Moving Beyond Concepts: Getting Urban High School Students Engaged in Science through Cognitive Processes

by

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ABSTRACT

In order to maintain its global position, the United States needs to increase the number of students opting for science careers. Science teachers face a formidable challenge. Students are not choosing science because they do not think coursework is interesting or applies to their lives. These problems often compound for adolescents in urban areas. This action research investigated an innovation aimed at engaging a group of adolescents in the science learning process through cognitive processes and conceptual understanding. It was hoped that this combination would increase students' engagement in the classroom and proficiency in science. The study was conducted with 28 juniors and sophomores in an Environmental Science class in an urban high school with a student body of 97% minority students and 86% students receiving free and reduced lunch. The study used a mixed-methods design. Instruments included a pre- and post-test, Thinking Maps, transcripts of student discourse, and a two-part Engagement Observation Instrument. Data analysis included basic descriptives and a grounded theory approach. Findings show students became engaged in activities when cognitive processes were taught prior to content. Furthermore it was discovered that Thinking Maps were perceived to be an easy tool to use to organize students' thinking and processing. Finally there was a significant increase in student achievement. From these findings implications for future practice and research are offered.

DEDICATION

To my two precious kids - Ujjesha and Rohin & all 28 students of the 8th hour
Environmental Science class 2013-14

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TABLE OF CONTENTS

Page

CHAPTER Page

CHAPTER Page

CHAPTER Page

APPENDIX

.

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure

CHAPTER 1 - INTRODUCTION

Leadership Context and Purpose of the Action

The United States (U.S.) was once a pioneer and leader in science, technology, engineering, and mathematics (STEM), but now our country's ranking in these subjects is not keeping up with those of other nations (Tucker, 2011). In a report by the National Center on Education and the Economy, Tucker (2011) noted that the science performance of students in the United States on the Program for International Student Assessment (PISA) as compared to other countries such as Canada, Finland, China, and Singapore has dropped from high performing to average. Moreover, per the Business for Higher Education Forum, only 15.6% of college students are graduating with STEM majors (BHEF, 2010). These findings show U.S. dominance in the field of science and engineering has eroded significantly (National Science Foundation, 2010). This decline has consequences because research, innovation, technology, and knowledge-intensive services are the things that keep our nation strong and competitive (National Science Board, 2010). As a result of globalization, the United States has realized that it needs to help its students to excel in STEM areas.

Professional organizations like the National Science Foundation (NSF) have tried to gain understanding as to why the United States has experienced its decline and through research, determined that education plays a major part. In 1956, the Science Education Reform movement was launched and in the 60's and 70's the space race put science at the forefront of our nation's schools. Investments were made to guide interested students into scientific careers (Tressel, 1994). From a pedagogical standpoint during this period, textbooks defined the science curriculum.

During the 1980s, there were fewer science reforms at the national level but by the end of that decade, Project 2061 was launched to place emphasis on "Science for all Americans" (Bybee, 1995). Through most of the 1990s reform work was dedicated to defining what scientific literacy means for all students.

Then in the early 2000s the inquiry as a method for teaching science, as well as content, was officially introduced (National Research Council, 2000). However, in spite of this new approach and years of effort to improve science teaching, test scores indicated that this approach was ineffective. Students were not learning the science they needed to be competitive in a global economy.

The latest PISA results are not encouraging in either science or mathematics and this outcome is even more problematic because the 21st century represents an era of rapid advancement in technologies. To make sense of complex and varied information, students will need to have a sound conceptual understanding of the core concepts of science and how cognitive processes work (Schank, 2011). The need for students to become knowers and thinkers has never been greater and, because of this, teaching science at the high school level continues to require modification.

Fortunately, educators in the United States with the help of the National Research Council and American Association for the Advancement of Science, are trying to change ineffective science teaching with new standards (Rutherford, 2005). The current wave of improvement released in 2013 is known as the New Generation Science Standards (NGSS). The NGSS focuses on three distinct dimensions: Scientific and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. The orientation of the NGSS is a distinctive shift in terms of teaching science. The new standards focus on thinking and development of core ideas in a cumulative manner in the physical sciences, biological science, earth and space sciences, and engineering, and technology. The newly developed NGSS focus aims to pave the way for teaching science in a way that is expected to bring better conceptual understanding to students, help students understand how scientists think (e.g., asking questions, investigating, modeling, planning), and help students connect science to real world phenomenon.

Personal Context

I am a high school science teacher in a large urban setting in the southwestern United States. Ninety percent of the students in my school are of minority descent and 86% of them are on free and reduced lunch. Given their urban environment, many of my students come to school with limited knowledge of science and this includes a lack of awareness of environmental science. Because of their economic status, my students cannot afford to go to summer camps or take vacations that would give them the foundational knowledge and experiences they need to understand their world. Further complicating matters is how my students have been educated in the past. The school at which I work focuses on developing students for fire and police career pathways and this type of focus encourages them to follow a regimental routine. Too many of my students think teachers are dispensers of knowledge and that their job is to complete worksheets for grades. In other words, the instruction they have received had made my students more tuned to procedural learning than the conceptual understanding and deeper thinking involved in science. This way of learning provides a drawback for a teacher like myself, because it is my role and responsibility to ensure that each and every one of my students master the science content (e.g., energy, ecosystems, earth's system) and develop the habits of mind scientists use.

Complicating matters is the fact that in 2013 the NGSS were released and will raise the stakes for both my students and myself. The strict standards do not account for a student's background. Even though my students are from low-income urban environments and lack experience, they must master the NGSS. I, as a teacher, must show student's progress and this progress must keep up with my district's growth model.

For me, successful teaching is more than students doing well on standardized tests. I want my students to master the science standards, enjoy learning science, and relate the content of what they learn to their lives. I want my students to build upon their prior knowledge and learn science concepts in depth. Yet I face external (national and district) pressures along with internal (classroom) challenges. External pressure includes helping my school maintain a grade of "A" awarded by the state and meeting the district-wide initiative of data driven instruction and continuous growth plan. The internal challenges I face are many. My students lack exposure to science, and their interest is the school Career and Technology Education (CTE) program. Despite these challenges, I want my students to use science in their lives and cultivate local involvement in science (Feinstein, Allen, & Jenkins, 2013). I want my students to succeed and believe they can impact the world.

