me in my life’s work”. The science-related items meet the criteria of following at least one of the three key components of the definition of individual interest:
1) willingness to reengage with particular content, 2) positive feelings, and 3) increased value for the topic (Rotgans, 2015). The Cronbach’s alpha for this science scale demonstrates a high degree of internal consistency reliability at $\alpha = .89$ as reported by Unfried et al. (2015). In this study, the Cronbach’s alpha of the total and each individual factor scores ranged from .79 to .91. The total score from the science-related items was used for analysis in this study.

**Views of the nature of science.** Students’ views of the NOS was a dependent variable (see Table 3-2) and was measured using the Views of Nature of Science Questionnaire (VNOS) Form-D (Appendix F) developed by Abd-El-Khalick and Khishfe (2002). It is a 10-item open-ended questionnaire with follow-up individual interviews to assess students’ views of the tentative NOS. The Form-D was adapted from its original version, Form-A, which demonstrated high construct validity as it was assessed by both NOS experts and non-experts at high school, college undergraduate, graduate, and preservice secondary science teacher levels across four continents (Abd-El-Khalick., 2001). Form-D was created with the aid of focus group of secondary teachers and students. It is easier to be administered as it takes less than one hour and yields the reliability comparable to the original version. The open-ended items allow students to elaborate on their views regarding the target aspect of NOS and the reasons that underlie their views. Students were encouraged to write as much as they can, address all sub-sections of an item, and provide supportive examples to illustrate their point when necessary. Students in both treatment and control groups completed the VNOS-D before and after the lesson in the pretest-posttest format. There was no page limit on their written responses. All participants’ responses to the VNOS-D survey were
categorized as either pertaining to informed or naïve views of the target NOS aspects.

VNOS scores were computed for each student by awarding 1 point for informed view, and 0 point for naïve view. The primary researcher and the teacher rated students’ responses to VNOS-D survey independently. Then, the independently rated VNOS scores for each student were compared. 80 out of 85 student responses were rated the same. The agreement percentage reached 94%. The individual semi-structured interviews were further explained in qualitative instruments section.

Science content knowledge. Science content knowledge was a dependent variable (see Table 3-2) in this study design. Science content knowledge acquired from the lesson was measured by scoring students’ “Megalodon Total Length Activity” worksheet (Appendix E). There were 7 questions on the student worksheet. Example questions were “Was the megalodon that these teeth belonged to bigger or smaller than our classroom? Is your data convincing? Why or why not?”, “If the identified tooth position for one of your Megalodon teeth was off by two positions (the L1 was identified as L3 or A2), what would be the difference in estimated total size?”, and “How do paleontologists infer anatomy and/or biology of an extinct animal such as Megalodon?”. Since the answer to each question was fairly straightforward, I independently scored all students’ answers. Learning scores were computed for each student by awarding 1 point for each complete answer, and 0 point for incomplete answer. In the end, total scores were added up for each student and used for analysis.

Qualitative Instruments

Classroom observation and field notes. As an auxiliary source of data, I conducted classroom observation throughout the entire lesson using The Practices of Science Observation Protocol (P-SOP) (Forbes, Biggers, & Zangori, 2013; Appendix G)
as a complete observer (Creswell, 2009). P-SOP is a valid and reliable observation protocol that can be used to investigate essential features of inquiry and scientific practices in which students engage in classrooms. The Cronbach’s alpha for this instrument ranges from .71 to .98, exhibiting a strong internal consistency. Example items are “students engage with an investigation question that is contextualized, motivating, and meaningful for students”, “students engage with phenomenon of interest” and “students clearly share and justify their investigation question”. I used P-SOP to focus my attention on the essential features of scientific inquiry in the lesson. I also referred to Lederman and colleagues’ (2014) definition of NOS and documented how different aspects of NOS were demonstrated in classroom teaching and learning. In addition, I documented how students responded to the anomalous results of Megalodon length, whether using Piaget (1975)’s adapted and unadapted responses or Chinn and Brewer (1993)’s more detailed classification of individuals’ reactions to anomalous data. I also paid attention to the possible fluctuation of students’ SI. I took intensive field notes, both descriptive and reflective, during the observations (Bernard, 2017). For example, I wrote “most of the students looked confused when they saw the anomalous result” to describe students’ initial action to the anomaly. I also made notes “students in treatment 2 reacted to the anomalous result more strongly than students in treatment 1 because the teacher varied the lesson sequence?” to reflect on what I observed. The observation served an evaluative purpose as well as a source of insights for stimulated recall in interviews (Zoshak, 2016) with students.

**Student interviews.** Interviews with students were an important source of data in my study. It allowed a collaborative and respectful exploration of several components:
students’ experience with CD, SI in the computational modeling learning activity, views of NOS, and overall learning experience. A list of semi-structured interview questions (see Appendix H) was generated based on the results of the self-reported surveys and classroom observations. However, due to the time constraints and school schedule, not all questions were addressed in each individual interview.

**Demographics.** Student participants were asked to provide background information regarding their age, gender, and ethnicity when they took the S-STEM survey prior to the learning activity. They provided demographics and S-STEM data as part of the larger iDigFossils project and this study used these data.

**Data Collection**

The study took place in one data collection phase, during which both quantitative and qualitative data were collected simultaneously (Creswell & Clark, 2017). Parents and guardians received a letter introducing the study along with consent information. The consent form used the opt-out format – namely, the parents only needed to return the form to the teacher if they chose not to allow their child to participate in the study. This format has proven to be effective in other studies conducted at PKYDRS. All parents agreed to have their child participate in the study.

To address Research Question 1, self-report measures of CD, T-SI and II were employed to examine the possible influence of the treatment on students’ CD, T-SI, and II. The CCLT (Lee et al., 2003) was used to measure the level of students’ CD (post). The SIS survey (Linnenbrink-Garcia et al., 2010) was used for assessing students’ triggered SI (pre and post), and the S-STEM survey’s Science attitudes subscale (Unfried et al., 2015) was used for measuring students’ II in science (pre).
To address Research Question 2, measures of NOS, science content knowledge, and M-SI were employed to gauge the influence of CD on these dependent variables. The VNOS-D (Khishfe & Abd-El-Khalick, 2002) was used for measuring students’ understanding of the NOS (pre and post). “Megalodon Total Length Activity” worksheets were scored for measuring students’ science content knowledge (post), and the SIS (Linnenbrink-Garcia et al., 2010) was used for measuring students’ M-SI (pre and post).

To address Research Question 3, I conducted classroom observations and student interviews to investigate students’ responses and strategies to resolve CD.

To address Research Question 4, I conducted classroom observations and interviewed 3 students from the treatment group and 2 from the control group to further explore students’ overall computational modeling learning experience with and without CD.

The lesson was used with the treatment and control groups during the same week in November 2018. All lesson components were identical except for the cognitive disequilibrium treatment. The procedures for data collection were kept the same for both groups. All quantitative measures were collected using Qualtrics™. Each middle-schooler at PKYDRS has a Chromebook™ that was used to access and complete the measures. Before the lesson began, students completed the SIS, S-STEM, and VNOS-D measures. The three measures took approximately 45 minutes to complete. During the lesson, students completed the “Megalodon Total Length Activity” worksheets as an in-class assignment. Students in the treatment group also completed the CCLT survey during the lesson. After the lesson, a week later, students completed the SIS survey
and VNOS-D. Students completed all measures in the classroom where they felt comfortable. All measures were analyzed and interpreted.

I conducted the classroom observation throughout the entire lesson using revised P-SOP to keep track of students' learning experiences. I conducted student interviews after the lesson when all other types of data were collected. Each interview lasted for about 15-20 minutes. All interviews were conducted within the same week following the lesson implementation.

Data Analysis

Quantitative Data

All quantitative data (see Table 3-3) were cleaned for analysis. Since the measures for CD, SIS and S-STEM surveys employed ordinal level data, responses on were summed for each student and for each survey factor. Scores for each measure factor as well as the total scores for the entire scale for each student were used in analyses. Learning scores from the worksheets were summed for each student before use. Each student’s responses on the VNOS-D measure were scored as 1 for informed view and 0 for naïve view. Then, all final data were entered into SPSS for analysis.

Step 1: Checking statistical test assumptions. Assumptions for specific statistic models were checked first. For independent samples t-tests, assumptions including independence, homogeneity of variance, and normality were checked. For dependent samples t-tests, assumptions including normality and paired groups were checked. For ANCOVA tests, assumptions of parametric tests (normality, independence, homogeneity of variance, linearity, homogeneity of regression slopes, and covariate error) were checked and if not met, non-parametric tests (e.g., Mann Whitney test) were adopted as an alternative. For chi-square tests, assumptions including categorical
nature of the data and the independence of the two groups were checked. For linear regression tests, assumptions including independence, homogeneity, linearity, normality, and collinearity were checked. For logistic regression tests, assumptions including linearity, independence of errors, non-zero cell counts, lack of influential data points, and noncollinearity were checked. As common in social and behavioral research, a criterion of .05 was used for determining the level of significance in all statistical tests.

Step 2: Exploring group homogeneity. To determine whether the treatment and control groups were homogeneous relative to SI (T-SI, M-SI-total, M-SI-feeling, M-SI-value), and II, independent samples t-tests were performed on the pre-intervention data. As these two groups were randomly assigned to each condition, the results were to indicate that there was no significant difference between the two groups on any of the variables and they did not differ with each other in SI (T-SI, M-SI-total, M-SI-feeling, M-SI-value), and II.

The homogeneity of NOS between the treatment and control groups was checked by performing chi-square test of independence on the pre-intervention data. As these two groups were randomly assigned to each condition, the results should indicate that there is no association between group and NOS.

Step 3: Examining the influence of CD. First, repeated measures ANCOVA tests with II as a covariate were performed on the pre- and post-intervention data to compare the differences between and within treatment and control groups respectively on the following dependent variables:

- Situational interest (T-SI, M-SI-total, M-SI-feeling, M-SI-value);
- Science content learning
Chi-square test of independence was performed on the post-intervention data to examine whether there was any association between group and NOS. McNemar test was performed on the pre- and post-intervention data to assess if a statistically significant change in NOS within each group.

Next, effect size was computed for all statistically significant findings to further determine the differences between and within the treatment and control groups.

Step 4: Examine the moderating effects of cognitive disequilibrium. To examine how cognitive disequilibrium predicted the influence of the CD treatment on each dependent variable for the treatment group, I used stepwise multiple regression analyses with CD including recognition of anomaly, interest, anxiety, and reappraisal of CD situation as the predictors for the following outcome variables:

- Situational interest (T-SI, M-SI-total, M-SI-feeling, M-SI-value);
- Science content learning

I used a binary regression analysis with CD including recognition of anomaly, interest, anxiety, and reappraisal of CD situation as the predictors for the following outcome variable:

- Views of nature of science

**Qualitative Data**

Qualitative data consisted of two components: classroom observation data and student interview data. I typed up all classroom observation notes and separated them by class periods for analysis. I transcribed all interviews myself through which I became familiar with the data and developed my understanding of the data.
Thematic analysis (Braun & Clarke, 2012) was used to analyze the qualitative data. The focus of the thematic analysis was on systematically identifying, organizing, and offering insight into patterns of meaning regarding students’ troubleshooting strategies and perspectives of NOS. Specifically, I followed Braun & Clarke (2012)’s six-phase approach to thematic analysis to analyze the classroom observation data and the student interview data separately:

- **Phase 1:** I started the analysis process by reading and rereading textual data (i.e. observation notes) or listening to audio recordings (i.e. student interview recordings) to get familiarized with the depth and breadth of the data and make notes on meaning and issues of potential interest in the data by referring to my research questions. As I read or listened to the data, I kept several questions in mind such as “How does this participant make sense of the experience?” “What assumptions do they make in interpreting their experience?” and “What kind of experience is revealed through their accounts?” as suggested by Braun & Clarke (2012).

- **Phase 2:** I started initial data coding by adopting the deductive approach, where I brought to the data a series of concepts, ideas, or topics that were related to my research questions. I coded the data based on the surface meaning of students’ experience with the lesson as well as by identifying or examining the underlying ideas, assumptions, conceptualization, and ideologies behind their experiences.

- **Phase 3:** I reviewed the coded data to identify similarity and overlap between the codes, sorted the different codes into potential themes, and collated relevant coded data extracts within the identified themes. In addition, I started to explore the relationship between different themes and decided how they worked together in giving an overall picture of the data.

- **Phase 4:** I reviewed and refined the themes in two levels. At level one, I read all collated extracts for each theme and decided whether they appeared to form a coherent pattern. At level two, I checked the validity of individual themes in relation to the data set and considered whether the thematic map accurately reflected the meaning evident in the data set as a whole.

- **Phase 5:** I defined and further refined the themes by identifying the essence of each theme and determined what aspect of the data each theme captures. Specifically, I conducted and wrote a detailed analysis for each individual theme and determined how each of them fits into the broader data set in relation to research questions.
Phase 6: I provided a concise, coherent and logical analytic narrative of the data and made an argument in relation to the research focus.

**Data Triangulation**

Triangulation was implemented to enhance the validity of the results (Jick, 1979). Specifically, “between/across method” (Denzin, 2017, p. 302) triangulation was conducted. Between/across method triangulation was used to compare data collected from different methods which were intended to measure the same constructs (Denzin, 1978). The data produced by both quantitative and qualitative methods were compared and contrasted to examine the degree of external validity of the data. For example, I compared the results from the VNOS survey and student interviews to determine whether the mixed methods produced any inconsistent findings. If any divergent results were found, additional interpretations were provided to further explain the findings.
<table>
<thead>
<tr>
<th>Phase</th>
<th>Topic</th>
<th>Focus of Activity</th>
<th>General Problem/Question Investigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fossil</td>
<td>Fossil information</td>
<td>-What is a fossil?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(whole class activity)</td>
<td>-What does a fossil tell scientists about the past?</td>
</tr>
<tr>
<td>2</td>
<td>Megalodon</td>
<td>Background of Megalodon (small group and whole class activity)</td>
<td>-What was Megalodon? Is Megalodon still alive?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-Why do we conduct research on Megalodon?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-How can we know about Megalodon?</td>
</tr>
<tr>
<td>3</td>
<td>The length of Megalodon</td>
<td>Shimada's method for predicting the length of Megalodon</td>
<td>-How to predict the length of Megalodon?</td>
</tr>
<tr>
<td>4</td>
<td>Prediction</td>
<td>Implement the prediction</td>
<td>-What is the length of the Megalodon?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment group: troubleshoot the anomalous data</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control group: reflect on the calculation activity</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Conclusion</td>
<td>Conclusion of the lesson</td>
<td>-What is students’ experience with the lesson?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-How does the lesson affect students’ perspectives on science?</td>
</tr>
</tbody>
</table>
Megalodon Body Size Estimates

Is your tooth from the upper or lower jaw?
Upper Jaw

Position
A1

Crown Height Measurement in Millimeters (mm)
61

Figure 3-1. Screenshot of the R Shiny Megalodon App
### Table 3-2. Research variables

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Cognitive disequilibrium vs. cognitive equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderating Variable</td>
<td>Individual interest (existing state)</td>
</tr>
</tbody>
</table>
| Dependent Variable   | Proximal outcome: Triggered SI (newly developed interest)  
|                      | Distal outcomes: Views of Nature of Science, Science Content Knowledge, Maintained SI (a more sustained form of interest) |

![Screenshot of the size comparison between Megalodon and Great White Shark on R Shiny Megalodon App](image)

**Megalodon**  
Estimated length: 7.08 meters  
The specimen you measured is 1 times longer than the longest Great White Shark on record.

**Size comparison with Great White Shark (below)**

Figure 3-2. Screenshot of the size comparison between Megalodon and Great White Shark on R Shiny Megalodon App
<table>
<thead>
<tr>
<th>Mixed method data</th>
<th>Data source</th>
<th>Data Analysis</th>
<th>Data Triangulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantitative data</strong></td>
<td>CD (during the experiment) SI (pre and post) • T-SI • M-SI-Feeling • M-SI-Value II (pre) Learning (Megalodon total length activity worksheet) (post) NOS (pre and post)</td>
<td>Repeated measures ANCOVA tests (between groups) Dependent samples t tests (within groups) Stepwise multiple regression Binary regression</td>
<td>Between/across method triangulation</td>
</tr>
<tr>
<td><strong>Qualitative data</strong></td>
<td>Observation data (post) Interview data (post)</td>
<td>Thematic analysis (Braun &amp; Clarke, 2012)</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 4
RESULTS

The results are organized according to the four research questions. Question 1, 2(a), 2(b) and 2(c) analyses focused on quantitative data to determine the influence of the intervention (use of CD in a middle school learning activity) on students' cognitive disequilibrium (CCLT posttest), T-SI (SIS pretest and posttest), views of the NOS (VNOS pretest and posttest), science content knowledge (“Megalodon Total Length Activity” worksheet posttest), and M-SI (SIS pretest and posttest). This section contains descriptive data about the participants, overview of the statistical analyses used, and findings related to the influence of CD on T-SI, views of the NOS, science content knowledge, and M-SI. Questions 3 and 4 primarily focused on the analysis of qualitative data to explore students' troubleshooting experience and their perceptions of the science computational modeling activity and to compare and contrast the quantitative and qualitative findings.

Participants Demographics

The participant pool consisted of four intact classes of 8th-grade students at PKYDRS that were randomly assigned to the treatment and control groups. There were forty-five students in the treatment group and forty-three students in the control group. Out of the eighty-eight student participants, forty-six were male, and forty-two were female. Five students identified themselves as American Indian or Alaska Native, 1 was Asian, 3 were Black or African American, 13 were Hispanic, 1 was Native Hawaiian or Other Pacific Islander, 44 identified as White, 11 were Mixed Race or Multi Race, and the rest of the students did not disclose their race. Demographics information for the participants is summarized in Table 4-1.
Influence of Cognitive Disequilibrium on Triggered Situational Interest, Views of Nature of Science, Science Content Knowledge, and Maintained Situational Interest

Quantitative data were collected for the following five variables: a) cognitive disequilibrium, b) situational interest, c) individual interest, d) views of the nature of science, and e) science content knowledge (Table 4-2). The Cognitive Conflict Levels test (CCLT) was administered during the intervention to measure CD resulting from the anomalous data. The Situational Interest Scale (SIS) was administered before and after the intervention to assess students’ situational interest toward the Megalodon lesson. The Science attitudes subscale of the student attitudes toward science, technology, engineering, and math (S-STEM) survey was administered prior to the intervention to assess students’ existing interest in science. Students’ prior interest in science was expected to affect their situational interest toward the lesson. The Views of Nature of Science Questionnaire (VNOS) Form-D was administered before and after the intervention to assess students’ change in views of the NOS as a result of the lesson. The “Megalodon Total Length Activity” worksheet was administered after the intervention to assess students’ science content knowledge from the lesson.

The quantitative data were statistically analyzed using Software Package for the Social Sciences (SPSS) version 25. Independent samples t-tests, ANCOVA, dependent samples t-tests, chi-square test, binary and stepwise multiple regression tests were the statistical analyses performed.

Group Homogeneity

To explore the homogeneity of the treatment and control groups relative to pre-intervention interest in science, independent samples t-tests were used to compare students’ pre-intervention T-SI, II, M-SI-total, M-SI-feeling, and M-SI-value scores. A
chi-square test of independence was used to determine if there was an association between group and views of NOS.

Table 4-3 demonstrates the descriptive statistics for the T-SI scores from the pre-intervention data. All assumptions were met for this test. The treatment group had higher level of T-SI scores ($M = 15.06, SD = 3.36$) than the control group ($M = 14.75, SD = 3.74$). Independent samples t-test indicated that there was not a significant difference in T-SI scores for the two groups, $t(69) = .06, p = .95$.

Table 4-4 shows the descriptive statistics for the II scores from the pre-intervention data. All assumptions were met for this test. The treatment group ($M = 30.28, SD = 5.99$) had higher level of II scores than the control group ($M = 28.00, SD = 6.05$). Independent samples t-test revealed that this difference in the II scores for the two groups was not statistically significant, $t(72) = -1.63, p = .108$.

Table 4-5 provides the distribution of students’ naïve and informed views of NOS from the pre-intervention data. All assumptions were met for this test. A chi-square test of independence indicated there was not an association between group and NOS, $X^2(1) = .34, p = .56$.

Table 4-6 shows the descriptive statistics for the M-SI-total scores from the pre-intervention data. All assumptions were met for this test. The treatment group ($M = 28.50, SD = 6.09$) had higher level of M-SI-total scores than the control group ($M = 25.06, SD = 8.97$). Independent samples t-test indicated that this difference in M-SI-total scores for the two groups was not significant, $t(69) = -1.68, p = .098$.

The descriptive statistics for the M-SI-feeling scores from the pre-intervention data were summarized in Table 4-7. All assumptions were met for this test. The
treatment group ($M = 13.82, SD = 3.62$) had higher level of M-SI-feeling scores than the control group ($M = 12.84, SD = 4.58$) but this difference in M-SI-feeling scores for the two groups was not significant, $t(69) = -.74, p = .461$.

Table 4-8 demonstrates the descriptive statistics for the M-SI-value scores from the pre-intervention data. All assumptions were met for this test. The treatment group ($M = 13.86, SD = 4.66$) had higher M-SI-value scores than the control group ($M = 10.29, SD = 6.26$). Unlike the analyses above, an independent samples t-test indicated that the difference in M-SI-value scores for the two groups was indeed significant, $t(81) = -3.01, p = .004, d = .65$.

The results summarized above suggest that the treatment and control groups were homogeneous relative to T-SI, II, NOS, M-SI-total and M-SI-feeling before the intervention. However, the groups differed in M-SI-value. Therefore, repeated measures ANCOVA tests were used in subsequent analyses to explore the influence of CD on students’ T-SI, NOS, M-SI-total, M-SI-feeling and M-SI-value, controlling for the influence of the pre-intervention M-SI-value. Since II was conceptualized as a moderator influencing the relationship between the CD-based intervention and T-SI/M-SI, it was included as the second covariate in the analyses investigating the influence of CD on students’ T-SI and M-SI.

**Effects of Cognitive Disequilibrium on Triggered Situational Interest**

The influence of CD on T-SI was examined using self-reported SIS scores as the data source for T-SI. A repeated measures ANCOVA test was conducted to compare the differences between and within the treatment and control groups in T-SI controlling for their pre-M-SI-value and II. Table 4-9 shows the descriptive statistics for the T-SI scores before and after the intervention from both the treatment and control groups.
With regard to the between group differences, the treatment group \((M = 15.68, SD = 3.76)\) had higher level of T-SI scores than the control group \((M = 14.47, SD = 3.41)\) after the intervention. The covariate, pre-M-SI-value, significantly predicted the T-SI score after the intervention \((F(1, 62) = 24.61, p < .01)\). The covariate, students’ II, did not significantly predict the T-SI score after the intervention \((F(1, 62) = .00, p = .959)\). A repeated measures ANCOVA test indicated that there was not a significant difference in T-SI between the two groups after controlling for pre-M-SI-value and II, \(F(1, 62) = .22, p = .638\).

With regard to the within group differences, the control group had lower post-T-SI score \((M = 14.47, SD = 3.41)\) than their pre-T-SI score \((M = 14.75, SD = 3.74)\). For the treatment group, their post-T-SI score \((M = 15.68, SD = 3.76)\) was higher than their pre-T-SI score \((M = 15.06, SD = 3.36)\). The covariate pre-M-SI-value did not significantly influence the change of the T-SI scores \((F(1, 62) = 1.80, p = .185)\). The covariate students’ II did not significantly influence the change of the M-SI-feeling scores \((F(1, 62) = .00, p = .96)\). A repeated measures ANCOVA test revealed that there was not a significant difference in T-SI after controlling for pre-M-SI-value and II within both groups, \(F(1, 62) = 2.33, p = .132\).

A stepwise multiple regression analysis was conducted to explore whether the CD factors of a) recognition of anomaly, b) interest, c) anxiety, and d) reappraisal of CD situation were significant predictors of T-SI for the treatment group. All assumptions were met for this test. Table 4-10 shows the descriptive statistics for the CD scores after the intervention for the treatment group. The results of the regression indicated that the factor reappraisal of CD situation significantly predicted students’ T-SI and explained
about 16% of the variance in students’ T-SI ($F(1, 39) = 7.42, \ p = .01, \ R^2 = .16$). The more students reappraised the CD situation, the higher the T-SI scores they reported ($b = .4, \ t(39) = -2.72, \ p = .01, \ d = .19$).

To summarize, there was not a statistically significant difference in T-SI between and within the treatment and control groups after the intervention. The factor reappraisal of CD situation was a significant predictor of T-SI for the treatment group.

**Effects of Cognitive Disequilibrium on Views of the Nature of Science**

The influence of CD on students’ views of NOS was examined using self-reported VNOS scores as the data source for VNOS. A chi-square test of independence was performed to determine if there was an association between group and students’ views of NOS. All assumptions were met for this test. Table 4-11 shows the distribution of students’ naïve and informed views of NOS. The treatment group had a smaller number of students who had naïve views of NOS ($n_{post} = 33$) than the control group ($n_{post} = 39$). The control group ($n_{post} = 5$) had almost the same number of students who had informed views of NOS as the treatment group ($n_{post} = 6$). A chi-square test of independence indicated that there was not an association between group and VNOS, $X^2 (1) = .29, \ p = .59$ after the intervention.

A McNemar test was performed to assess if there was any statistically significant change in VNOS within each group. All assumptions were met for this test. The number of students who had informed VNOS remained almost the same for the treatment ($n_{pre} = 7, \ n_{post} = 6$) and control groups ($n_{pre} = 5, \ n_{post} = 5$) after the intervention. However, the number of students who had naïve VNOS increased for both treatment ($n_{pre} = 27, \ n_{post} = 33$) and control groups ($n_{pre} = 28, \ n_{post} = 39$). A McNemar test revealed that there was
not a statistically significant difference in the proportion of informed and naïve VNOS before and after the intervention within each group, \( p = .23 \).

A binary regression model was performed to examine whether CD factors a) recognition of anomaly, b) interest, c) anxiety, and d) reappraisal of CD situation were significant predictors of students’ VNOS. The resulting model was not significant.

To summarize, there was not a statistically significant difference in VNOS between the treatment and control groups. The CD treatment did not significantly influence students’ VNOS. CD factors were not significant predictors of students’ VNOS.

**Effects of Cognitive Disequilibrium on Science Content Knowledge**

The influence of CD on students’ science content knowledge was examined using their scores on “Megalodon Total Length Activity” worksheet as the data source for science content knowledge. An ANCOVA test was implemented to explore potential differences between treatment and control groups relative to their science content knowledge controlling for their pre-M-SI-value. All assumptions were met for this test. Table 4-12 shows the descriptive statistics for students’ scores on the science content knowledge measure for the treatment and control groups. The treatment group (\( M = 3.29, SD = 1.53 \)) had a lower level of science content knowledge scores than the control group (\( M = 3.68, SD = 1.53 \)) after the intervention. The covariate, pre-M-SI-value, did not have a statistically significant influence on science content knowledge score after the intervention (\( F(1, 75) = .20, p = .65 \)). An ANCOVA test indicated that there was also not a significant difference in science content knowledge between the two groups after controlling for their pre-M-SI-value, \( F(1, 75) = 2.37, p = .13 \).

A stepwise multiple regression analysis was conducted to explore whether CD factors a) recognition of anomaly, b) interest, c) anxiety, and d) reappraisal of CD
situation, were significant predictors of students’ science content knowledge for the treatment group. All assumptions were met for this test. Table 4-10 shows the descriptive statistics for the CD scores after the intervention for the treatment group. The regression model was not significant.

To summarize, there was not a statistically significant difference in science content knowledge between the treatment and control groups. CD factors were not significant predictors of students’ science content knowledge.

**Effects of Cognitive Disequilibrium on Maintained Situational Interest**

The influence of CD on students’ M-SI-total, M-SI-feeling, and M-SI-value were examined using SIS total and factor scores for M-SI as M-SI data sources and reported in separate sections.

**Maintained situational interest – total scores**

A repeated measures ANCOVA test was conducted to compare the differences between and within treatment and control groups in M-SI-total controlling for pre-M-SI-value and II. Table 4-13 shows the descriptive statistics for M-SI-total scores before and after the intervention from both the treatment and control groups. With regard to the between group differences, the treatment group ($M = 30.15$, $SD = 5.75$) had higher level of M-SI-total scores than the control group ($M = 25.66$, $SD = 6.54$) after the intervention. The covariate, pre-M-SI-value, significantly influenced their M-SI scores after the intervention ($F(1, 62) = 112.79$, $p < .01$). The covariate, students’ II, did not significantly influence their M-SI scores after the intervention ($F(1, 62) = .93$, $p = .339$). A repeated measures ANCOVA test indicated that there was not a significant difference in M-SI-total between the two groups after controlling for their pre-M-SI-value and II, $F(1, 62) = .53$, $p = .47$. 132
With regard to the within group differences, the control group had higher post-M-SI-total scores ($M = 25.66$, $SD = 6.54$) than their pre-M-SI-total scores ($M = 25.06$, $SD = 8.97$). The treatment group post-M-SI-total scores ($M = 30.15$, $SD = 5.75$) were higher than their pre-M-SI-total scores ($M = 28.50$, $SD = 6.09$). The covariate, pre-M-SI-value, significantly influenced the change in the M-SI-total scores ($F(1, 62) = 49.13$, $p < .01$). The covariate, students’ II, did not significantly influence the change of the M-SI-total scores ($F(1, 62) = 1.48$, $p = .228$). A repeated measures ANCOVA test revealed that the interaction between time and group was statistically significant, controlling for their pre-M-SI-value and II, $F(1, 62) = 8.51$, $p = .005$, $d = .12$. Dependent samples t-tests were conducted as follow-up tests to examine the change of M-SI-total scores within each group. The results indicated that there was a significant difference between pre-M-SI-total and post-M-SI-total scores for the treatment group, $t(37) = -2.31$, $p = .026$, $d = .08$. There was not a significant difference between pre-M-SI and post-M-SI scores for the control group, $t(32) = -.72$, $p = .476$.

**Maintained situational interest – feeling scores**

Table 4-14 provides the descriptive statistics for M-SI-feeling scores before and after the intervention from both the treatment and control groups. With regard to the between group differences, the treatment group ($M = 15.15$, $SD = 3.49$) had higher level of M-SI-feeling scores than the control group ($M = 12.94$, $SD = 3.46$) after the intervention. The covariate, pre-M-SI-value, significantly predicted M-SI-feeling scores after the intervention ($F(1, 62) = 39.73$, $p < .01$). The covariate, students’ II, did not significantly influence their M-SI-feeling scores after the intervention ($F(1, 62) = .40$, $p = .527$). A repeated measures ANCOVA test indicated that there was not a significant
difference in M-SI-feeling between the two groups after controlling for their pre-M-SI-value and II, $F(1, 62) = .05, p = .828$.

With regard to the within group differences, the control group had higher post-M-SI-feeling scores ($M = 12.94, SD = 3.46$) than their pre-M-SI-feeling scores ($M = 12.84, SD = 4.58$). Treatment group post-M-SI-feeling scores ($M = 15.15, SD = 3.49$) were also higher than their pre-M-SI-feeling scores ($M = 13.82, SD = 3.62$). The covariate, pre-M-SI-value, significantly influenced the change of the M-SI-feeling scores ($F(1, 62) = 17.52, p < .01$). The covariate, students' II, did not significantly influence the change of the M-SI-feeling scores ($F(1, 62) = .30, p = .586$). A repeated measures ANCOVA test revealed that the interaction between time and group was statistically significant, controlling for their pre-M-SI-value and II, $F(1, 62) = 8.35, p = .005, d = .12$. Dependent samples t-tests were conducted to examine the change in M-SI-feeling scores within each group. The results indicated that there was a significant difference between pre-M-SI-feeling and post-M-SI-feeling for the treatment group, $t(37) = -3.00, p = .005, d = .37$. There was not a significant difference between pre-M-SI-feeling and post-M-SI-feeling scores for the control group, $t(32) = -.28, p = .783$.