Previous Cycle of Action Research

As a teacher, I want my students to become scientific thinkers and to understand their perceptions. Yet, this did not seem to be the case, so I conducted an investigative cycle of action research to answer the following questions:

1. How do my students perceive scientists?
    a. What do my students think scientists do?
2. How do my students believe scientists think?
3. Will instruction in cognitive processes and use of thinking maps help my students think more deeply?
4. What will my students say if I ask them how science relates to their lives?

To answer the first question, I asked all of the students in my environmental science class to draw a picture of a scientist with as many details as possible. After looking at the 74 drawings collected, I found that 96% of my students drew male scientists. Thirty students (22%) drew a scientist with glasses, 87% gave their scientist a lab coat, and 98% made the scientist's surroundings related to chemistry with items like test tubes, beakers, burners, and/or Erlenmeyer flasks. Interestingly, most students drew scientists with smiling faces.

To gain a finer perspective into question one (students' perceptions of scientists), I also interviewed one male and one female student based on their availability after school. Going through the interview transcripts established that the two students thought scientists needed cognitive processes, but what that meant was not clear. For example, when asked about cognitive processes the female student said, "Scientists always think outside of the box to solve things, a normal person just goes along with it." This interviewee also noted that scientists have, "good imaginations." The male interviewee stated that scientists "test their hypothesis." Both interviewees confirmed that scientists engage in prediction and to them prediction was what would happen in the future based on the evidence they collected. They also expressed that there was little connection from science to their lives. From the interview it became clear that these two students thought scientists had a special way of thinking, but just what that thinking was, was not clear.

In this investigative cycle of action research, I also tried a mini-innovation to pilot test the effect of teaching cognitive process. To do this I chose my Forensic Class and asked them to solve a case by collecting facts and evidence in a logical way. To achieve this goal, students were asked to work in groups of three and to create different kinds of Thinking Maps (a bubble map and a multi flow map; Thinking Maps Inc., 2011). The maps were to contain: 1) background information on the case, 2) criminal personality descriptions using (bubble map - description), 3) motive of the criminal (multi flow map - causation), 4) solving of the case based on evidence (flow map), and 5) presenting the case to the class (describing). From the Thinking Maps, I found that students were able to study the complexity of the case in depth and analyze the evidence from multiple angles. Thinking Maps, with my explicit teaching of causation and description, helped my students think deeper about the case.

Given these findings and wanting my students to learn, I was compelled to wonder if Schank's (2011) ideas of developing cognitive processes, along with scaffolding using Thinking Maps, could help students in my Environmental Science class understand concepts in depth and understand how science applies to local issues. Schank emphasizes that students should be taught cognitive skills in a story-centered curriculum and the local issues could be linked to this idea. I think story is important and also believe that students need to understand content knowledge (core ideas) gained through formal instruction and scaffolding**.** Thus, teaching cognitive processes through Thinking Maps along with content knowledge might prove beneficial if they were woven throughout an environmental issue or a story to which students can relate.

The purpose of this mixed methods action research study was to investigate what my students learned when thinking processes were taught in an explicit fashion prior to teaching concepts. The goal of my study was to understand my students' conceptual understanding and engagement.

Research Questions

1. How, and to what extent, will teaching cognitive processes prior to teaching content help my students' conceptual understanding of science content and ability to think scientifically? If I use this innovation will students' achievement improve?
2. How will using Thinking Maps engage my students and encourage them to become scientific thinkers?
3. If my students learn science concepts through cognitive processes and maps, will they be more engaged during class?

Definition of Terms

A few unfamiliar terms will be used throughout this dissertation. The definition of each of these terms is provided below.

Cognitive process: The specific things learners do mentally as they try to interpret and remember what they see, hear, and study.

Conceptual understanding: When students form many logical connections among specific concepts and principles related to a topic, they gain a conceptual understanding of the topic.

Engagement: Student engagement consists of three indicators: (a) affective-emotional engagement; (b) cognitive engagement; and (c) behavioral engagement

Scientific thinkers: All cognitive processes involved in scientific endeavor.

Social constructivism: Social constructivism is a sociological theory of knowledge that applies the general philosophical constructivism into social settings, wherein groups construct knowledge for one another, collaboratively creating a small culture of shared artifacts with shared meanings.

CHAPTER 2 - LITERATURE REVIEW

Review of Supporting Scholarship

In Chapter 1, I outlined how science education in the United States has changed throughout the years from direct teaching to a more inquiry-based approach. Furthermore, I acknowledged how these changes have not been effective and that PISA results continue to show downward trends in both science and mathematics. In Chapter 1, I also offered a glimpse into my personal context, teaching urban students with limited science backgrounds. My students are disinterested in the content, yet at the same time, my district is data driven and upcoming National Generation Science Standards (NGSS) are putting pressure on teachers like myself.

In this chapter, I report on research to support my argument that explicit teaching of cognitive processes, before content, may be a way to help high school students build their conceptual knowledge, and at the same time increase student engagement in science class.

The Trouble with Science Education Today

In the information age, a deeper knowledge base will be needed to keep up with the world market. However, in the United States, 65% of science, technology, engineering, or mathematics (STEM) college graduates are from foreign countries (Patton, 2013) and many of these graduates leave the U.S after the completion of the program. *The Business-Higher Education Forum* (2010) notes that in the U.S., a mere 15.6 % of college students are opting for STEM majors. Out of the 1.7 million students enrolled in college, only 233,000 students (13.7%) graduated in 2007 with bachelor degrees in STEM areas. Research also shows that after graduation the number of students opting for STEM careers had decreased dramatically (BHEF, 2010). STEM related occupations are increasing at a higher pace than any other (National Science Foundation, 2010; DOL, 2007), but the supply of domestic STEM graduates remains short of current and predicted needs (Fox & Hackerman, 2003; Hall, Dickerson, Batts, Kauffmann, & Bosse, 2011). These facts have brought STEM majors into focus and despite increasing awareness and a few more majors, the number of STEM graduates will not be enough to meet the needs of our ever growing the labor market (Commission on Professionals in Science and Technology, 2007; Lowell & Regets, 2006). This presents a critical challenge for the U.S. because our economy is connected to skilled leadership in these areas. Furthermore, research shows that students will not be even considering STEM majors or careers if they lack scientific knowledge. Students cannot make choices if they do not understand the wealth this content brings, especially in terms of better thinking and reasoning. Educators and 87% of the public support higher thinking but in high schools this ideal currently is not in place (Achieve, 2013). The Alliance for Excellent Education (2007) confirms that the content and instruction in most high school courses are not aligned to college readiness. The preparedness and perceptions students hold about science matters to their choices (Wang, 2013). Yet, choosing math and science as majors is sluggish as compared to our nation's need of STEM majors (ACT, 2006).