**Maintained situational interest – value scores**

Table 4-15 shows the descriptive statistics for M-SI-value scores before and after the intervention from both the treatment and control groups. With regard to the between group differences, the treatment group ($M = 14.92, SD = 3.03$) had higher level of M-SI-value scores than the control group ($M = 13.16, SD = 3.56$) after the intervention. The covariate, students' II, significantly influenced their M-SI-value scores after the intervention ($F(1, 71) = 10.27, p = .002$). A repeated measures ANCOVA test indicated
that there was a significant difference in M-SI-value between the two groups after controlling for their II, \( F(1, 71) = 7.44, p = .008, d = .10 \).

With regard to the within group differences, the control group had higher post-M-SI-value scores \((M = 13.16, SD = 3.56)\) than their pre-M-SI-value scores \((M = 10.29, SD = 6.26)\). For the treatment group, their post-M-SI-value score \((M = 14.92, SD = 3.03)\) was higher than their pre-M-SI-value score \((M = 13.86, SD = 4.66)\). The covariate, students’ II, did not significantly influence the change of the M-SI-value scores \((F(1, 71) = .11, p = .745)\). A repeated measures ANCOVA test revealed that the interaction between time and group was not statistically significant, controlling for their II, \( F(1, 71) = 1.66, p = .202 \).

Stepwise multiple regression analyses were conducted to explore whether CD factors a) recognition of anomaly, b) interest, c) anxiety, and d) reappraisal of CD situation were significant predictors for M-SI-total, M-SI-feeling and M-SI-value for the treatment group. All assumptions were met for these tests. Table 4-10 shows the descriptive statistics for the CD scores after the intervention for the treatment group. The results of the regression analyses indicated that reappraisal of CD situation significantly positively predicted students’ M-SI-total score and explained about 14% of the variance in M-SI \((F(1, 39) = 6.16, \ p = .018, R^2 = .14)\). The more students reappraised the CD situation, the higher M-SI-total scores they reported \((b = .37, t(39) = -2.48, p = .018, d = .16)\). Reappraisal of CD situation also significantly positively predicted students’ M-SI-feeling and explained 20% of the variance in M-SI-feeling \((F(1, 39) = 9.59, \ p = .004, R^2 = .20)\). The more students reappraised the CD situation, the higher M-SI-feeling scores they reported \((b = .61, t(39) = -3.10, p = .004, d = .25)\). In
addition, the results of the regression indicated that CD anxiety significantly positively predicted students’ M-SI-value and explained 13% of the variance \((F(1, 39) = 5.75, \ p = .021, R^2 = .13)\) in M-SI-value. The more anxious students felt about their CD, the higher M-SI-value scores they reported \((b = .41, t(39) = -2.40, p = .021, d = .15)\).

### Students’ Troubleshooting Strategies and Perceptions of the Activity

Students’ troubleshooting experience and strategies were explored using classroom observations, interview data, VNOS data, and overall perceptions of the science computational modeling activity. The classroom observation data were recorded by me in the form of intensive field notes, both descriptive and reflective, during the observations (Bernard, 2017). The student interview data were all recorded and transcribed verbatim. I interviewed five students and assigned each student pseudonym. They were Joy, Mia and Dan from the treatment group and George and Peggy from the control group. Thematic analysis was used to analyze the qualitative data by following the Braun and Clarke’s (2012) six-phase approach.

### Strategies to Resolve Cognitive Disequilibrium

Qualitative data were explored to understand students’ experience with CD in the computational modeling activity. In this study, students’ CD was described as a state of uncertainty accompanied by anxiety or interest and reappraisal of the CD situation when students were confronted with the anomalous result of the Megalodon body length calculated by the flawed R Shiny Megalodon App. During my classroom observations, I paid close attention to students’ CD experience, their emotions, and reactions, and documented the strategies they negotiated and used to resolve CD in my field notes. During student interviews, I probed students’ experience after receiving the anomalous result of the Megalodon length by asking relevant questions, even though the
terminology “cognitive disequilibrium” was never mentioned to students. Because only students in the treatment group experienced CD with the anomalous data, qualitative data from only the treatment group were analyzed to address this research question. I interviewed three students from the treatment group: Joy, Mia, and Dan. Thematic analysis (Braun & Clarke, 2012) was used to systematically identify, organize, and offer insights into the qualitative data. Based on the analysis of the qualitative data, the following themes emerged relative to our understanding of student experiences and strategies to resolve CD.

**Theme 1: the CD experience was different for students in different classes.**

My observations of the classes from the treatment group revealed that students had different CD experiences in different classes. Although the classes were taught by the same teacher, the lesson sequence was slightly different for the two classes. In the first treatment group, the teacher did not tell students that the Megalodon teeth they were working with were from the same Megalodon until after they completed the inquiry. Therefore, students did not expect their answers to be the same as they assumed their teeth were from different Megalodons. In the second treatment group, the teacher told students that the Megalodon teeth they were working with were from the same Megalodon before the inquiry. Thus, students were expecting their estimated results to be the same as their teeth were from the same Megalodon. As a result, even though students were all surprised at the anomalous result calculated by the flawed R Shiny Megalodon App, their resulting level of CD was different. As my observation notes revealed,
Students in the first treatment group say, “My result is low”, “This is no way”, “This is too big”, “It’s not good” and “The shark is big as the ocean”. Students in the second treatment group say, “My result was way bigger than yours”, “Why is mine different from yours”, and “Mine was absolutely right. Yours is too small for Megalodon”. Students in the first treatment group are only confused about their own anomalous data while students in the second treatment group also compare their anomalous data with their peers.

Students in the first treatment class experienced CD only as a result of the anomalous data. In contrast, students in the second treatment class experienced CD triggered not only by their own anomalous result, but also through its comparison with their peers. Consequently, students in the second treatment group had a more complex experience with CD than did the students in the first treatment group. Joy from the second treatment group commented in her interview, “I was a little confused when I got the weird answer and I was more confused when I found out everybody was getting different things. It made me uncomfortable”.

**Theme 2: students chose to communicate with each other to make sense of the anomalous result.** Based on my observation, most students chose to talk to others after experiencing confusion and CD as a just-in-time strategy. As I wrote in my observation notes,

Students in the first treatment class are very confused about their results. Some of them show their results to others and ask what is wrong with their results. Some choose to talk to their partners and try to figure out how they come to such ridiculous results. Some shout their results out and try to communicate with students who sit at the opposite side of the classroom. Students in the second treatment class have very similar reactions. They are also very eager to express their confusion and want to discuss their results with their peers. They either want to find out what went wrong or get reassurance from their peers regarding their anomalous results.

Students became very emotional with their results in both treatment classes and wanted to resolve the uncomfortable state of CD by talking to their peers. The three
interviewees from the treatment group all chose to collaborate with their peers in an attempt to resolve their CD. Dan from the treatment group mentioned in the interview,

Mine was like 20 times bigger than the Great White Shark. I don’t think that’s right. I was totally confused. And I talked to my partner so we could problem solve together. It wasn’t like you were just sitting and don’t know what to do. I could ask my partner so we could work together to solve the problem.

Joy compared her anomalous result with others in the class and felt less uncomfortable after knowing that her peers also received the anomalous results. She commented in the interview,

It made me feel more comfortable when I found out everybody was getting different things. It made me feel like I could present my answer and be confident even my answer was no norm. I could feel everybody was on the same page and we could all explore what answer we got together. It might be true or it’s not but it presented the idea of there being some abstract part of it.

She enjoyed being in the uncomfortable state of CD and being confused about something. She even regained her confidence by knowing that everybody was in the same situation as she commented, “it was a really fun experience because we got to be comfortable with not knowing everything and be confident about not knowing everything”.

**Theme 3: some students chose to compromise on the anomalous result.**

Mia chose a different strategy to cope with her CD experience. After getting the anomalous result of the Megalodon length, she wasn’t surprised by it but thought the answer was true by considering that Megalodon was huge. She only experienced a fleeting moment of CD when the teacher gave them an estimated range of body length for this specific Megalodon, which did not fit her own result. However, she still chose to believe her result and thought this Megalodon was perhaps an exception. During the
interview, she commented, “I know it was really big, but I kind of believe it. Because I thought maybe this Megalodon was just different from others. Although it does not fall into the normal range, it is still possible since the tooth was from a real Megalodon. The result has to be true”. Some other students had similar responses to the anomalous result as Mia’s. I made some notes when I observed the first treatment class,

The first group on the left is quiet. Two pairs of students are working on estimating the Megalodon length without talking too much. One pair of students get the result of 7.08 meters and the other pair get the result of 55.01 meters. They seem a little surprised at their results at first, but are not quite unhappy with the results. One student says “Seven is small. Maybe ours is just a baby Megalodon”. Another student says “Fifty-five meters is big. It’s bigger than the normal range, but it’s possible because we are not sure of the exact size of Megalodon”.

Theme 4: students were very quick to blame the technology. Students were provided with a guide for troubleshooting the anomalous result. The guide listed three potential errors that could produce the anomalous result. However, based on my observation notes, the majority of the students blamed the R Shiny App very quickly without carefully considering the other two potential sources of errors. They were supposed to troubleshoot each potential error led by the teacher. They started the troubleshooting process by first checking the tooth position they identified earlier. Students were supposed to make a careful observation of the shape and size of the Megalodon tooth and reference the diagram listing the whole set of the teeth on their student handouts to make their best guess on the tooth position again. However, based on my observations, only a few of them were able to redo the entire process within the limited amount of time. Most of them did not have enough time to replicate the process, let alone have the opportunity to reflect on this potential error and its connection with CD and targeted aspects of the NOS.
When students engaged in troubleshooting the second potential error, the teacher was not able to provide sufficient scaffolding to ensure the best learning outcomes. When students were conducting the initial inquiry, the teacher’s initial instruction on measuring the Megalodon tooth was varied across the two classes receiving the CD treatment. She only used a 3D printed Megalodon tooth to demonstrate how to measure its crown height for the first treatment class. For the second treatment class, she turned the tooth into a triangle by marking three points on a sheet of paper, which was easier for student to understand and follow. Consequently, students in the second treatment class achieved more accuracy in measuring the Megalodon tooth than did the students in the first treatment class. During the troubleshooting phase, the teacher only gave instructions on how to use a sheet of paper to mark the three points of the tooth verbally without modeling it to students in the first treatment class. Thus, their accuracy rate in measuring the Megalodon tooth was still not improved. Besides, the teacher only told students the answer of the estimated crown height in the end without explaining specifically how the measurement error was connected with the targeted aspects of the NOS and their CD experience.

After students knew the tooth position and estimated crown height, they started troubleshooting the third potential error, which was the R Shiny Megalodon App. It was easy for them to realize that the App did not function properly at this point since the teacher already shared with them the correct tooth position and crown height. Based on my observations, students looked more relaxed than before after knowing that the App was ultimately responsible for the anomalous result. I noticed that students in some
groups talked with each other more and were more willing to share their thoughts about this activity,

The second group on the left became more active than before. One girl talked to her partner that she knew from the very beginning that there was something wrong with the app but had nothing to prove it. One boy said "Aha! I knew it! I knew that app was weird". His partner said "Yeah. We did everything else right. That must be the app". The third group on the right even did the "high five" hand gesture to celebrate their finding.

The interview data were consistent with my observations. Joy and Dan from the treatment group chose to blame the R Shiny Megalodon App immediately after making sure everything else was handled correctly. Dan noted that when he and his partner troubleshooted the second potential error, they kept getting different anomalous results each time they entered the data into the App and decided that it was the App that produced the anomalous result. He further added that they blamed the App for the anomalous result because they were getting impatient with the anomalous results and were eager to find an answer to the problem. He commented in the interview,

We went back and forth and we measured it for many times but we always got some weird results. We thought like eventually we’re OK so it’s gonna be like the app. I was like I am not stuck. I want to move on. This is getting nowhere.

Joy was confident in the accuracy of the R Shiny Megalodon App at first. However, she still kept getting anomalous data after multiple trials, which made her start questioning the App. She later commented in the interview,

We measured the tooth multiple times and put the data into the app multiple times but we always got different measurements. Some were quite small and some were quite large. I was very confused. I thought since the teacher gave us the app, it must be good. But it turned out not be the case. Maybe the technology is not always reliable.
All three students that I interviewed focused their attention entirely on the R Shiny Megalodon App when I asked them what caused the anomalous result. Joy said, “I think the app led us to the wrong answer”. Similar to Joy, Mia said, “Definitely the app. If it could function properly, we could get the right answer immediately”. Dan also commented, “If we could start with the right app, we would get the right answer much faster”.

**Perceptions of the Science Computational Modeling Activity Incorporating Cognitive Disequilibrium**

Qualitative data were also explored to gain insight into students’ perceptions of the science computational modeling activity incorporating CD, especially the fluctuations in their SI, VNOS, and overall learning experience with CD. Both classroom observation data and student interview data were analyzed using thematic analysis (Braun & Clarke, 2012). The following themes emerged relative to student perceptions of this CD-infused science computational modeling activity.

**Theme 1: the inquiry-based activity was meaningful for students.** The student interview data revealed that students enjoyed the inquiry-based lesson for a variety of reasons. Joy commented on the intellectual ownership given by the lesson, “I feel like it kept a lot of us really entertained because we are not learning about what other people already discovered. We are learning about things that we can apply and will discover and explore ourselves”. As for Dan, he enjoyed taking part in the inquiry-based activity and making discoveries about the Megalodon length with his partners. He said, “it was so interesting to do what scientists do in their life. I like the idea of having a question and doing all kinds of inquiry to discover the answer and problem solve together with a partner. I also like the process of collecting our own evidence to make
an argument”. Nevertheless, he also pointed out some aspects of the inquiry process could be improved to engage more students. For example, he suggested, “maybe everyone could have actually different teeth so we could have different estimates to compare with. It will be more fun”. In addition, he mentioned that the guidelines of measuring the Megalodon tooth and identifying the tooth position were only handed to them without giving sufficient explanation such as why Shimada’s equation was chosen. He said, “I wasn’t sure why we have to use this one but not others. I believe there are other methods we could use to estimate the length of Megalodon. Maybe we could choose to use other methods next time? Maybe we could use different methods and we could compare our results. That will be interesting”.

George did not directly comment on the inquiry process itself, but he expressed how much he enjoyed working with the concrete 3D printed Megalodon tooth. He said, “Just holding and seeing the size of the supposedly small tooth but it really be a bigger shark than the one tooth that was this big and then it was a smaller shark”. His interaction with the Megalodon tooth helped him form a better idea of this giant shark and experience what scientists experienced in real-world practice. Peggy enjoyed having the ownership of the learning by collecting data and discovering the body length of Megalodon herself. She said, “I like putting the information we collected on our own into the website and figuring out how big that actually was”. She also talked about how hands-on activity made learning more meaningful and engaging for her,

As long as it wasn’t super like just lecturing. I like more hands-on stuff like actually getting to do or find something. I don’t like just sitting and listening to somebody else talk. I mean it’s interesting but it just isn’t very fun because you just sit there and listen to somebody talk.
She also suggested that more background information about Megalodon could be provided, such as how it lived in the past, what its predators were, and where it lived so that their inquiry process could be more engaging and meaningful.

**Theme 2: students in the treatment group demonstrated more informed views of NOS than the students in the control group.** The student interview data revealed that students in the treatment group understood the tentative, empirically-based, social and cultural aspects of the VNOS implied by the activity better than the students in the control group. I first talked about students from the treatment group and then students from the control group about their views of NOS. All three students that I interviewed from the treatment group were expecting a correct answer for the estimated length of the Megalodon, assuming that objects in natural world “followed consistent patterns that were understandable through measurement and observation” (NRC, 2012, p.6). For example, Joy mentioned, “There should be a wrong or a right answer for the body length and there cannot be like a variety of answers for that”. However, they were surprised to find out the anomalous result and wanted to understand the anomalies through proper evaluation and investigation, one of the purposes of doing science.

For the reasons causing the anomalous result, all three students agreed that technologies played a significant role in the advancement of scientific knowledge as they improved ways of observing the phenomenon and provided more evidence to justify the theory. As Joy mentioned in her interview, “As the technology increases, we are able to collect more data and get smarter and have more material to work with. Technology does help science change”. Mia also commented,

Technology is becoming a part of everyday life. It’s helping scientists to do research so they can collect better evidence with technology. Technology
is helping us. Like maybe exploring sometimes even though we haven’t gone like really deep into the ocean like because technology is improved we can go deeper. And so if that keeps improving maybe we’ll be able to go deeper and deeper. We are gonna be able to explore more.

They also understood that humans make mistakes. Joy argued that the anomalous result was perhaps caused by different ways students used to measure the Megalodon tooth. She commented, “It all depends on where you are thinking, where you measured this part of the crown, how far up did you go on this part”. Dan said that scientific knowledge was constrained by human capacity and limited to systems that can be researched, thus, leading different students to different results because of the differences in their structure of knowledge, theoretical orientations, and the evidences available to them. He said, “It’s interesting to see how people got like different measurements. I think it happened to scientists too because they would have different pieces of evidence to support what they think”.

All three students provided different historical examples to illustrate the importance of NOS. Dan and Mia talked about the continental drift theory to explain how a theory was developed and accepted by people. Joy talked about how Pluto was redefined as a “dwarf planet” instead of a “planet”. She compared the example of Pluto to Megalodon to illustrate that scientific knowledge was subject to change as new evidences were found and the certainty of scientific findings varied. She also questioned the method of estimating the length of Megalodon and was confident that more rigorous methods could replace what we have right now to produce more accurate results in the future.

Compared to the students from the treatment group, students from the control group demonstrated less informed views of NOS during the interview. George and
Peggy had a more difficult time connecting the lesson to various characteristics of the NOS. George was a strong believer in what he learned in the science class. When we discussed if there were other methods that could be used to estimate the body length of Megalodon, he said, “I believe that is a possibility. But for right now that’s the only way”. When I asked him how scientific knowledge changed from time to time, he said that new evidence might change what we knew and newer technology could help us go deeper than we used to be. Other than that, George didn’t say anything that was related to NOS. Peggy had limited understanding of NOS and said, “I knew a little bit about nature of science. I thought about that question when I was doing the survey. But I don’t know too much about it”. Even when I explicitly used the uncertainty of the length of Megalodon to illustrate the tentative nature of science, she still had a hard time recognizing the targeted aspects of NOS embedded in the lesson,

Yes, I do think that the information we find could change. Because I mean there’s still parts of the world like oceans that we have yet to discover. So I mean they could still be alive or could be extinct. There could be areas in the oceans where we just haven’t looked yet that we can find fossils in parts of the land that might give clues and stuff.

**Theme 3: CD was not the only factor that triggered and/or maintained students’ SI.** Student interview data indicated that CD can be a factor that triggers and maintains students’ SI. Joy said,

My result was 33 meters. Though it was not super weird, it was larger than what we were told earlier. However, I feel like it kept me entertained because we were learning about things that was confusing. I like the abstract part of it. I like to explore and discover the abstract idea.

Dan also enjoyed exploring the anomalous result of Megalodon body length. He commented, "Comparing our different sizes for the Megalodon was interesting to me. Even though it’s the same tooth, people got like different measurements. It made me
want to discover more, especially to find out what happened to the data”. Mia was also intrigued by the anomalous data, “I was a little bit surprised by the result. It kind engaged me more because I wanted to know the right answer”.

However, they also mentioned about other things that interested them during the lesson. Joy mentioned that watching the movie trailer of the The Meg at the beginning of the lesson was the most interesting moment of the lesson. She said, “the most interesting part of the lesson I think was the contrast between what the media portrays a certain character or being as versus what a certain character or being really is”. She further explained that watching the movie trailer was much more intriguing than watching a documentary about the Megalodon for middle schoolers, who preferred fantasy than the real-world account. She commented,

The movie trailer that we watch about the Megalodon was definitely like Disney field. It was like made for Hollywood and it was made to be interesting. It you watch a documentary just about the Megalodon and what we know about it to the average human it’s not a scientist, it might be a little boring. But if you are really into it for the right reasons that a scientist would be into it for it definitely gonna be interesting. So just the difference between how the media portrayed and the real parts and the fake parts kind of was really interesting for people like us.

In addition, she enjoyed discovering the body length of the Megalodon in the inquiry-based learning format and having the opportunity to experience what scientists were experiencing in real-world practice. She said, “we haven’t done a lot of these types of inquiry lesson. It was really, really nice to be able to see and experience a lot of elements of real science”.

Dan also enjoyed the learning process in which he needed to engage in the inquiry process and found out how big the Megalodon was by himself instead of learning the factual knowledge given by the teacher. He pointed out, “it was interesting
how we kind measured the tooth ourselves and we had to figure it out ourselves and it wasn’t given to us. I liked how we ended up getting to find out how big it was”.

Furthermore, he said that having a partner to solve the problem together made the whole process more engaging and enjoyable.

In contrast, Mia stated, “I liked touching the real Megalodon teeth and measuring it and typing it into like figuring out how big the Megalodon would actually be”. She had never interacted with a real Megalodon tooth before this lesson and never saw her connection with Megalodon since it was depicted as a prehistoric animal that only showed up in textbooks. The concrete experience of observing and manipulating the real Megalodon tooth brought her closer to this prehistoric ocean giant and ignited her interest in learning more about it.

Similar to Mia, both George and Peggy from the control group enjoyed the experience of holding the 3D printed Megalodon tooth. George said, “I like hands-on activities because I like to move all the time and I always want to play with something. I think I can learn more with actually looking and studying the concrete stuff myself”. Similarly, Peggy commented in the interview, “I don’t like lectures. I prefer hands-on stuff like actually holding the tooth. I don’t like sitting and listening to somebody else talk. I mean it’s interesting but it just isn’t very fun”. She also mentioned that learning about the past life really engaged her, “It was very interesting and I really like to learn about the past life because I’ve never seen it. Most people have I think never see it before. So learning about it and learning what it might have looked like was very interesting”.

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### Table 4-1. Participants Demographics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male: 46; Female: 41</td>
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<tr>
<td>Race</td>
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</tr>
<tr>
<td></td>
<td>Asian: 1</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Native Hawaiian/Other Pacific Islander: 1</td>
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<td>Mixed Race/Multi Race</td>
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<td>Other</td>
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### Table 4-2. Alignment of variables and instruments

<table>
<thead>
<tr>
<th>Variable Measured</th>
<th>Description</th>
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<tbody>
<tr>
<td>Cognitive Disequilibrium</td>
<td>Cognitive Conflict Levels test posttest</td>
</tr>
<tr>
<td>Situational Interest</td>
<td>Situational Interest Scale pretest and posttest</td>
</tr>
<tr>
<td>Individual Interest</td>
<td>Student Attitudes Toward Science, Technology, Engineering, and Math – Science Attitudes subscale pretest</td>
</tr>
<tr>
<td>Views of the Nature of Science</td>
<td>Views of Nature of Science Questionnaire Form-D</td>
</tr>
<tr>
<td>Science</td>
<td>pretest and posttest</td>
</tr>
<tr>
<td>Science content knowledge</td>
<td>Megalodon Total Length Activity Worksheet posttest</td>
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### Table 4-3. Mean scores and standard deviation of pre-triggered-situational-interest

<table>
<thead>
<tr>
<th>Pre-Triggered Situational Interest</th>
<th>Control Mean</th>
<th>Control SD</th>
<th>Treatment Mean</th>
<th>Treatment SD</th>
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<tr>
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<td>14.75</td>
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Table 4-4. Mean scores and standard deviation of pre-individual interest on science

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<thead>
<tr>
<th>Pre-Triggered Situational Interest</th>
<th>Control</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>28.00</td>
<td>6.05</td>
<td>30.28</td>
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Table 4-5. Distribution of students’ naïve and informed views of NOS before the intervention

<table>
<thead>
<tr>
<th>Pre-Views of Nature of Science</th>
<th>T-Naive</th>
<th>T-Informed</th>
<th>C-Naive</th>
<th>C-Informed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>27</td>
<td>7</td>
<td>28</td>
<td>5</td>
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Table 4-6. Mean scores and standard deviation of pre-maintained-situational-interest-total

<table>
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<tr>
<th>Pre-Maintained Situational Interest-total</th>
<th>Control</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
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<tr>
<td>25.06</td>
<td>8.97</td>
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Table 4-7. Mean scores and standard deviation of pre-maintained-situational-interest-feeling

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<tr>
<th>Pre-Maintained Situational Interest-feeling</th>
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<th>Treatment</th>
</tr>
</thead>
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<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>12.84</td>
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Table 4-8. Mean scores and standard deviation of pre-maintained-situational-interest-value

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<th>Pre-Maintained Situational Interest-value</th>
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<th>Treatment</th>
</tr>
</thead>
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<td>SD</td>
<td>Mean</td>
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<td>10.29</td>
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Table 4-9. Mean scores and standard deviation of students' pre- and post-triggered situational interest

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<tr>
<th>Triggered Situational Interest</th>
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<th>Post-Control</th>
<th>Pre-Treatment</th>
<th>Post-Treatment</th>
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<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
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<td>3.41</td>
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<tr>
<th>Cognitive Disequilibrium Scores</th>
<th>Treatment Group</th>
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<tr>
<td></td>
<td>Recognition of Anomaly</td>
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<td>Mean</td>
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Table 4-11. Distribution of students’ naïve and informed views of NOS

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<tr>
<th>Views of Nature of Science</th>
<th>Pre</th>
<th>Post</th>
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<tbody>
<tr>
<td>T- Naïve</td>
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<td>28</td>
</tr>
<tr>
<td>T- Informed</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>C- Naïve</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td>C- Informed</td>
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<td>5</td>
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Table 4-12. Mean scores and standard deviation of science content knowledge

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<tr>
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<th>Treatment</th>
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<tbody>
<tr>
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<tr>
<td>SD</td>
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Table 4-13. Mean scores and standard deviation of students’ maintained-situational-interest-total

<table>
<thead>
<tr>
<th>Maintained Situational Interest Total</th>
<th>Pre-Control</th>
<th>Post-Control</th>
<th>Pre-Treatment</th>
<th>Post-Treatment</th>
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<tbody>
<tr>
<td>Mean</td>
<td>25.06</td>
<td>25.66</td>
<td>28.50</td>
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<tr>
<td>SD</td>
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<td>6.09</td>
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Table 4-14. Mean scores and standard deviation of students' maintained-situational-interest-feeling

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<tr>
<th>Maintained Situational Interest Feeling</th>
<th>Pre-Control</th>
<th>Post-Control</th>
<th>Pre-Treatment</th>
<th>Post-Treatment</th>
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<tbody>
<tr>
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<td>12.84</td>
<td>12.94</td>
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<td>SD</td>
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Table 4-15. Mean scores and standard deviation of students' maintained-situational-interest-value

<table>
<thead>
<tr>
<th>Maintained Situational Interest Value</th>
<th>Pre-Control</th>
<th>Post-Control</th>
<th>Pre-Treatment</th>
<th>Post-Treatment</th>
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<tbody>
<tr>
<td>Mean</td>
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<td>13.16</td>
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<tr>
<td>SD</td>
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<td>4.66</td>
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CHAPTER 5
DISCUSSION

The goal of this study was to explore the potential of CD to influence students’ T-SI in a middle-school science classroom as the proximal outcome, as well as their (a) views of the NOS, (b) science content knowledge, and (c) M-SI as the distal outcomes. Using a concurrent embedded mixed method design, this study was performed to explore the “what” and “how” of CD influence on students’ SI and learning. Quantitative methods (i.e. learning tests, surveys) played the primary role in guiding the research and qualitative methods (i.e. interviews, observations) played the supporting role and provided possible triangulation in the procedures (Creswell, 2009). This chapter discusses the limitations and delimitations, findings related to each research question and the implications this study.

Limitations and Delimitations

Limitations

Critics might object to the intention of using anomalous data to create CD for middle schoolers on the grounds that confusing students is not in their best interests. I acknowledge this but should point out that: 1) the anomalous result was discussed and corrected at the end of the lesson, 2) the CD-based activity was designed based on the findings on decades of relevant research that showed benefits of CD for learning, 3) no negative learning effects were found in the study, 4) all research protocols were approved by the university IRB board, and 5) all students participated after their parents consented. Both quantitative and qualitative data actually showed a positive pattern in that students who experienced CD had a steady increase in their T-SI and M-SI respectively.
With regard to the measurement of CD, I used the CCLT survey developed by Lee et al. (2003). Although CCLT is easy to use to measure students’ CD in most situations, its inherent constraint of depending entirely on students’ self-reported data should be acknowledged. Other objective measures, such as observing students’ behaviors when experiencing CD, should also be taken to improve the accuracy of the CD measurement. To offset this limitation, I relied partly on my classroom observation notes during data analysis. Researchers are also beginning to utilize psychophysiological measurement tools for measuring CD such as electroencephalography (EEG; Zhou, Xu, Li, & Li, 2018). Future studies of CD may consider employing both subjective and objective measures as tools for gaining a better understanding of the CD experience.

Our finding was also limited to the experience of middle school students who participated in the study. Older or younger students may respond differently to CD-based instruction in their classrooms and develop differently in terms of SI, views of NOS, and science content knowledge. For example, Chen and Darst (2002) found that students in lower grades, in comparison with higher grade students, tended to show more SI after having experienced the tasks in physical education classes. Moreover, learners of different ages might be in different phases of the four-phase model of interest development relative to their interest in the topic or content area, which would also have affected their response to CD-based instruction (Renninger & Hidi, 2016). Therefore, it is possible that students of different ages might show different levels of SI after experiencing CD, leading to different changes in views of NOS and understanding.
of the science content knowledge. Similar studies could be implemented with students of different ages to confirm this hypothesis.

The follow-up semi-structured student interview was limited in time due to student availability. It was originally designed to consist of two major components. The first component was designed to explore students’ experience with CD, SI, and overall learning experience. The second component was designed to substantiate the validity of the researchers’ interpretations of students’ responses. However, the second component was not implemented because of the significant time constraint. During the second component, students were supposed to be provided with the VNOS questionnaires and asked to explain and justify their responses. However, students were not provided with the VNOS questionnaires and were only asked to explain how the lesson was connected with the NOS in general. Therefore, the interview did not serve the purpose of probing students’ ideas in-depth and exploring relationships between these ideas (Khishfe & Abd-El-Khalick, 2002). Moreover, the number of students who were interviewed was less than what had been planned. As a consequence, the lack of in-depth questions and limited number of student interviews might have affected the validity of my interpretation of students’ responses. If the follow-up interviews were implemented as planned, students’ responses to the VNOS questionnaires would be interpreted with more accuracy and could provide a more comprehensive picture of students’ evolving views of NOS.

**Delimitations**

An important delimitation for the current study has to do with measuring students’ SI. As the SI was only measured before and after the lesson, its fluctuation throughout the lesson wasn’t captured using the SIS survey, thus, providing limited insight on the
dynamics of what happened during the task (Ainley, Hidi, & Berndorff, 2002).

Loukomies et al. (2015) argued that “there is a difference between measuring interest at a certain moment in time and retrospectively trying to remember that moment and then to figure out how interesting it was” (p. 3018). The measurement of SI in the present study posed the problem of memory bias (Hektner, Schmidt, & Csikszentmihalyi, 2007) when students had a difficult time recapturing their emotional state during the lesson, or remembering what was actually happening during the lesson. However, although measuring SI multiple times might have offered us a better picture of the SI development, it would have caused interruption to students’ authentic learning experience and teacher’s instruction. Therefore, in order to achieve a comprehensive picture of the SI development while maintaining the ecological validity of a typical science lesson, I conducted classroom observations and recorded manifestations of SI throughout the lesson. The qualitative data from the observations combined with the quantitative results from the SIS survey provided a better representation of SI development over the lesson.