Figure 1 represents the STEM Educational Model prepared by the Raytheon Company. According to the model, both interest and proficiency in STEM subjects are necessary prerequisites if students are to select and succeed in a STEM major. This illustration indicates how both interest in STEM activities and proficiency in math can contribute to students who will likely choose a STEM major and career. However, to get students interested in a science track takes time and hard work for teachers. Students do not suddenly become interested and proficient in science, technology, or math (BHEF 2010).

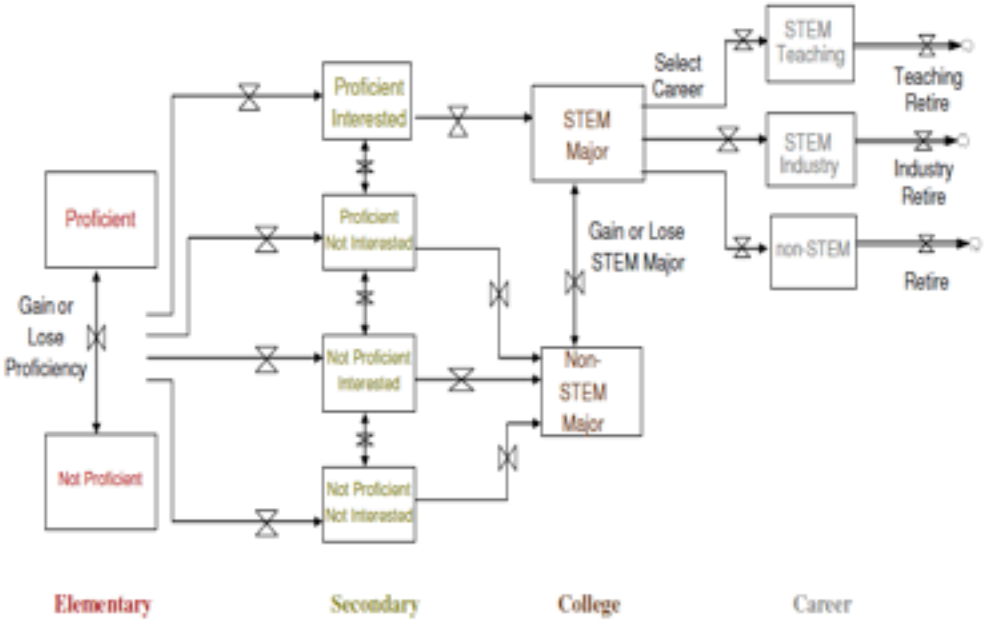


Figure 1. A simplified representation of the BHEF U.S. STEM Education Model. From *Increasing the Number of STEM Graduates: Insight from U.S. STEM Education and Modeling Projects* (BHEF, 2010).

At present K-12 science education is fragmented. Research indicates that elementary school science is an undervalued school subject and that the emphasis on language arts and mathematics as a result of high-stakes assessments, has hurt students' interest in science (Spillane, Diamond, Walker, Halverson, & Jilta, 2001). This trend continues into the middle grades, and by the time students reach high school, they are typically neither interested, nor proficient, in STEM subjects. In 2003-2004, only 14% of all undergraduate students entering postsecondary institutions were enrolled in STEM fields (U.S. Department of Education, 2008). Thus, building proficiency and interest in science early and continuing this through middle and high school may be a critical step toward producing more STEM graduates.

The Need to Build Conceptual Understanding

The term *concept* refers to a general category of ideas, objects, people, or experiences whose members share certain properties (Woolfolk, 2007). Conceptual understanding is defined as meaningfully learned and well-integrated knowledge about a topic, including many logical connections among specific concepts and ideas (Ormrod, 2008). Although there is no consensus on the actual definition of conceptual change, in general it the process by which a learner will come to adjust their initial ideas to fit a normative conception (Turcotte, 2012). Schnotz, Vasniadou, and Carretero (1999) define conceptual change as the reorganization of existing knowledge referred to when the common sense understanding of children gleaned from everyday experiences, is incompatible with the knowledge they are being taught in the school. Conceptual understanding leads to conceptual change and, according to Zirbel (2004), teachers need to confront students with discrepant events that contradict their existing understanding so that conceptual change can occur. Posner, Strike, Hewson, and Gertzog (1982) proposed a conceptual change theory that is a combination of Kuhn's (1970) idea of a paradigm shift and Piaget’s (1977) idea of the accommodation of new information. A paradigm shift is a change from thinking one way to another while accommodation occurs if the new ideas do not correspond with preexisting knowledge. Accommodation requires what is known to be changed. Posner et al. (1982) hypothesized that there are four essential conditions needed for conceptual change:

1. Dissatisfaction: The learner realizes that what they know will not solve the problem at hand.
2. Intelligibility: The learning material needs to make sense to the learner and the learner should be able to explain the concept to others.
3. Plausibility: The newly learned concept should make sense in a way that could be accommodated into one's prior knowledge and lead to solving problems.
4. Fruitfulness: The newly learned concept should not only help the learner solve a problem but also open up new areas of inquiry.

Fensham, Gunstone, and White (1994) and Dykstra, Boyle, and Monarch (1992) contend that conceptual change is rarely an abrupt phenomenon, but rather a gradual addition. Old ideas are not abandoned, but they are revised incrementally. These ideas are further reinforced by Driver Guesne, and Tiberghien (1985), Pfundt and Duit (1985), and West and Pines (1985) who note that conceptual change traverses from a learner's prior knowledge to an intermediate understanding and eventually to a specific conceptual change. Conceptual changes are built on what students already know (Zierbel, 2006).

These ideas connect to learning science because it builds on students "informal ideas about the scientific community" (Hewson, 1981; Posner et al., 1982; West & Pines, 1985). Building proficiency in science is one of the main criteria to keep high school students engaged in courses and motivated in the STEM field (BHEF, 2010). It may also be a mechanism for enhancing students' interest and engagement in science (Pintrich, Marx, & Boyle, 1993).