**Effects of Cognitive Disequilibrium on Triggered Situational Interest**

The proximal outcome of this study was hypothesized to be enhanced triggered situational interest (T-SI) in the treatment group, while controlling for the effect of pre-maintained-situational interest-value (pre-M-SI-value) and individual interest (II) in science. The study results revealed that the treatment group did not report higher T-SI than the control group. In other words, the CD-based intervention did not result in a measurable difference in T-SI between the treatment and control groups. This result is not consistent with previous literature advocating the use of CD-based instruction to trigger students’ SI, such as using unexpectedness of information (Hidi, 2000),
suspense (Jose & Brewer, 1984), and cognitive conflict (Kang et al., 2010). However, most of those studies focused on text-based learning and weren’t implemented in authentic classroom settings. This study was one of the first studies using anomalous data to trigger students’ SI in an inquiry-based middle school science classroom. The results generated from this study should be interpreted from multiple perspectives.

First, the extent to which students’ CD was triggered had an impact on their self-reported T-SI scores. The descriptive data revealed that all students experienced CD and half of them scored above the mean on the measure of CD. A closer examination of their scores in the four subscales of CD, a) recognition of an anomalous situation, b) interest, c) anxiety, and d) cognitive reappraisal of the situation, measured by the CCLT survey revealed more details regarding their CD experience. Students scored the highest in interest, followed by recognition of anomaly, reappraisal of cognitive conflict situation, and lowest on the anxiety subscale. This result suggests that most students were able to realize that the Megalodon length was abnormal and demonstrated interest in further exploring it. However, their relative low score in anxiety indicated that although students were interested in the anomalous result, they were not very anxious about the anomaly. In other words, the anomalous result caused cognitive disturbance in students as it was indeed incongruent with their prior knowledge of the Megalodon body length but didn’t necessarily elicit an uncomfortable state of anxiety in students that needed to be resolved immediately. As T-SI is a psychological state of interest resulting from short-term changes in both cognitive and affective processing (Hidi & Renninger, 2006), the lack of change in student’s affective processing might explain the relative ineffectiveness of this CD-based activity relative to triggering SI in this study.
Students' low score on the anxiety subscale of CD was surprising. Mallow (2006) argues that science anxiety starts as soon as children begin to learn science and constantly occurs throughout their school careers. It has many causes, including negative experiences in science class, science anxious teachers in elementary and secondary schools (Ucar & Sanalan, 2011), gender, lack of role models, and stereotypes about scientists (Bryant, Kastrup, Udo, Hislop, Shefner, & Mallow, 2013). As students in the present study did not report high anxiety scores as a result of CD, it can be hypothesized that the inquiry-based learning features of the Megalodon lesson might have actually reduced their anxiety. Udo, Ramsey, Reyholds-Alpert, and Mallow (2001) found that different pedagogies were correlated with anxiety reduction. The inquiry-based approach implemented in the lesson might be effective in alleviating students' anxiety since it was found to increase students' inquiry skills, autonomy over their learning tasks, and collaboration with their peers (Palmer, 2009). Future research could explore whether and what specific aspects of the inquiry-based approach are effective in reducing students' anxiety induced by CD and how we can manage anxiety at a reasonable level to keep students engaged at the affective and cognitive level, and attentive to the learning content.

Students' relative lack of anxiety in dealing with the anomalous data in this learning activity was perhaps due to their underdeveloped coping strategy in dealing with anomalous results. Chinn and Brewer (1993) proposed four key interacting components that would determine how students respond to anomalous data. They are a) students' prior knowledge, b) characteristics of a possible alternative theory, c) characteristics of the anomalous data, and d) processing strategies. Both the interview
and classroom observation data revealed that although students were aware of the anomalous result, they still possessed naïve epistemological beliefs about the scientific enterprise and could not understand how the anomaly was connected with various aspects of NOS. In addition, the teacher did not have opportunities to help students develop a comprehensive understanding of the anomalous result through explicit discussion because of the time constraint. Under such circumstances, the ambiguity of the anomalous result was difficult for students to interpret if no or few supports were provided. As a result, students might have overlooked the significance of the anomalous result and felt less anxious about its influence.

How CD was resolved might have also had an impact on their self-reported T-SI. In this study, the design of students’ CD experience was informed by Limón (2001) three-step strategy, which is to 1) use an anomalous result to cause CD in students, 2) let students troubleshoot the anomalous result to resolve CD, and 3) prompt students to reason and arrive at a conclusion with teacher’s scaffolding. Step 1 was achieved since CD was triggered successfully by presenting the anomalous result of the Megalodon body length to students. Step 2 was planned to resolve students’ CD by engaging them in troubleshooting the anomalous result. Teacher’s scaffolding was intentionally included in Step 3 to help avoid negative affective states resulting from the troubleshooting experience. However, the troubleshooting experience was not implemented as originally planned. First, since the lesson was shortened to accommodate the school’s Wednesday short-day schedule, students’ troubleshooting process was simplified without spending enough time reflecting and discussing its implication. Also, my observation notes indicated that the teacher did not follow the
teacher’s guide to give a step-by-step instruction on how to measure the crown height to the first treatment class, either during their initial inquiry or the later troubleshooting process. Therefore, students in the first treatment class were easily frustrated when measuring tooth crown height. In addition, even though the breakdown of the R Shiny Megalodon App explained the anomalous result at the end of the troubleshooting process, whether students’ CD was completely resolved or not was still unclear. It is possible that students’ CD was only resolved superficially since they would still keep wondering why the R Shiny Megalodon App could break down without knowing how each potential error was related to the whole inquiry process, their connection with the targeted aspects of NOS, and implications for broader science learning context. Therefore, insufficient teacher’s scaffolding during the troubleshooting process could have led to frustration or disengagement, which is detrimental to the resolution of CD (D’Mello & Graesser, 2011). To explore this potential effect, future studies could measure CD again after the troubleshooting process to determine whether CD is completely resolved and whether students have a pedagogically useful CD experience. In addition, more objective measures of CD, such as observing students’ delayed responses because of CD, could be employed since how well students can introspect on CD was still unclear.

Students’ T-SI could also have been affected by the complex variables intervening in the context of classroom learning. The qualitative data of the present study confirmed previous findings underscoring the role peer interactions in T-SI development (e.g., Cartun, Kirshner, Price, & York, 2014; Hidi et al., 1998). During my interviews with students, Joy mentioned that she was not only surprised by her own
anomalous result but also her peers’ anomalous data. She thought it was her fault causing the anomalous result at first. However, after realizing her peers also produced anomalous results that were quite different from hers, she became more curious about the anomalous data and more interested in exploring this issue. Peers like Joy were aware of her own lack of knowledge, which was the underlying mechanism responsible for triggering SI (Rotgans & Schmidt, 2011), and thus were more likely to take actions for knowledge acquisition.

However, interaction with peers could sometimes reduce the effectiveness of CD in triggering SI. For example, Dan simply chose to blame the R Shiny Megalodon App because he and his partner did not want to be stuck with the anomalous data but wanted to finish the inquiry process as soon as possible, having no intention for any forms of deep learning. Mia said the anomalous result of the Megalodon length was successful in capturing her attention but shared that students in her group misdirected her attention by doing things that were unrelated to the learning. The results were in line with the Cognitive Reconstruction of Knowledge Model (CRKM; Dole & Sinatra, 2005), which argues that social context can support or undermine students’ motivation to engage. Therefore, the SI induced by CD was perhaps counterbalanced by the negative influences from peers.

Teacher plays a significant role in affecting students’ T-SI as well. According to Limón (2001), teacher’s characteristics, such as domain-specific subject matter knowledge, motivation and interests, and teaching strategies, were key determinants of the effectiveness of CD-based strategy. As the lesson was developed by the iDigFossils project and assigned to the teacher to teach, problems occurred during the actual
implementation. For teachers who might not be familiar with Megalodon-related content knowledge, more preparation or professional development could be provided to teachers so as to implement the introductory activity in a more engaging way and more consistent way across two treatment classes. Moreover, although the lesson was planned to take an explicit and reflective approach to teaching NOS, the teacher did not explicitly discuss NOS with students as frequently as originally planned. All these factors might have affected students’ journey through a pedagogically meaningful CD experience, which was not only about being confused, but also about making sense of the conflicting data and information. If either of the conditions was not satisfied, CD-based intervention would fail to be an effective instructional strategy to trigger students’ SI (Dreyfus, Jungwirth, & Eliovitch, 1990).

Although the treatment and control groups did not report statistically significant differences in T-SI after the intervention, their T-SI changed in different directions. The descriptive statistics revealed that the control group had lower post-T-SI score than their pre-T-SI score, while the treatment group had higher post-T-SI score than their pre-T-SI score. That is to say, the treatment group experienced an increase but the control group experienced a decrease in T-SI. Since both groups experienced the same lesson except the CD treatment, it is reasonable to conclude that the CD-based approach had a positive impact on students’ T-SI but this impact did not have the magnitude to be detected by inferential statistics. Positive evidence for this was also found in students’ interviews, where all three students from the treatment group shared that the anomalous results caught their attention, triggered their curiosity, and engaged them more with the learning task.
The effect of the anomalous result in getting students’ attention was probably due to its novelty. Based on my interview data, students in the study didn’t have any similar CD experience caused by anomalous data before this lesson and it appears their CD experience in this lesson was novel to them. Empirical evidence from previous studies suggests the effectiveness of novelty in triggering students’ SI. Palmer (2009) found that novelty was the main source of triggering SI for 9th graders in a science lesson focused on inquiry skills. Hunsu et al. (2017) even suggested that the novelty factor alone would be enough to arouse a psychological response to some interesting detail of the learning situation, and such response could result in students being emotionally invested in tasks associated with learning. The interview data of the present study revealed that students were excited about engaging in the inquiry process and said discovering and resolving the anomalous result was exciting to them. It was also observed that most of the students were on task when troubleshooting the anomalous results. These were all indications of the novelty effect. The statistically insignificant difference between the treatment and control groups in T-SI was perhaps due to the small sample size. This study could be replicated with a larger sample size consisting of students with various degrees of interest in science.

As T-SI is short-lived, it is likely that the novelty effect of using CD-based intervention in triggering students’ T-SI was minimized by other accompanying unintended effects (Ronimus, Kujala, Tolvanen, & Lyytinen, 2014). All three students from the treatment group commented that the anomalous result of Megalodon length did catch their attention, which was an indication of T-SI (Mitchell, 1993). However, two of them felt exhausted by troubleshooting the anomaly when the appropriate way of
measuring the crown height was not clearly presented to them by the teacher. According to Linnenbrink-Garcia et al. (2010), T-SI can be short-lived without the continuous support from the teacher, peers, or the environment. Therefore, the T-SI that lasted momentarily was not captured by the self-reported SIS survey conducted after the entire lesson was finished. If SI had been measured immediately after students’ encounter with the anomalous result, their T-SI results might have been different. It is also possible that some parts of the Megalodon lesson not well designed, such as asking students to connect the lesson with the NOS without enough scaffolding from the teacher, which imposed extrinsic cognitive load associated with learning (Leahy & Sweller, 2019), thus, affecting their rating of the T-SI.

Besides the CD treatment, which was integrated to trigger students’ SI, other components of the lesson might have influenced students’ T-SI. Student interview data revealed that hands-on activities, such as interacting with the real Megalodon tooth, measuring the 3D printed version of the tooth, and calculating the tooth crown height, were successful in catching students’ attention and increasing their persistence over the tasks. As hands-on activity is known to be a significant factor in inducing SI in previous studies (Bergin, 1999; Hunsu et al., 2017; Mitchell, 1993; Palmer, 2004; Tapola et al., 2013), it might have contributed to the increased T-SI for both treatment and control groups. Besides, both observation and interview data showed that students were engaged in inquiry-based learning and perceived it to be a meaningful learning experience. Since Palmer (2009) found that inquiry-based activity triggered SI for both low and high achievement groups, it might have improved T-SI for the treatment group irrespective of the CD treatment. Moreover, discussion of a charismatic and enigmatic
species such as Megalodon not only elicited initial curiosity and SI, but also had the potential of supporting ongoing inquiry and information search, which further supported interest development (Renninger & Hidi, 2016). To test whether this is indeed the case, future studies need to be conducted in which measures of perceptions of hands-on activities, inquiry-based learning and learning topic are administered to examine whether they have interactive effects with T-SI.

Although previous studies have examined the links between T-SI and different variables in a number of learning contexts (e.g. Rotgans & Schmidt, 2011; Schraw, Flowerday, & Lehman 2001), this study was particularly focused on exploring how CD, including a) recognition of anomaly, b) interest, c) anxiety, and d) reappraisal of CD situation, would predict T-SI when the CD treatment altered students’ learning experience. Regression analysis revealed that reappraisal of CD situation was a significant positive predictor of students’ T-SI. That is to say, the more students reappraised the CD situation, the higher T-SI score they reported. In this study, students’ reappraisal of the CD situation means students consciously engaged in the process of cognitive conflict and were trying to reconcile their initial conceptions and the anomalous situation. It was a cognitive process that occurred after their affective response toward the CD treatment. This finding provided evidence that it was not students’ affective states (i.e., interest or anxiety), but the accompanying cognitive reappraisal of CD that predicted their T-SI. This result is in line with that of Dorfner et al. (2018)’s regression model, which found cognitive activation explained 16% of the variance in students’ T-SI in middle school biology classes. As reappraisal of the CD situation was one of the characteristics of cognitive activation, it was suggested to be a
significant factor in predicting students’ T-SI again in the present study. Nevertheless, reappraisal of the CD situation was a cognitive activity initiated by students themselves after encountering the CD in the present study. In contrast, cognitive activation, such as assessing students’ pre-knowledge and conceptions, dealing with students’ conceptions, and reappraising knowledge gaps, was a series of cognitive activities initiated by the teacher in Dorfner et al. (2018)’s study. Therefore, both of the studies suggest that in order to increase the chance of triggering SI, it is important for students to reappraise their CD through reflecting on their CD experience, assessing their prior knowledge, and identifying their knowledge deficiency, either on their own or scaffolded by the teacher before actions are taken to resolve the CD. As there are no previous studies that explicitly investigate the relationship between cognitive reappraisal of CD and T-SI, it can only be hypothesized that the reappraisal process could increase students’ chances of identifying the root causes for CD and finding the appropriate solutions to solving CD, all of which could ensure the T-SI initially triggered by CD did not decrease as the lesson progressed.

Nevertheless, the result is contradictory to our previous understanding of T-SI. According to Renninger & Hidi (2015), T-SI is associated with individuals’ affective response triggered by the learning condition, rather than resulting from cognitive appraisal in the same way as more developed forms of interest. Therefore, interest or anxiety are of particular importance in the triggering process (Renninger & Hidi, 2015) and was expected to predict T-SI in this study. One possible explanation for this was that the construct of interest used in the CCLT survey to measure interest was not provided by Lee and colleagues (2003). Among the three items measuring interest, only
one of them was related to T-SI, while the other two seemed to be more related to II. If that was the case, there was no wonder why interest was not a significant predictor of T-SI since II did not influence the relationship between the CD-based intervention and T-SI in the present study. As for anxiety, since it was found to have both positive and negative effects on response behavior (Kwon, Lee, Park, Kim, & Lee, 2000), whether it would increase or decrease T-SI varied across different learning contexts.