Social Constructivist Views of Learning

Social constructivism is a sociological theory of knowledge that applies the general philosophy of constructivism into social settings. Social constructivism has three components: (a) knowledge and knowing originate in social interaction; (b) learning proceeds from the interpsychological plane (between individuals) to the intrapsychological (within an individual) plane with the assistance of knowledgeable members of the culture; and (c) language mediates experience, transforming mental processes (Vygotsky, 1962, 1978).

Mercer (2002) emphasizes that science teachers should understand the importance of constructivism especially in terms of the discourse that happens. Treagust and Duit (2008) maintain that conceptual change recognizes the importance of dialogue. However, Scott (1998) posits that teachers’ talk focused on everyday concepts and scientific perspectives is critical to helping students learn science concepts. Discursive teaching is supported by Vygotsky’s (1978) view of socially mediated learning. In Vygoysky words, social contexts facilitate meaning and learning. When students first hear outward descriptions they then turn these words inward, thus leading to modifications or transformations of their knowledge base. Cognitive engagement is enhanced when students are actively involved in social spaces where they discuss, debate, or critique each other’s idea (Gutherie & Wigfield, 2000; Meloth & Deering, 1994; Newmann, 1992).

According to Wells (2000), an individual learns by interacting with a competent person. So this means that a teacher’s talk can play a critical role in students’ meaning making and conceptual development (Scott, 1998). A teacher’s encouragement for exploration of scientific ideas through discourse can help students understand concepts. Extended and elaborate teacher discourse helps students shift their conceptual understanding.

From a social-constructivist position, classroom discourse provides opportunities for students to test the validity of their ideas and develop meaning of higher complexity (Aufschnaiter & Aufschnaiter, 2007). Discourse within a group provides potential for the clash of ideas. Student-to-student and student-to-teacher discourse is important in a science classroom. Discourse provides students with the tools and a culture of scientific community (Beeth & Hewson, 1999). Thus, discourse provides a platform for students to be socially engaged in a meaningful learning process.

The Importance of Student Engagement

According to Lawson and Lawson (2013), engagement rests on three basic assumptions. The first is that engagement is malleable and can be improved through pedagogy and other interventions. The second is that engagement often leads to powerful learning outcomes. The third is that engagement and motivation are different from each other. Motivation is the energy to get things started, whereas engagement is seen as energy in action (Ainley, 2012; Skinner & Pitzer, 2012).

Engagement is further divided into two categories: *academic* when students focus their engagement on educational endeavors (Appleton, Christenson, & Furlong, 2008; Finn & Zimmer, 2012) and *classroom* when students' engagement takes place in classroom activities (Skinner & Pitzer, 2012). Academic engagement is school-based engagement while classroom engagement is more specific because it is in specific classroom activities. Fredericks, Blumenfeld, and Paris (2004) explain that engagement can be captured by three indicators: affective-emotional engagement, cognitive engagement, and behavioral engagement (Appleton et al., 2008; Fredericks et al., 2004; Furlong & Christenson, 2008). Affective-emotional engagement describes students' social, emotional, and psychological attachment to school. Part of affective engagement is a student's level of interest, enjoyment, happiness, boredom, and anxiety during an academic activity (Ainley, 2012; Appleton et al., 2008; Pekrun & Linnenbrik-Garcia, 2012; Skinner, Furrer, Marchand, & Kindermann, 2008). Cognitive engagement focuses on the psychological investment made in academic tasks (Fredericks et al., 2004). Cognitive engagement describes the ways in which a student thinks about ideas and concepts, how they make meaning of the material presented to them, and how they use self-regulating and metacognitive strategies to master academic content and tasks (e.g., Cleary & Zimmerman, 2012; Corno, 1993; Lam, Wong, Yang, & Liu, 2012; Pekrun & Linnenbrink-Garcia, 2012; Pintrich & De Groot, 1990; Pintrich & Garcia, 1991; Pintrich, Wolters, & Baxter, 2000). Finally, many researchers (Finn & Zimmer, 2012; Griffiths, Liles, Furlong, & Sidhwa, 2012; Rumberger & Rotermund, 2012) think behavioral engagement is shown in a student's demeanor during an academic pursuit. Thinking and affection for the academic activity are primary indicators of behavioral engagement.

Another interesting aspect of engagement is student positionality (Rogoff, 2003), which refers to who the student is and what they are doing during a particular activity at a given point in time. Reeve (2012) describes a student's engagement to teaching and learning process as *agentic engagement*. Agentic engagement is expressed when students actively share their thoughts, opinions, and interests during an activity, (Ainley, 2012; Assor, 2012; Brooks et al., 2012; Hipkins, 2012), when they direct their own learning

(Cleary & Zimmerman, 2012; Reeve, 2012), when they work collectively and critically with others (Davis & McPartland, 2012; Mahatmya, Lohman, Matjasko, & Farb, 2012; O'Conner, Hanny, & Lewis, 2011; Polman & Miller, 2010), and when they use culturally relevant tools and technologies (Dockter, Haug, & Lewis, 2010; Mitra & Serriere, 2012).

Another aspect of student engagement is social-cultural engagement. Research has identified that students are deeply engaged when their experience of content/activity is relevant to their needs (Crick, 2012). One indicator of socio-cultural engagement is cultural relevance, which refers to the emotions and cognitions students experience when an activity has personal significance (Guthrie, Wigfield, & You, 2012) and practical value (Eccles & Wang, 2012; Voelkl, 2012). Researchers (Davis & McPartland, 2012; Dockter et al., 2010) note the importance of this citing that students prefer activities that tie in to their social-cultural background. Further, Newmann, Wehlage, and Lamborn (1992) theorize that engagement in learning is enhanced when a task is authentic, provides opportunity for enjoyment and utilization of their diverse talents, and when students take ownership.

Learning From a Neuroscience Perspective

According to Kaplan (1998), adolescents and young adults process information at faster rates than younger children or adults. *Neurosciences and Education: Issues and Opportunities* supports this finding and states that the efficiency of communication in the brain improves during puberty because of myelination, the process by which axons become insulated with a fatty substance (myelin; Howard-Jones, 2007). Brain development proceeds naturally but environments also play a role. The most frequently used neurons become thicker with myelin coating resulting in efficiency.