**Effects of Cognitive Disequilibrium on Views of Nature of Science**

One of the secondary goals of the study was to examine the influence of CD on students’ views of NOS. A chi-square test of independence showed that students’ VNOS were not affected by their group membership, meaning that the treatment and control groups had similar distribution of naïve and informed views of NOS. In other words, the CD treatment did not produce a measurable effect on VNOS. The result is consistent with the findings of previous research, which indicate that CD does not necessarily produce conceptual change (Baddock & Bucat, 2008) and would just be an important factor rather than a necessary prerequisite for it (Limón, 2001). For example, Kang et al. (2010) explored the relationship between cognitive conflict, induced by a discrepant event, and middle school students’ conceptual change in learning the concept of density. The results indicated that CD only had an indirect effect on students’ conceptual change, which was mediated by the effect of attention allocated to learning.

In addition, there was not a statistically significant change in the proportion of informed and naïve views of NOS before and after the intervention within each group. The total number of students who completed the survey increased for both groups after the intervention. Among those, the number of students who had informed views of NOS remained almost the same for the treatment and control groups after the intervention.
However, the number of students who had naïve VNOS increased to a larger extent for the control group than for the treatment group.

The relative ineffectiveness of the CD treatment in improving students’ VNOS may be due to a number of factors. First, whether the CD triggered by the anomalous result of the Megalodon length had a high arousal effect was questionable. According to Berlyne (1960), conceptual conflict has high arousal potential to motivate learners to resolve the conflict by seeking new information or reorganizing the existing knowledge one already has. In this study, students tried to restore their cognitive equilibrium by troubleshooting each potential error and found out it was the R Shiny Megalodon App that produced the anomalous outcome in the end. However, as the troubleshooting process was constrained by time and was not sufficiently scaffolded, students did not have the opportunity to examine the inadequacies in their existing knowledge of NOS and find resolutions to bridge the knowledge gap (Siegler, 1983). Students tended to resolve their CD in a superficial way (i.e., blaming the R Shiny Megalodon App) without reaching conceptual change in situations of CD (Vosniadou, 1999). Relevant evidence was found in students’ interviews, in which all three treatment group interviewees agreed that it was the App that held responsibility for the anomalous result and didn’t mention how other components of the activity (e.g., measurement error) might have affected the result. However, since the high arousal potential of CD should be built upon the wide knowledge gap between what is known and what is unknown (Johnson & Johnson, 2018), the approach students took to restore their CD was not adequate for them to become dissatisfied with their existing VNOS. The result suggests that instructional activity providing opportunities for students to reflect on the gap between
their existing knowledge and the anomalous situation supported by the teacher can promote volitional acts such as checking students’ existing conceptions, knowing what needs to be changed, and comparing their conceptions against new information (Chan et al., 1997; Limón, 2001) that can lead to better results of conceptual change.

Anxiety might have directed the level of engagement, and thus affecting students’ conceptual change in views of NOS. Gregoire (2003) argues that emotional responses occur prior to processing the message. The CCLT survey revealed that students only experienced moderate anxiety before critical aspects of NOS were openly discussed in the lesson. As anxiety promotes deeper, systematic processing of the message (Broughton, Sinatra, and Nussbaum, 2013), it can be hypothesized that CD was not successful in facilitating a deeper and systematic cognitive processing of the anomalous result and the critical aspects of NOS in students since they did not report a high level of anxiety along with CD. However, since the research investigating the influence of negative emotions in conceptual change is still emerging (Broughton et al., 2013), there is another possibility that anxiety made students resistant to conceptual change as negative emotions are related to attitudes of resistance (Linnenbrink & Pintrich, 2002).

Since the NOS was not explicitly and reflectively taught to students as originally planned, it might also explain the ineffectiveness of CD-based intervention in influencing students’ VNOS. The explicit and reflective approach to teaching NOS was originally planned to be implemented in the lesson so that the CD-induced aspects of NOS could be investigated and discussed. However, the classroom observation data indicated that the educator could have benefited from more professional development on how to explicitly connect students’ CD experience with VNOS and develop their integrated
VNOS by reflecting on their CD experience before the lesson. The teacher took a more implicit approach to teaching NOS, in which the CD experience was not explicitly related to NOS. As research has consistently shown that the implicit approach was not effective in helping students develop informed NOS views (Bell et al., 2003; Khishfe et al., 2002), there is no wonder students’ views of NOS was not improved after the CD experience.

Students’ unchanged views of NOS might be caused by the inadequacy of the lesson in meeting students’ needs in their views of NOS. The Megalodon lesson was designed to provide an authentic inquiry-based learning experience for middle schoolers. NOS and, specifically, uncertainty in science served as an epistemological underpinning of the lesson and the characteristics of the resulting knowledge (Lederman, 2014). However, the measurement of students’ VNOS was implemented one week before the lesson was given to the students. Therefore, there wasn’t enough time to build the lesson based on students’ initial conceptions of NOS, customize the lesson to bridge what students already knew and what they still needed to know about NOS, and design purposeful activities and discussion to render students dissatisfied with their naïve views. Inhelder and Sinclair (1969) argued that CD should be related to the students’ existing stage of cognitive development so that its benefit can be maximized. In this study, the topics of NOS discussed in the Megalodon lesson, such as the tentative nature of our knowledge about Megalodon, scientific knowledge is based upon observation, doing science involves imagination, were perhaps already familiar to students. Other NOS-related topics, such as whether the Shimada’s equation is suitable for measuring Megalodon length and what the technology breakdown implies, were not sufficiently and explicitly discussed with students. According to Dole and Sinatra (2005),
students’ awareness of conflict that exists between their prior knowledge and the scientific view of the learning content will improve their cognitive engagement, which can increase the likelihood of conceptual change. Therefore, as students’ experience with CD was not adequate enough to let them see their knowledge deficiency in NOS, it was less likely to promote conceptual change in VNOS. Activities such as analyzing their CD experience from various NOS perspectives, mapping connections between their CD experience and ones undertaken by scientists, and drawing generalizations about the epistemology of science could have helped students become dissatisfied with their existing views of NOS and motivate them to bridge the gap through knowledge acquisition.

Students’ conceptual change in VNOS also depended on the content and context within which these views were presented and learned. In the present study, students had more informed views of the tentative and subjective NOS in their discussions of Megalodon. In Khishfe and Abd-El-Khalick (2002)’s study, participants explicated more informed views of the empirical, inferential, and imaginative and creative NOS in their discussions of dinosaurs compared with their discussions of the atomic structure of matter. The result indicated that students’ views of NOS seemed to interact with the content and its context in major ways.

Admittedly, it was difficult to impact students’ VNOS by using only one lesson that lasted only sixty minutes. According to Murphy and Mason (2015), conceptual change is a complex process that occurs gradually over an extended period of time and requires individuals to revise their mental representations to align with the accepted scientific perspective. As the concept of NOS involves a large body of knowledge, and
values and beliefs inherent to scientific knowledge and its development (Lederman 2006), it may take a substantial amount of time for it to develop. Liu and Lederman (2002) conducted a 5-day summer camp that involved intensive NOS activities but found little change in students' VNOS. Carey, Evans, Honda, Jay and Unger (1989) involved 7th-grade students in NOS instruction that consisted of intensive inquiry and NOS activities followed by explicit discussions and reflection for three weeks and only found modest gains in students' VNOS. When interpreting results, these scholars recommended implementing longitudinal studies to observe students' conceptual change in their VNOS since it was a slow process involving complex factors. In addition, Kang et al. (2010) found that middle school students took longer than high school students integrating their conceptions with new information when resolving their CD. After all, developing an informed VNOS was not an easy undertaking for middle school students and was a difficult and involved process (Driver, Leach, & Millar, 1996). Therefore, longitudinal intervention incorporating CD should be implemented in future studies to investigate its efficacy in influencing students' views of NOS.

Similar to the results of chi-square and McNemar tests, a binary regression analysis revealed that CD, including a) recognition of anomaly, b) interest, c) anxiety, and d) reappraisal of CD situation were not significant predictors for students' VNOS. Thus, CD induced by anomalous result did not result in significant change in students' views of NOS. The result is in support of Kang et al. (2010) and Lin et al. (2013), who found cognitive conflict was not a statistically significant predictor of conceptual understanding. Kang et al. (2010) found a small but significant path coefficient ($\beta = .136$) between cognitive conflict and attention, indicating that cognitive conflict had an
indirect effect on conceptual change mediated by attention. It is therefore tentatively deduced that other variables, such as attention and effort, might have mediated the relationship between CD and conceptual change in the present study. Since CD was successful in capturing students’ attention as previously discussed, future research could include the measurement of attention to inform our understanding of the relationship between CD and conceptual change.

**Effects of Cognitive Disequilibrium on Science Content Knowledge**

Unlike my hypothesis, there was not a significant difference in science content knowledge between the treatment and control groups as result of CD. Students who experienced the CD treatment did not achieve a better understanding of science content than those without the CD experience. On the contrary, the descriptive statistics indicated that students without the CD experience had a slightly higher average science content knowledge score after the activity than students who experienced CD. This finding is inconsistent with previous research arguing for the benefits of using CD to increase student learning of content. As the impasse-driven theories of learning posit, CD and its associated state of confusion are beneficial to learning because they stimulate engagement and further learning opportunities (VanLehn et al., 2018). That is, once CD is experienced, students need to engage in effortful cognitive activities in order to resolve their CD. In this study, students’ CD was supposed to be resolved through the troubleshooting process. However, as previously discussed, various issues decreased quality of students’ troubleshooting experience, and students did not have enough time to “stop, think, engage in careful deliberation, problem solve, and revise their existing mental models” (D’Mello et al., 2012, p.154).
A regression analysis revealed that none of the CD variables were significant predictors of students’ science content knowledge. It is inconsistent with Craig and colleagues’ (2005) finding, which revealed that confusion, the emotion stemming from CD, was the only variable that significantly predicted learning outcomes. However, although confusion was an indication of CD, the present study and Craig et al. (2005) did not measure exactly the same construct. Also, the present study only used students’ self-reported CD scores, whereas Craig et al. (2005) used observers to code students’ affective state of confusion. Additionally, the seven questions used to measure students’ science content knowledge were relatively low based on Bloom’s taxonomy of learning objectives and outcomes and targeted mostly basic knowledge concepts addressed in the lesson, such as “what are the two variables you need to predict body length of Megalodon?” Since CD is supposed to impact deeper development of conceptions such as generating cohesive arguments (D’Mello et al., 2012), make conceptual comparisons (Graesser, Ozuru, & Sullins, 2010), and demonstrate application (D’Mello et al., 2012), rather than retention of facts, which is what the science content knowledge measure in this study mostly focused on, the seven questions might have not been sufficient to capture potential deeper learning gains of students who experienced CD. This might explain why CD was not a significant predictor of students’ science content knowledge. Future studies could employ objective measures of CD and use items measuring deeper learning such as transfer of science knowledge and skills to offer more insights regarding the relationship between CD and science content learning.

Effects of Cognitive Disequilibrium on Maintained Situational Interest

Another secondary goal of the study was to examine how CD generated in a middle school science troubleshooting activity influenced students’ M-SI controlling for
the effect of II in science and pre-M-SI-value. The construct of M-SI was analyzed at M-SI-total, M-SI-feeling, and M-SI-value levels.

Results of this study revealed that the treatment and control groups did not differ significantly relative to M-SI-total after the intervention. This result can be explained by considering the treatment of this concept and function of M-SI in prior research (Hidi & Renninger, 2006; Linnenbrink-Garcia et al., 2010; Schiefele, 2001). Compared to T-SI, M-SI is not only associated with feelings emerging from the form of the instruction, but is also a deeper form of SI in which students start to establish the personal value of the content and build meaningful connections with it. It is similar to the concept of individual interest (II) because both these interest constructs consist of feeling-related and value-related components (Schiefele, 2001). M-SI serves as a link between T-SI and II as discussed by Hidi and Renninger (2006)’s four-phase model of interest development. As the CD treatment did not improve the T-SI of the treatment group to a level that significantly differed from that of the control group, it was less likely for it to make a difference in M-SI, which is a more developed and sustained form of SI and was more difficult to be influenced than T-SI.

As the concept of M-SI can be decomposed into M-SI-feeling and M-SI-value (Linnenbrink-Garcia et al., 2010), inferential analyses were also performed to further explore how M-SI-feeling and M-SI-value contributed to the development of M-SI. The results showed that there was not a significant difference in M-SI-feeling between the two groups after the intervention. However, the treatment group experienced a statistically significant increase in M-SI-feeling than the control group. That is to say, the CD treatment led to a larger increase in M-SI-feeling for the treatment group. This result
suggests that the CD treatment elicited a stronger affective response from students toward the content of the lesson. In other words, the anomalous result of the Megalodon body length was able to stimulate and maintain students’ attention before a meaningful relationship could be built between learners and the learning content. Nonetheless, some other factors might have contributed to the M-SI-feeling for the control group at the same time as well since there was not a significant difference in M-SI-feeling between the two groups.

The results also showed that the treatment group had significantly higher M-SI-value than the control group. However, this difference should be interpreted with caution since the two groups already differed with each other in M-SI-value before the intervention. The effect size of the difference between the treatment and control groups in M-SI-value decreased from moderate (d = .65) to small (d = .10) as a result of the intervention. Thus, the significant difference between the two groups in M-SI-value became smaller after the intervention. The descriptive statistics further explained the decreased effect size by demonstrating that the control group increased in M-SI-value faster than the treatment group. Therefore, it can be hypothesized that the CD treatment might only have a limited contribution to the increase of M-SI-value for the treatment group because the control group increased faster in M-SI-value without the CD treatment. It is possible that other elements of the lesson contributed more in helping students establish a meaningful relationship with the lesson than the CD treatment.

The learning topic and activities might be one of the factors that contributed to the development of M-SI-value. Azevedo (2018) studied interest-driven participation across formal and informal scientific settings and concluded it was the learning topic
and its relevant activities that continuously sustained learners’ involvement and
maintained their engagement. In the present study, both interview and observation data
revealed that students were very active in participating in various activities throughout
the lesson. For example, students expressed the hands-on experiences with the real
fossils increased their engagement. Moreover, learning about a charismatic species
such as Megalodon in the context of paleontology connected and informed their
understanding of socially relevant topics, including evolution and climate change, as
evidenced in the qualitative data. Therefore, the result of the present study suggested
the content of the learning yielded beneficial outcomes for M-SI-value.

Hands-on activities can be an important factor contributing to M-SI-value. The
students interview data indicated all five students enjoyed the hands-on activities
included in the lesson. Although they were discussed as potential sources of triggering
SI in earlier section, they may have also been effective in maintaining students’ SI since
they represented both involvement and meaningfulness (Mitchell, 1993). The classroom
observation data showed students were active participants in these hands-on activities
and were learning concepts that were beneficial for their future science learning. It thus
indicated that students’ M-SI-value might be improved when they were building a
meaningful relationship with the learning content through active involvement in these
hands-on activities to a larger extent than through induction of CD.

As there was a statistically significant increase in M-SI-feeling but not in M-SI-
value for the treatment group, the significant increase in M-SI-total can be largely
explained by its increase in M-SI-feeling. That is, the CD treatment was more effective
in increasing students’ M-SI-feeling than M-SI-value. In other words, it was easier to
trigger students’ positive feelings toward the learning situation than to sustain the positive feelings and establish a meaningful relationship between the students and the learning content by using the anomalous result. This finding is likely related to whether the CD experience was perceived as meaningful for students. Although the result of the CCLT survey showed that all students in the treatment group experienced CD, it didn’t mean all of them had a pedagogically meaningful CD experience. According to Limón (2001), instructional strategies, motivation, prior knowledge, attitudes and epistemological beliefs, as well as discussion and work with peers are all important factors to reach a stage of meaningful CD. The qualitative data indicated that students’ troubleshooting experience, which was designed to help students better understand their CD experience, was constrained by the short class duration and limited instructional scaffolding. Also, some students shared that their lack of prior knowledge about Megalodon prevented them from fully engaging in estimating its body length. Moreover, the VNOS survey conducted before the intervention revealed students had varied VNOS, which likely also affected their CD experience. Consequently, it is possible that some students couldn’t appreciate the value of the CD experience and its contribution to their science learning, relation to the real-world science practices, and its implications for their future science learning. Failure to reach a meaningful CD experience might have explained why the CD treatment could only lead to a transient M-SI-feeling, but not establish a more stable M-SI-value for students.