The report also indicates that the frontal lobe and parietal cortices are developing rapidly in adolescence. The frontal lobe of the brain is responsible for coordinating different aspects of reasoning and movement, whereas, the parietal lobes are involved in integrating information from the senses. During adolescence, the brain is undergoing "reconstruction" (Spinks, 2000; Knox, 2010; Yurgelun-Todd, Killgore, & Young, 2002). Upon the onset of puberty, the brain overproduces dendrites, synapses, and neurons. This stage is followed by pruning, or removal of unused synapses, making the brain a more focused and efficient processor. Giedd et al. (1999) explain that once the dendrite network is formed during pre adolescence, it undergoes a through process of reshaping and reorganizing based on its use. Feintein (2009) states, "If they aren't reading, doing science, or solving problems, the synapses for those activities will be pruned and lost forever" (p. 11). Brain development and the cognitive process in it, are works in progress. As students continue to learn, neurotrophin (a type of brain protein) increases in the region responsible for new learning (Kang, Welcher, Shelton, & Schuman, 1997). Research indicates that a given capability, such as music or athletics, if not nurtured will never develop (Feinstein, 2009).

Cognitive load theory (CLT) is based on the assumption that our short-term or working memory is limited to seven plus or minus two information elements (Miller 1956). This is the information that one can process at a certain moment. Another point, noted by Jancke, Wüstenberg, Scheich, and Heinze (2002) is that practice makes the neural network becomes more efficient because it requires less brain metabolism to carry out the same activity. Thus, the practiced task requires less brain energy and area results in efficiency. Currently there is no clear indication that teaching cognitive processes is good for adolescents, but given the fact that many are beginning to think abstractly and that their cognition improves, it seems cognitive process-related instruction may help build neural connections.

Theoretical Framework: Shank's Cognitive Processes

Schank (2011) contends that teaching should move from subject-based to cognitive-based yet, when it comes to adolescent learners, he acknowledges that these students do not always want to learn what teachers plan to teach. According to Schank, there are twelve thinking processes that underline all learning and he categorizes these into three groups:

- *Conceptual Processes*: thought processes that help understand abstract concepts. This includes prediction, modeling, experimentation, and evaluation;
- *Analytic Processes*: thought processes that help in reasoning. Analytical processes include diagnosis, planning, causation, and judgment.
- *Social Processes*: thought process of group formation, which includes influence, teamwork, negotiation, and describing.

Schank (2011) posits that teaching should help students think about their experiences and how to handle cognitive processes better. He explains that one’s survival in life depends not on facts but on how well one is able to handle these facts with cognitive processes.

Willingham (2009) supports this idea and stresses that humans are inherently curious, but not thinkers, unless the cognitive conditions are right. Given this, he stresses five conditions necessary for students to learn:

1) their ability to learn what teachers teach;

2) the feasibility of what teachers teach;

3) how the methodology of teaching fits with what students want to learn;

4) time constrains; and

5), how teaching aligns with students' real-time goals.

Further, Willingham suggests that human beings are goal oriented, but he notes that what is being taught in schools is too often not related to students' inherent goals. Facts devoid of students' interests will not likely be absorbed or effectively transferred into their memory.

Willingham's views are progressive and align with ideas posed by Schank (2011) in his book *Teaching Minds*. In the book, Schank poses that cognitive processes such as reasoning, prediction, and describing should be taught. Schank explains that learning requires creation of new knowledge that comes from an amalgamation of cognitive processes and information. From his perspective, students are more likely to become engaged in learning when these processes are encouraged because they align with their own life goals. As he noted, "...[Cognitive process] has to be the curriculum, not be ancillary to the curriculum" (Schank, 2011, p. 113). He further emphasizes that cognitive processes are unconscious mental activities, which is why learners should be coached to practice how to perform them. Practice helps the learner chunk together pieces of information in their long-term memory and this enables her/him to combine information into cohesive wholes. A study conducted on master chess by players Ross (2006), shows that practice helps these players retrieve a vision of the board and remember more pieces.

In a similar vein, Aufschnaiter (2003) believes in holistic learning but focuses on the environment, which to him provides tasks of increasing complexity. Scaffolding is a critical supportive piece in these learning situations. In terms of Vygotsky's theory, while planning, a teacher should ensure that activities fall within a student's Zone of Proximal Development (ZPD). Learning occurs more efficiently when educators design instruction that is comfortable but stretches the cognitive processes students already possess. Chi, Roscoe, Slotta, Roy, and Chase (2012) confirm that building on students' emergent schema (thinking skills) increases their learning of non-linear scientific concepts. Willingham (2009) also stresses the importance of practice to enable further learning, improve transfer and increase memory. Thus, explicit teaching of science concepts in a social environment could help students learn. However, Schank (2011) fails to explain how teachers should scaffold the teaching of thinking processes.

Thinking Maps as Scaffolds

Ausubel (2000) notes that advanced graphic organizers can be learning aids to help students integrate new information with their existing knowledge. Therefore, Thinking Maps may provide a scaffold to teach cognitive processes and they could act as a visual tool teachers could use to understand the thinking of their students (http://thinkingmaps.com/). Thinking Maps enable students to communicate what they know and at the same time may act as scaffolding tool to promote clarity and organization.

Judy Willis (2006), a neurologist and educator, emphasizes that graphic organizers, like Thinking Maps, help students make associations, discover patterns, sort information, and store new information as relational memories in long-term memory. The more interrelationships students form within the subject matter, the more organized their thoughts become and the more easily they can remember and apply it later (Anderson, 1993; Bedard & Chi, 1992; White & Rumsey, 1994). These tools coincide with the brain's seeking of patterns.

Science teaching and learning researchers Tytler and Prain (2013) accentuate representations of any kind support students' thinking processes, where it can function as both process marker and product of understanding. Thinking Maps, or graphic organizers, are intrinsically engaging, as students are constantly interacting, interpreting, and making connections between their personal knowledge and the maps (Willis, 2006). Thinking Maps allows students to reflect on the information and use it for critical thinking and problem solving (Hyerle, 1996; Willis, 2006). They also act as tools for teaching, learning, and assessment. There are eight different Thinking Maps that, in this study, will be connected to specific cognitive processes (e.g. Flow Map, Multi Flow Map, and Bubble Map).

Conclusion

The literature has demonstrated the importance of cognitive processes in science teaching, but it also indicates that very little work has been conducted in this area (Marzano & Aredondo, 1996). Research from neuroscience confirms the connection between the adolescent brain and cognition, but there remains a need for more integration of these two realms of study. I expect to explore conceptual shifts in learning from instruction that entails the explicit teaching of cognitive processes using different types of Thinking Maps.

CHAPTER 3 - METHODS

In the previous chapter, I detailed the performance of students in the United States on the PISA test and noted their continual decline. Through a review of the literature, I have made the case that conceptual understanding coupled with cognitive processes can result in higher student achievement and student engagement. In this chapter, I explain my innovation based on this idea and the methodology I used to gather evidence to answer my research questions.

Action Research

Stenhouse's (1981) idea aligns with my philosophy of action research that teachers are the change agent in the world of the school. That is, teachers are not only agents for dispensing knowledge but are agents capable of designing instruction that can meet the demands of the future workforce. Many writers (e.g. Bransford, Brown, & Cocking, 1999; Lieberman & Miller, 2005; Ziechner & Noffke, 2001) believe teachers are educational leaders. These ideas resonate with me, as I want to be a teacher who effectively teaches science to her urban high school students. I want my students to be become fully engaged in my lessons and become better scientific thinkers and problem solvers.

To accomplish this vision, I have adopted the role of an insider action researcher (Herr & Anderson, 2005). Insiders conduct action research to close the theory to practice divide and make things better (Hinchey, 2008; Stringer, 2007). In education, action research is treated as a fundamental component for instruction, assessment, and reflection (Hendricks, 2006; McNiff & Whitehead, 2006; Mills, 2006; Noffke & Stevenson, 1995; Sagor, 2004; Stringer, 2004). My role in this study was of teacher and researcher. I was responsible for unrolling the innovation in three cycles and collecting data from each cycle.

Setting

This study took place in the STAR school district (a pseudonym as are all others). The district was established in 1895, and is one of the oldest and largest districts in the country. The district has 11 comprehensive schools, 2 specialty schools, and 3 alternative schools. These schools, together, offer 500 different academic courses to about 26,000 students. STARS serves 94% minority students of which 75% are Latino along with many refugee students.

Millennium School is located in STARS and has a focus on Career and Technical Education (CTE). In 2013-2014, the school had a total enrollment of 315 students, which was not up to its capacity of 400 students. Due to its limited seat availability students are selected to come to Millennium through an application and interview process. Eighty-six percent of students at the school are on free and reduced lunch and many students are of minority descent. Hispanic students make up 86% of the student body while the remainder is comprised of 9.5% Anglo students, 3% African Americans, and 1.5% Native Americans. For the last three years, the school has been a performing-plus school and a recipient of an “A” grade from the state of Arizona. Millennium School, being a specialty school, with stringent requirements of passing all required courses, leads to a 100% graduation rate. To graduate, students must take three years of science courses that are tailored to fit with the school’s CTE program and a forensic and environmental course that has been recently added to complement CTE courses. The science pathways in the school provides two different options (See Figure 2).

Pathway A:

Physical Science → Biology → Environmental Sciences → Forensic Sciences Honors

Pathway B:

Biology Honors → Environmental Sciences → Anatomy Physiology → Forensic Science Honors

Figure 2. Science pathways available.

Participants

The class in which this study took place is one of the five science classes I teach. Participants were the students in my last hour (8th hour) of Environmental Science class. I chose this class as a convenience sample. Convenience sampling is a type of purposive sampling used mostly by qualitative researchers. Convenience sampling involves the selection of valued participants, those closest to the issue (Gelo, Braakmann, & Benetka, 2008). In my case convenience sampling was a pragmatic move.

There were 28 students in the chosen class, a good mix of juniors and seniors. The class had 14% Caucasian and rest Hispanic students. There was a mix of 13 female and 15 male students with ages ranging from 16 to 17 years old. None of these students qualified for English language services, but 8% received special education services. On Arizona's Instrument to Measure Standards (AIMS), 0% of the students were labeled as “Falls Far Behind” in reading or writing, but in mathematics, 15% of the students were in this category, while in science 35% of the students were in this category. On the district Criterion Reference Test (CRT) of Environmental Sciences, these students scored an average of 38% but following instruction, their average typically increased to 70% on the post-test. Though the science AIMS test, at this point, was not a requirement to graduate from high school, it still brought my attention to the fact that science teaching has to be geared toward scientific thinking skills.

Innovation and Timeline

At the time of my innovation, Arizona was seriously considering adopting the New Generation Science Standards (NGSS) and, because of these new standards, all science courses had to be revised to align with them. District teachers are required to make data driven decisions and statewide pressures from Race to the Top are demanding teachers be accountable for showing improvement in on a pre/post-content Criterion Reference Test (CRT).

For my students to do well on upcoming state tests, they must understand concepts of science and develop scientific thinking skills. Thus, my innovation is based on Schank's (2011) idea of cognitive processes (scientific thinking). However, I have expanded upon his ideas through an effort to mix content and Thinking Maps with cognitive processes. This idea is captured in Figure 3.

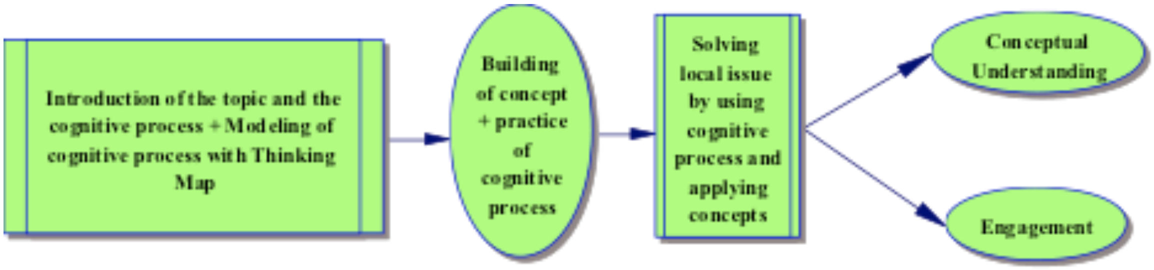


Figure 3. Innovation flowchart.

My 15-week innovation was conducted from August 2013 to December 2013 and was divided into three cycles. In the first cycle, I taught the concept of population and the cognitive process of prediction. The second cycle of instruction focused on the biomes and biodiversity and the cognitive process of causation, while the final cycle focused on policy and the cognitive processes of modeling. The concepts chosen for the cycles align with the district curriculum and the NGSS core ideas. Each cycle was comprised of the following components:

- Introduction of the concept and the cognitive process (Week 1).
- Increasing knowledge of the concepts with the cognitive process and placing both of these within an issue related to students' lives (Weeks 2 and 3).
- Application of the cognitive process and concepts learned to solve a new, but similar, issue (Weeks 4 and 5).