There could be another possible explanation that students had limited meaningful choices during the lesson. During the student interviews, some students expressed frustration about only having Shimada’s equation and having no other choices for
estimating the body length of Megalodon. Other students suggested each group could
measure different Megalodon teeth rather than only working with the same two
Megalodon teeth. These comments suggested that students had a need for autonomy,
which is a major component of the self-determination theory. Deci’s (1992) self-
determination theory proposes that people have an innate psychological need for
autonomy, which can be satisfied by giving meaningful choices. During students’ inquiry
of estimating the body length of Megalodon, they weren’t allowed to make meaningful
decisions relative to equation choice, measurement of the crown height, and
troubleshooting process. As a result, it can be hypothesized that students didn’t
experience a sense of autonomy, which might explain why the meaningful relationship
between students and the learning content was hard to build for the treatment group.

Nevertheless, the fact that the CD-based approach made a small but significant
difference in M-SI-value but not in T-SI between the treatment and control challenged
the validity of the four-phase model of interest development proposed by Hidi and
Renninger (2006). According to this model, interest develops cumulatively and
progressively from T-SI to M-SI. Surprisingly, this study showed that the CD-based
approach contributed to the maintenance of SI without substantially triggering students’
SI with to begin with. In other words, students did not have to be necessarily aroused
affectively by the incongruous features of the CD-based approach before engaging with
the learning content and realizing the personal value of the knowledge. Although no
similar results were found in previous research, findings regarding the effects of II on SI
might be helpful for explaining this surprising result. For instance, many studies have
demonstrated that pre-existing II can influence learners’ approach to situations (Durik &
Harackiewicz, 2007; Krapp, 2002; Schiefele, 2009; Tapola et al., 2013), therefore, affecting their experience of SI. As the treatment group had a higher level of II than the control group, it is possible that students in the treatment group could connect with the content in the Megalodon lesson more easily and see its value without being aroused by the anomalous result of the Megalodon length – since they already had a high level of II in science. As they already enjoyed learning science topics and recognized its value and relevance to their life, they could quickly identify the purpose and meaning of the CD-based approach, which contributed to their M-SI-value.

Previous studies have identified factors that predict students’ M-SI-total (e.g. Hunsu et al. 2017) but haven’t differentiated between factors those that predict M-SI-feeling and those predict M-SI-value. This study was specifically focused on exploring how CD, including recognition of anomaly, interest, anxiety, and reappraisal of CD situation, would predict M-SI-total as well as M-SI-feeling and M-SI-value as individual factors. The results suggested the reappraisal of CD situation significantly positively predicted M-SI-total and M-SI-feeling. That is, if students evaluate an anomalous result, reassess their prior knowledge and conceptions, and identify the causes for the anomalous result after experiencing CD, their M-SI will likely improve, especially relative to their positive feeling toward the learning content. Since the present study was the first to use the CCLT survey to explore the relationship between CD and M-SI, it contributed to our knowledge of sources that could maintain SI. This result suggests that science teachers should encourage students to reassess their existing conceptions and identify potential factors that caused CD before any actions were taken to resolve CD. Students’ reappraisal of CD situation may increase their chances of identifying the causes of CD
and participating in relevant cognitive activities to resolve CD. The process of reappraisal may therefore lower the possibility of experiencing negative emotions and establish a positive relationship with the learning content.

The results also revealed anxiety was significant positive predictor of the variance in M-SI-value. That implies that the more anxious students feel, the more they will recognize the value of the learning content and build a personally relevant relationship with it. Though no studies have explicitly dealt with the relationship between anxiety and M-SI, research on the influence of anxiety on engagement can shed light on this finding. Anxiety has been found to have both positive and negative effects on student engagement. Interference models of test anxiety posit that anxiety reduces performance on complex learning tasks since cognitive resources are consumed by anxiety (Pekrun & Linnenbrink-Garcia, 2012). In line with this model, anxiety was found to be related negatively to motivational variables, such as interest and intrinsic motivation (Pekrun, Goetz, Perry, Kramer, Hochstadt & Molfenter, 2004). However, anxiety has also been found to strengthen extrinsic motivation to invest effort in order to avoid failure and attain success (Turner & Schallert, 2001) and promote focused, detail-oriented, and analytical ways of thinking (Clore & Huntsinger, 2009). The present study provided empirical evidence to support the positive role of anxiety in impacting students’ SI, especially in its value component. However, this interpretation was largely implied from previous research on anxiety. Future research could incorporate more cognitive (e.g., learning strategies, attention, effort, etc.) and motivational variables (e.g., intrinsic and extrinsic motivation) into the research design to further understand the processes underlying the effects of anxiety on M-SI and M-SI-value.
Student Strategies to Resolve Cognitive Disequilibrium

The strategies students used to resolve their CD in the present study are discussed relative to Piaget’s (1975) classification of responses toward CD. Piaget distinguished between adapted and unadapted responses to contradictory information. There were no unadapted responses in the study as all students experienced CD, indicating that they all realized the anomaly of the result. Therefore, student responses to CD fell into the three types of adapted responses proposed by Piaget (1975), alpha, beta and gamma.

Students who chose the alpha approach ignored or did not take into account the anomalous result. They believed the scientific knowledge they learned in class was absolutely certain or true and thus were not critical about it. Once they saw the anomalous result, they knew it was anomalous but regarded it as an exception without further thinking about its implication. In the present study, even though some students got extremely small or large body length of Megalodon from the flawed R Shiny Megalodon App, they were trying to find explanations to justify instead of doubting their results. The anomalous result did not influence their epistemological beliefs of scientific knowledge. Thereafter, the anomalous result was largely ignored and did not influence students’ theory.

Students who chose the beta approach tended to use an “ad hoc” answer to explain the CD. The observation data revealed that most students did not spend sufficient time troubleshooting each potential error and understanding the implication of CD for the critical aspects of NOS. Consequently, some of them thought the flawed R Shiny Megalodon App was the main source of causing CD. Their CD experience only made them realize that the breakdown of technology could affect the results of the
scientific discovery but did not give them a chance to deepen their understanding of how other critical aspects of NOS, such as subjectivity, inference, and imagination, could influence the scientific process as well. As a result, the CD experience only produced partial modifications in the students’ theory.

Students who employed the gamma approach benefited the most from the CD experience. They not only understood how the flawed R Shiny Megalodon App resulted in the anomalous result of the body length of Megalodon, but also knew how the anomalous result could be caused by other factors. Joy was one of the students who took the gamma approach. She reported a relatively high CD score and demonstrated interest in resolving her CD. During our interview, she talked about how she believed technology could advance our scientific understanding before the inquiry but realized that technology could lead to erroneous findings if it was not functioning properly. Furthermore, the quantitative data showed that her views of NOS improved from naïve to informed after the intervention, indicating that she improved her understanding of the targeted aspects of NOS and their implications to her CD experience. As a result, her gamma approach modified the central core of her theory.

It seems obvious that students’ approach to resolving CD was affected by their pre-existing knowledge, motivation, and goals, indicating both cognitive and motivational constructs interacted to influence students’ conceptual change. Students who chose the alpha approach tended to believe knowledge was stable and fixed, which did not provide an appropriate “conceptual ecology” (Posner et al. 1982) for conceptual change. Their preconceived notion about the nature of scientific knowledge was not sufficient for them to recognize the knowledge discrepancy induced by CD, or
the anomalous result was not well designed to be comprehensible, plausible, and compelling to these students. As interaction between students and the characteristics of the anomalous data affected conceptual change described by Cognitive Reconstruction of Knowledge Model (CRKM; Dole & Sinatra, 2005), this might explain why the anomalous result was largely ignored by these students. Therefore, relevant strategies should be implemented to increase their dissatisfaction with their existing conceptions as explanations for scientific phenomena before using CD-based strategies to promote their conceptual change.

Students who chose the beta approach may have a better understanding of the NOS but lack motivation to engage with the learning content. As sufficient modeling and scaffolding was not provided to help students in understanding their CD experience, this might have undermined students’ motivation and cognition and hindered the potential for conceptual change. As a result, the lack of instructional scaffolding might have affected students’ cognitive engagement, such as resolving their CD superficially by simply blaming the technology, which was unlikely to result in conceptual change. Therefore, teachers should have more professional support on how to facilitate students in bridging the gap between what they already know and what they need to know through modeling and scaffolding.

Students who chose the gamma approach had a “conceptual ecology” (Posner et al., 1982) prepared for conceptual change. They usually had a high individual interest in science, clear achievement goals, and a strong motivation when facing new challenges in science learning. The self-reported survey data showed that Joy, who took the gamma approach, had a strong interest in learning science, possessed mastery goal
orientation, and understood the uncertainty of scientific knowledge. Therefore, compared to her peers who adopted an alpha or beta approach to resolving CD, students like Joy tended to use more elaborate metacognitive and self-regulatory strategies that led to deeper processing of the information (Pintrich & Schrauben, 1992).

**Students’ Perceptions of the Science Computational Modeling Activity Incorporating Cognitive Disequilibrium**

Additional sources of SI were identified in student interviews. Joy mentioned that the movie trailer of The Meg was the most interesting part of the lesson. She said the movie trailer was more effective than the documentary in attracting her attention as the movie trailer contained elements such as suspense, imagination, and excitement. Although the movie trailer hasn’t be studied in previous educational research as a potential source of SI, it has the same characteristics as other sources, such as novelty, mystery, and uncertainty, that are effective in capturing students’ attention and triggering affective responses toward the topic. Another student, Peggy, mentioned that learning about past life was very interesting to her. She felt excited about exploring the Megalodon as no one had ever seen it before. This suggested that paleontology represented a charismatic gateway to engage middle school students and learning about the past life that once existed on Earth was a source for triggering students’ SI. If more students had been interviewed, more sources of SI might have been identified to inform the results of this study.

Although the Megalodon activity embedded with CD did not significantly improve students’ SI, it might have brought out some other positive outcomes that were not directly measured but were relevant to SI. Chen et al. (2001) found that instant enjoyment was the main source of SI. It resulted from the features of challenge, novelty,
exploration intention, and attention demand. In the present study, the qualitative data showed students had achieved different levels of instant enjoyment, which were resulted from their CD experiences with features such as challenge and novelty but were not directly measured. The SI developed from instant enjoyment might have be counterbalanced by the process of resolving CD through troubleshooting the anomalous result of Megalodon length, which was perhaps not well designed to keep students’ exploration intention and high attention demand, another two important contributors to instant enjoyment. Therefore, the Megalodon activity with high challenge and novelty but low exploration intention and attention demand was not able to maintain students’ instant enjoyment, which was the major source of SI.

The essential features of scientific inquiry were present in the lesson and achieved the purpose of engaging students. As the intervention placed a strong emphasis on student inquiry process, instructional activities and all relevant discussion questions and topics were designed by focusing on the essential features of scientific inquiry. Students’ engagement in the inquiry helped them develop understanding of the target science content, and acquire and practice science process skills, such as observing, predicting, measuring, and interpreting. In addition to focusing on practicing scientific inquiry skills, the troubleshooting activity and wrap-up discussion made students aware of the science process skills they engaged and contemplated ways to improve their performance of these skills.

However, the scientific inquiry implemented in the study focused largely on students’ abilities to engage in scientific inquiry yet ignored improving their understanding about scientific inquiry. For example, the interview data revealed that all
five students knew the importance of using technology to gather, analyze, and interpret data. However, they knew less about why scientists use technology to advance their thinking and how they use technology to enhance accuracy and quantify investigation results. Furthermore, as each step of the inquiry was strictly prescribed, students didn’t have too much freedom in designing the investigation, selecting tools and techniques, and exploring alternative explanations. Therefore, they had less chance to discuss and externalize how scientific reasoning and critical thinking were reflected in the scientific inquiry process and how scientific investigations sometimes resulted in new ideas and phenomena for study.

The CD treatment provided students with more opportunities to experience aspects of NOS. As evidenced in student interview data, students who experienced CD had more developed views of NOS and were capable of discussing how the lesson was connected to NOS compared to their counterparts in the control group. Therefore, there is still a possibility that students in the treatment group were exposed to more aspects of NOS and had more opportunities to experience CD in their inquiry process. However, since the quantitative data did not find a significant difference between treatment and control groups in views of NOS, simply providing students with the opportunities to experience CD was not enough.

If students are to develop informed views of NOS, explicit and reflective approach to teaching NOS should be contextualized into inquiry-based activities. Although students enjoyed conducting the inquiry to estimate the body length of Megalodon, most of them maintained naïve views of NOS after participating in the inquiry. As previous research indicates, the inquiry by itself is insufficient to teach
students about NOS (Khishfe & Abd-El-Khalick, 2002), the result was perhaps largely caused by the insufficient use of the explicit and reflective approach to teaching NOS. Students in both treatment and control groups did not have enough opportunities to reflect on what they did in those activities within a framework of the target NOS aspects. If the teacher treated NOS as a cognitive instructional outcome that was as important as science content learning, specific instructional activities would be more likely to gear toward teaching such an outcome, leading to more positive change in students’ NOS views. Efforts could also be made in aligning the objectives, instructional attention, and assessment with the target NOS aspects so that the efficacy of explicit and reflective approach could be maximized (Schwartz et al., 2004). Besides, some components of the student inquiry could be liberated, such as giving students the authority to choose the methods for estimation and making the troubleshooting process less structured, so that they would have more characteristics of authentic inquiry carried out by scientist in real-world practice and move students from the periphery to the core of the science learning community (Richmond & Kurth, 1999).

**Implications**

First, the study provided evidence that supports the inclusion of CD in middle school science classrooms. CD was evidenced to be a source for triggering students’ SI in science. However, its potential in triggering SI was rather limited because other factors, such as students’ individual differences and influence of the teacher and peers were not examined. Also, students’ reappraisal of CD has been found to predict students’ T-SI. The practical implication of the present study is that science teachers should consider including CD in instructional activities, especially for motivating students who are traditionally unmotivated toward science. They also need to realize
that merely using anomalous data or discrepant events to introduce CD will not automatically trigger students’ SI. They should carefully consider students’ preconceptions, motivation, interest, and epistemological beliefs when designing CD-based learning activities and use appropriate scaffolding and grouping strategies to resolve students’ CD. Future research could explore how various variables, such as teachers, peers, and students’ characteristics mediate the relationship between CD and T-SI to provide more effective instructional strategies for science teachers. Research could also focus on exploring what other emotions and cognitive activities students are experiencing while they are in the state of CD and how they interact with each other.

Second, the study suggested the CD experience should be carefully designed if it were to improve students’ views of NOS and science content knowledge. In the present study, the CD treatment has not contributed to the improvement of students’ views of NOS and science content knowledge. These results suggest that in order to use CD-based strategy to promote students’ conceptual change, the CD experience itself should be meaningful in terms of offering students opportunities to see the inadequacies in their existing knowledge, encouraging them to resolve CD by seeking new information, and providing appropriate scaffolding to maintain students’ optimal emotional state. Since the meaningful CD experience is primarily contingent upon instructional approaches, science teachers should build the lesson based on students’ existing views of NOS and use the explicit and reflective approach (Abd-El-Khalick & Lederman, 2000) to teach NOS to help bridge their CD experience with targeted views of NOS. In addition, they should provide a variety of cognitive activities for students to participate, to deliberate, and to revise their existing mental models. Besides, implementing a CD-
based strategy to promote students’ conceptual change should be a long-term effort that requires iterative implementations. Future studies should continue to explore the effect of affective variables on cognition, especially the reciprocal relationship between negative emotions (e.g. anxiety, frustration) and students’ conceptual change in views of NOS and science content knowledge.