Each cycle was carried out in the following manner with minor modifications as needed.

Introducing the Concept and the Cognitive Process Through an Issue

An NBC news clip was used to introduce students to the environmental concept through a real-life issue. The video was used to pique students' interest and help them understand that scientists use cognitive processes to understand and solve complex environmental issues. After students watched the news clip, they were asked to think like a scientist. This type of thinking was aimed to help the students understand the complexity of a cognitive processes and what scientists must know (the concept). For example, to help students understand the concept of population and the cognitive process of prediction, I used the Thinking Map in Figure 4 and modeled how I as a scientist thought about both.

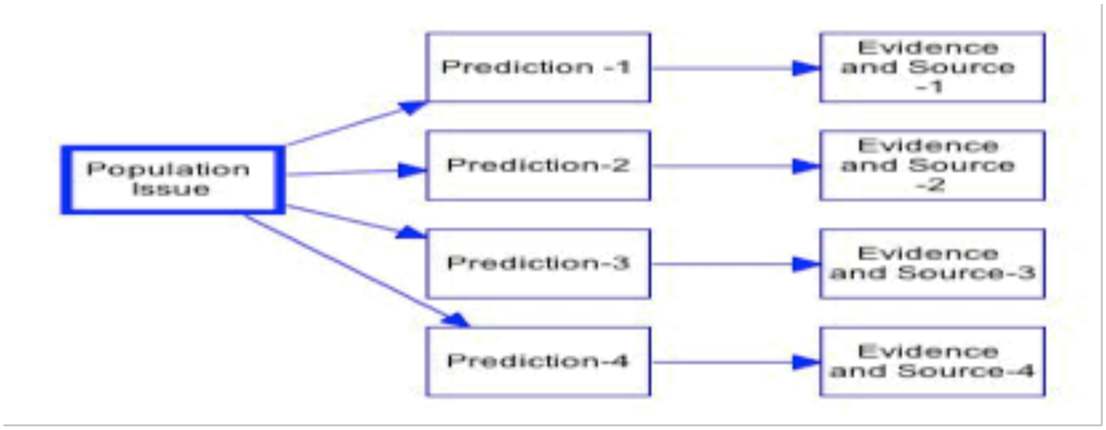


Figure 4. An example of prediction Thinking Map.

As a means to introduce students to the cognitive process, they worked through a series of steps designed to promote understanding of the process being taught. For example, the steps to make a reasoned prediction step included:

a. When students made a prediction about the issue in the news clip, they were asked to explain what they knew about the issue (use their prior experience and information as evidence);

b. Students were then asked to explain how their prior experience was and was not helpful to make a prediction;

c. Finally, students were asked to revisit the Thinking Map they created and add more predictions with evidence.

Students were divided into groups of three and then each student was given time to practice these steps using Thinking Maps. The purpose for this practice was to help students capture their thoughts about the issue, understand what they knew, and help them understand the complexity of the cognitive process. As Schank (2011) stresses, during practice situations teachers should help students to learn from their errors. Practice prepared students not only to become conscious of the cognitive process, but also helped them understand when they had made errors. Each student worked in a group but created his\her own Thinking Map in their Environmental Science Notebook.

Building the Conceptual Understanding with the Cognitive Process

Once students understood what a cognitive process was and how a Thinking Map captured their thoughts, I began to build their conceptual knowledge in my normal fashion. Various instructional strategies were used for content delivery, but I embedded the cognitive process into the content. For example, when I used a PowerPoint slide to share information about population, students made predictions on their Thinking Maps. Thus, students were given multiple opportunities in instruction to associate content and the cognitive process. The cycle of prompt-based reflection writing continued; students wrote their reflections in their Environmental Science Notebooks.

Applying Content and Using the Cognitive Process

Schank (2011) posits that if the twelve cognitive processes are thoroughly ingrained in students' mental systems, they will be able to effectively apply them to their lives as well as the subject/content. He also points out that many of the cognitive processes require domain knowledge. Willingham (2007), a neuroscientist also emphasizes the importance of content knowledge and practice, states, "Knowing that one should think critically is not the same as being able to do so. That requires domain knowledge and practice" (p.13). The previous steps equipped students with an understanding of the scientific issue through concept building with learned cognitive process; therefore they were ready to apply, explore, and extrapolate this information to a local environmental issue.

Based on Schank's ideas, students were given a local environmental issue on which to work. To bring students' attention to the issue on the first day, I facilitated discussions with questions, such as how scientists who face environmental issues like this would think. Based on their understanding of the concept and the cognitive process, students were asked to create a new Thinking Map in their notebook that applied the process and supplied evidence and the source of these. Students then made a product such as a PowerPoint or Prezi presentation on the understanding of the issue, the concept and the process with evidence and the source of evidence. After this stage, a post-test was administered to check students' conceptual understanding.

Mixed Methods

Mixed methods research design is practical and outcome-oriented (Johnson & Onwuegbuzie, 2004). In this study, I used an integrated mixed method designed to investigate the increase in students' conceptual understanding, their use of the cognitive process, and their engagement in my class. In mixed methods, integration of qualitative and quantitative methods is critical (Creswell & Plano Clark, 2011; Greene, Caracelli, & Graham, 1989; Morse & Niehaus, 2009; Teddlie & Tashakkori, 2009). The four possible points of integration occur at the level of design, data collection, data analysis, or interpretation (Creswell & Plano Clark, 2011; Greene et al., 1989; Morse & Niehaus, 2009). I integrated qualitative and quantitative data during the data analysis and interpretation phase. The strand, sequence, and mixing of methods in my study is provided below.

Study strand: My study was comprised of a qualitative and quantitative strand. The qualitative strand helped me understand the shift in conceptual understanding on the part of students, their engagement in science, and the complexity and clarity of their cognitive processes. Quantitative data focused on student achievement as a measure of conceptual change.

Sequence and Timing: The quantitative and qualitative data were collected independently but concurrently. The results from both qualitative and quantitative data served as triangulation in this study.

Integration and Mixing: The qualitative and quantitative data were integrated during the data analysis and interpretation phases. The pre- and post-test scores, student document, and discourse content analysis were compared for triangulation and validation.

Data Collection Tools

To answer following research questions, I used Thinking Maps, Engagement Observation Instrument (teacher part and student part) student discourse, and pre- and post-tests.