Third, the study suggested the CD treatment contributed to the maintaining of SI along with other factors. The CD treatment has been found to be more effective in increasing students' M-SI-feeling than in M-SI-value. Among the subscales of the CCLT survey in measuring CD, reappraisal of CD situation has been found to predict M-SI-total and M-SI-feeling, and anxiety has been found to predict M-SI-value. These findings suggest that science teachers can use CD-based activity to draw students’ attention and increase their excitement about the learning content. In addition, they should encourage and scaffold students to reappraise the CD experience before any actions are taken to resolve the CD. However, the short CD-based activity alone was not sufficient in this study to transition the transient feeling into a deeper form of connection with the learning content if no other sources of M-SI were involved. Science teachers could use hands-on activities, group work, scientific inquiry, and examples of charismatic species along with CD to establish a meaningful relationship between students and the learning content. Maintaining a certain level of anxiety is also recommended as it will help to sustain students’ attention and persistence on the tasks. Future research could use other measurement tools (e.g., asking students to brainstorm sources of SI) to explore other sources of M-SI that can be utilized in combination with the CD-based strategy to achieve the optimal learning outcomes.
The present study not only contributes to our understanding of CD as a source of SI, but also its interaction with other sources within the same lesson. Previous studies usually focus on investigating individual sources that trigger and maintain SI but haven’t attempted to address their interactive effects when being used in one setting. This study determined that multiple sources of SI are usually present in science classrooms and interact with each other to affect students’ SI. In the future, additional measures (e.g. asking open-ended questions) could be administered to identify additional sources of SI that are not manipulated by the research design. Once they are identified, more investigations could be made to explore their relationship among each other in affecting students’ SI.

The study also indirectly challenged the validity of the four-phase model of interest develop proposed by Hidi and Renninger (2006). The results of the present study indicated that students’ M-SI could be developed under the influence of CD without any prior triggering of SI. This result contradicts Hidi and Renninger’s (2006) model, which argued that SI should be sparked by environmental or external features before other strategies could be used to hold and sustain it. Since interest is the outcome of an interaction between a person and a particular content (Krapp, 2000), the participants, context, and content of this study might have played a major role in leading to this result. Therefore, similar studies should be replicated in a different learning domain by working with participants of different ages to explore whether similar findings could be found. Moreover, since this study only focused on the short-term effects of the CD-based instruction on the development of students’ SI, future research can be
conducted on investigating its long-term effects, especially in how it would contribute to the more well-developed form of interest.

This study investigated the development of SI by focusing on the experience of the entire sample. Future studies could explore variability among individual participants regarding their complex trajectories of SI development (Jung & Wickrama, 2007). As discussed before, students perceive and respond differently to CD-based interventions, which may produce distinct trajectories of students' SI. Moreover, since previous research has demonstrated the effect of II in mediating the relationship between specifically designed learning situations and students' SI (e.g., Durik & Harackiexicz, 2007), future studies should investigate how CD-based interventions affect students who have high and low II in science differently. Besides, as students respond differently to the anomalous result as evidenced in the present study, future research can explore how students' cognitive and motivational variables interact with the features of the CD-based intervention and provide solutions to customize the CD experience for individual learners to promote optimal outcomes.

Although no significant findings were found with regard to using scientific inquiry to improve students’ views of NOS, some relevant evidence was generated that can inform future science instruction. First, students enjoyed practicing science process skills, improved their abilities to conduct scientific inquiry and developed their understanding of the target science content. Second, since the explicit and reflective approach to teaching NOS was not adequately implemented in the context of scientific inquiry, students’ understanding of scientific inquiry and views of NOS were not improved as evidenced in both quantitative and qualitative data. Third, the CD treatment
provided students with more opportunities to experience and discuss important aspects of NOS. Therefore, the practical implication is that science teachers should explicitly and reflectively discuss the relevant aspects of NOS that are implied in students’ inquiry process to help them understand not only what science process skills are, but also why they are practiced in this way. CD-based instruction has the potential to expose students to more aspects of NOS (besides uncertainty caused by anomalous data) and is relatively easy to implement in inquiry-based science classroom.

**Conclusion**

This study was designed to investigate the potential of cognitive disequilibrium to influence middle school students’ triggered situational interest, views of nature of science, science content knowledge, and maintained situational interest. Findings suggested that cognitive disequilibrium is a multidimensional construct and its effectiveness in improving interest and promoting conceptual change depends upon a number of cognitive and non-cognitive factors interacting with each other. Specifically, the incorporation of cognitive disequilibrium in middle school science instruction was effective in triggering students’ situational interest, which however, could be enhanced or hindered by their anxiety level, fluctuation of negative emotions, the role of teacher and peers, the specifics of the learning content, and the novelty of the learning experience that were present in the classroom. Also, cognitive disequilibrium-based instruction was effective in elicitig students’ affective response toward the learning content but should be used with other sources of situational interest, such as hands-on activities and meaningful choices, to build and sustain a meaningful relationship between students and the learning content.
Importantly, this study challenged the validity of Hidi and Renninger (2006)’s four-phase model of interest development by demonstrating that M-SI could be developed without triggered situational interest when using cognitive disequilibrium-based strategy. Moreover, the research findings supported the importance of building the cognitive disequilibrium-based lesson based on students’ initial conceptions, providing sufficient learning opportunities for them to make sense of the cognitive disequilibrium experience, and offering appropriate scaffolding to promote conceptual change in their views of nature of science and science content knowledge.
APPENDIX A
LESSON PLAN: HOW BIG WAS MEGALODON?

Driving Questions

1. How could scientists determine the length of Megalodon using fossil teeth?
2. How do scientists use modern sharks to help them gain understanding of fossil sharks?

Intended Audience

Middle School
8th Grade

Time Frame

2, 45 minute class periods

NGSS Performance Expectations

MS-LS4-1 Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.
MS-LS2-1 Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
MS-LS2-4 Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
MS-LS1-5 Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.

NGSS Disciplinary Core Ideas

LS2.A: Interdependent Relationships in Ecosystems
In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. (MS-LS2-1)

Growth of organisms and population increases are limited by access to resources. (MS-LS2-1)

LS2.C: Ecosystem Dynamics, Functioning, and Resilience

Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (MS-LS2-4)

Common Core State Standards Connections

Mathematics

6.EE.C.9 Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation. (MS-LS1-6),(MS-LS2-3)

MP.4 Model with mathematics. (MS-LS2-5)

Cross Cutting Concepts

Patterns

Patterns can be used to identify cause and affect relationships. (MS-LS2-2)
• Small changes in one part of a system might cause large changes in another part. (MS-LS2-5)

Cause and Effect

• Cause and effect relationships may be used to predict phenomena in natural systems. (MS-LS3-2)

Science and Engineering Practices

Developing and Using Models

Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

• Develop and use a model to describe phenomena. (MS-LS3-1),(MS-LS3-2)

Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. (MS-LS4-5)

Resources and Materials

Megalodon Student Handout and data collection sheet

Megalodon Power Point

Student Interactive Notebooks

Rulers

2D or 3D Megalodon teeth

iPads or Laptops (optional)
Calculators (optional)

**Key Academic and/or Scientific Language**

Fossil, paleontology, algorithm, crown height, lateral, anterior, posterior, root, neonate, juvenile, adult, lingual, labial, serrations, bourlette

**Objectives**

What knowledge and skills will students acquire?

Student will be able to:

- Use an interactive notebook
- Collaborate with peers during discussions
- Take measurements in millimeters
- Convert between units
- Ask questions about the scientific process when determining Megalodon total length
- Understand relationships between modern and fossil sharks
- Identify basic parts of a Megalodon tooth
- Solve a linear equation
- Identify and discuss variables that cause discrepancies in total length calculations

**Assessments**

- Student handouts will be assessed for completeness and math computation
- Student reflections on data analysis will show understanding of variables that cause differences in total length calculations
- Questions about the activity and outcomes will be included on unit assessment
<table>
<thead>
<tr>
<th>Phase</th>
<th>Topic</th>
<th>Focus of Activity</th>
<th>General Problem/Question Investigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (review)</td>
<td>Fossil</td>
<td>Fossil information</td>
<td>-What is a fossil? -What does a fossil tell scientists about the past?</td>
</tr>
<tr>
<td>2 (engage)</td>
<td>Megalodon</td>
<td>Background of Megalodon</td>
<td>-Who was Megalodon? -Why do we conduct research on Megalodon? -How can we know about Megalodon?</td>
</tr>
<tr>
<td>3 (demonstrate)</td>
<td>The length of Megalodon</td>
<td>Methods for predicting the length of Megalodon</td>
<td>-How to predict the length of Megalodon?</td>
</tr>
<tr>
<td>4 (apply) (Cognitive disequilibrium treatment)</td>
<td>Prediction</td>
<td>Implement the prediction</td>
<td>-What is the length of the Megalodon?</td>
</tr>
<tr>
<td>5 (reflect)</td>
<td>Conclusion</td>
<td>Conclusion of the lesson</td>
<td>-What is students’ experience with the lesson? -How does the lesson affect students’ perspectives on science?</td>
</tr>
</tbody>
</table>
APPENDIX B
COGNITIVE CONFLICT LEVELS TEST

Recognition of contradiction
1. When I saw the result, I had doubts about the reasons.
2. When I saw the result, I was surprised by it.
3. The difference between the result and my expectation made me felt strange.

Interest
1. The result is interesting.
2. Since I saw the results, I have been curious about it.
3. The result attracts my attention.

Anxiety
1. The result confuses me.
2. Since I cannot solve the problem, I am uncomfortable.
3. Since I cannot understand the reason for the result, I feel depressed.

Cognitive reappraisal of situation
1. I would like to ascertain further whether my idea is incorrect.
2. I need to think about the reason for the result a little longer.
3. I need to find a proper base for explaining the result.
APPENDIX C
SITUATIONAL INTEREST SCALE

T1    My science teacher is exciting.
T2    When we do science, my teacher does things that grab my attention.
T3    My science class is often entertaining.
T5    The science class is so exciting it’s easy to pay attention.
MF1   What we are learning in the science class is fascinating to me.
MF2   I am excited about what we are learning in science.
MF5   I like what we are learning in science.
MF6   I find the science class interesting.
MV1   What we are studying in the science class is useful for me to know.
MV2   The things we are studying in the science class are important to me.
MV4   What we are learning in the science class can be applied to real life.
MV5   We are learning valuable things in the science class.
APPENDIX D
SCIENCE ATTITUDES SUBSCALE OF THE S-STEM SURVEY

1. I am sure of myself when I do science.
2. I would consider a career in science.
3. I expect to use science when I get out of school.
4. Knowing science will help me earn a living.
5. I will need science for my future work.
6. I know I can do well in science.
7. Science will be important to me in my life’s work.
8. I can handle most subjects well, but I cannot do a good job with science.
9. I am sure I could do advanced work in science.
APPENDIX E
MEGALODON TOTAL LENGTH ACTIVITY WORKSHEET

1. Was the megalodon that these teeth belonged to bigger or smaller than our classroom? Is your data convincing? Why or why not?

2. If the identified tooth position for one of your teeth was off by two positions (the L1 was identified as L3 or A2), what would be the difference in estimated total size?

3. How do paleontologists infer anatomy and/or biology of an extinct animal such as megalodon?

4. What are the two variables you need to predict body length of megalodon?

5. Why do you think megalodon is no longer living today?

6. How can learning about the past help us prepare for the future?
APPENDIX F  
VIEWS OF NATURE OF SCIENCE QUESTIONNAIRE FORM-D

1. What is science?
2. What makes science (or a scientific discipline such as physics, biology, etc.) different from other subject/disciplines (art, history, philosophy, etc.)?
3. Scientists produce scientific knowledge. Do you think this knowledge may change in the future? Explain your answer and give an example.
4. (a) How do scientists know that dinosaurs really existed? Explain your answer.
   (b) How certain are scientists about the way dinosaurs looked? Explain your answer.
   (c) Scientists agree that about 65 millions of years ago the dinosaurs became extinct (all died away). However, scientists disagree about what caused this to happen. Why do you think they disagree even though they all have the same information?
   (d) If a scientist wants to persuade other scientists of their theory of dinosaur extinction, what do they have to do to convince them? Explain your answer.
5. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.
   (a) Do you think weather persons are certain (sure) about the computer models of the weather patterns?
   (b) Why or why not?
6. The model of the inside of the Earth shows that the Earth is made up of layers called the crust, upper mantle, mantle, outer core and the inner core. Does the model of the layers of the Earth exactly represent how the inside of the Earth looks? Explain your answer.
7. Scientists try to find answers to their questions by doing investigations / experiments. Do you think that scientists use their imaginations and creativity when they do these investigations / experiments?
   a. If NO, explain why.
   b. If YES, in what part(s) of their investigations (planning, experimenting, making observations, analysis of data, interpretation, reporting results, etc.) do you think they use their imagination and creativity? Give examples if you can.
8. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
9. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? Explain and give an example.
10. Is there a relationship between science, society, and cultural values? If so, how? If not, why not? Explain and provide examples.
Engaging students in scientifically oriented questions
1a. Students engage with an investigation question that is contextualized, motivating, and meaningful for students 0 1 2 3
1b. Students engage with an investigation question that focuses on standards-based content/phenomena 0 1 2 3
1c. Students engage with an investigation question that is answerable through scientific inquiry 0 1 2 3
1d. Students engage with an investigation question that is feasible and answerable in the context of the classroom 0 1 2 3

Engaging students in giving priority to evidence in responding to questions
2a. Students engage with phenomenon of interest 0 1 2 3
2b. Students work with data related to phenomena of interest 0 1 2 3
2c. Students generate evidence by organizing and analyzing data 0 1 2 3
2d. Students reflect upon and verify the data collection process, accuracy of data, and transformation of evidence from data 0 1 2 3

Engaging students in formulating explanations from evidence to address scientifically oriented questions
3a. Students formulate explanations about phenomenon of interest that are based on evidence 0 1 2 3
3b. Students formulate explanations about phenomenon of interest that answer investigation question 0 1 2 3
3c. Students formulate explanations about phenomenon of interest that propose new understanding 0 1 2 3
3d. Students formulate explanations about phenomenon of interest that build on their existing knowledge 0 1 2 3

Engaging students in evaluating their explanations in light of alternative explanations
4a. Students evaluate their explanations by comparing to alternative explanations to consider whether evidence supports their proposed explanation 0 1 2 3
4b. Students evaluate their explanations by comparing to alternative explanations to consider whether their proposed explanation answers the investigation question 0 1 2 3
4c. Students evaluate their explanations by comparing to alternative explanations to consider any biases or flaws in reasoning connecting evidence with their proposed explanation 0 1 2 3
4d. Students evaluate their explanations by comparing to alternative explanations to consider whether alternative explanations can be reasonably derived from the same evidence 0 1 2 3

Engaging students in communicating and justifying their explanations
5a. Students clearly share and justify their investigation question 0 1 2 3
5b. Students clearly share and justify their procedures, data, and evidence 0 1 2 3
5c. Students clearly share and justify their proposed explanation and supporting evidence 0 1 2 3
5d. Students clearly share and justify their review of alternative explanations. 0 1 2 3
APPENDIX H
STUDENT INTERVIEW QUESTIONS

1. What was your reaction to the anomalous result of the body length of Megalodon? Were you surprised/confused at it? Why or why not?
2. What do you think caused the anomalous result?
3. What was your overall experience with the Megalodon activity? What interested you the most?
4. How do you think the Megalodon activity was different from other activities you've experienced before? What specific aspects of the Megalodon activity you liked/disliked?
5. How do you think the nature of science was connected to this lesson?
6. Why do you think the Shimada’s equation didn’t work?
7. Which part of the lesson do you think needs to be improved in the future?
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BIOGRAPHICAL SKETCH

Wenjing Luo received her Ph.D. in Curriculum and Instruction with an emphasis on Educational Technology from the University of Florida in 2019. She completed her bachelor’s degree in English at Leshan Normal University during 2008-2012. She graduated from Vanderbilt University in 2014 with a Master of Education degree in English Language Learners and she taught English and reading at Wekiva High School, FL after graduation. During her Ph.D. study, Wenjing’s research focused on cognitive disequilibrium, situational interest, and educational robotics.