1. How, and to what extent, will teaching cognitive processes prior to teaching content help my students' conceptual understanding of science content and ability to think scientifically? If I use this innovation, will students' achievement improve?
2. How will using Thinking Maps engage my students and encourage them to become scientific thinkers?
3. If my students learn science concepts through cognitive processes and maps, will they be more engaged during class?

Figure 5 contains my research questions and data collection tools.

Research Questions	Pre and Post Test	Engagement Observation Instrument Teacher Part Student Part Student Part-2	Thinking Maps	Student Discourse while Working on an Issue	Exit Questionnaire	Researcher Field Notes
1. How, and to what extent, will teaching cognitive processes prior to teaching content help my students' conceptual understanding of science content and ability to think scientifically? If I use this innovation, will students' achievement improve	X		X	X	X	X
2. How will using Thinking Maps engage my students and encourage them to become scientific thinkers?		X	X	X	X	X
3. If my students learn science concepts through cognitive processes and maps, will they be more engaged during class?		X			X	X

Figure 5. Research questions and data collection tools.

Measure 1: Pre and Post-test

Purpose of the measure. In this study, there were two tests administered. A teacher-made pre- and post-test and the district Criterion Reference Test (CRT). The teacher pretest served as a formative assessment of my students' conceptual understanding of the science concepts and the cognitive processes; the post-test served the purpose of a summative assessment of students' learning. The CRT was a cumulative measure and developed by our school district. The CRT test covered all concepts learned through the first semester in any of the Environmental Science classes in our district.

What it contained. The pre- and post-test was a paper and pencil measure with five multiple-choice questions aimed to measure the specific thinking processes and science concepts covered in each cycle. For the cycle 1 and cycle 2 tests, students were asked to provide a one-line explanation for their answer. Explanations helped the researcher to gauge if the students understood the concept behind the chosen option.

How it was administered. I administered both pre- and post-tests during the first 20 minutes of class. Students were not allowed to talk with each other during the testing and could not use any resources. At the end of 20 minutes, I collected all tests prior to the start of typical class activities.

How it was be scored. The researcher graded all questions manually. Correct answers were recorded as one point out of a total of five points possible.

Measure 2: Engagement Observation Instrument

Purpose of the measure. As an action researcher, I wanted to understand part two of my research question: If I teach science concepts through cognitive processes and Thinking Maps, will my students be more engaged during class?

What it contained. The Student Engagement Instrument (see Appendix B) is a modified version of the International Center for Leadership in Education's tool and is supported with research. This instrument had two parts: an observation part completed by the teacher and a student part. The teacher part contained five items on a 5-point Likert-type scale ranging from 5 = *very high* to 1 = *very low*. Ratings were based on the observation of students' body language, consistent focus, verbal participation, confidence, and excitement toward learning.

The student part was designed to measure their perceptions of the clarity of their learning, meaningfulness of work, and rigorous thinking. The student part contained a checklist with five items on a 5-point Likert-type scale that ranged from 5 = *very high* to 1 = *very low*. The second part asked students to explain the ratings of their items.

How it was used. I conducted each observation for 5 minutes while students were working on an environmental issue using the cognitive process and learned concept. The first observation was after 10 minutes and the second after 20 minutes during a class period of 50 minutes. Observations were video-recorded to ensure trustworthiness of the observations.

With whom it was used. I did the ratings on the Engagement Observation Instrument on two groups comprised of three students each. Based on standardized testing, each group had one high, one low, and one medium-performing student. One group had two females students and one male student. The other two groups had two male students and one female student. As a trial for cycle 1, I asked students in the groups to sit in the front row. However, I found that the classroom background noise hindered the videotaping of the conversations so for cycles 2 and 3 students were sent to an adjacent room. This allowed clearer recoding.

Measure 3: Thinking Maps

Purpose of the measure. The purpose of this data collection tool was to capture students' ability to capture what students knew about the concept and their ability to apply the cognitive process in a Thinking Map. It also answered my research question: How will using Thinking Maps engage my students and encourage them to become scientific thinkers?

How they were used. Students made several Thinking Maps. The first one came from the video clip. They made another when they applied their content knowledge and used the cognitive processes to solve a local environmental issue.

With whom they were used. The researcher assigned students to create the Maps in their notebook. Each Map was collected and analyzed for the number of concepts and cognitive processes it contained. The researcher analyzed the notebooks of the same six students who were videotaped and observed for engagement purpose.

Measure 4: Student Discourse While Working on an Issue

Purpose of the measure. The purpose of this data source was to answer my overarching question: How, and to what extent, will teaching cognitive processes prior to content help students learn science content and ability to think scientifically?

Discourse was gathered (via videotaping) at the end of each cycle as students worked on a local environmental issue (see Appendix A). For this activity, students applied their content knowledge and used the cognitive processes they learned during that cycle. To gather data, two groups were videotaped as they worked and created a Thinking Map.

How it was used. The audio of the videotapes were transcribed and examined for students' learning of concepts and use of processes.

With whom it was used. Discourse was gathered from the same groups of students whom I observed using the Engagement Observation Instrument.

Measure 5: Exit Questionnaires

Purpose of the measure. The intent of the Exit Questionnaire was to gather information about Thinking Maps. I wanted to understand to what extent teaching cognitive process with Thinking Maps helped my students be scientific thinkers. There were three questions asked to the same six students who were observed and videotaped.

How it was used. The Exit Questionnaire was sent to students through email and then they replied through email. The email was sent at the conclusion of the three innovation cycles.

With whom it was used. The Exit Questionnaire was given to the same six students whose discourse were videotaped

Measure 6: Researcher Field Notes

Purpose of the measure. Starting in August 2014, I maintained a journal with field notes. The reason for writing field notes was that I wanted capture to the effectiveness of the innovation on both my students and myself.

How it was used. I wrote down instances and events that happened out of the norm. Being that the innovation occurred in the last class of the school day, it was convenient for me to write my perspective on the events.

Data Analysis Plan

The concurrent analysis of qualitative and quantitative data revealed the effectiveness of my innovation. As noted by Green et al. (1989), one of the major rationales for conducting mixed methods research is for the purpose of triangulation (Creswell & Plano Clark, 2007; Johnson & Onwuegbuzie, 2004). Both quantitative and qualitative measures were integrated in the data analysis phase to answer the research questions.

Measure 1: Pre- and Post-test Analysis

The test was hand-graded with points assigned. These scores were put into an Excel spreadsheet to graph and calculate the mean and standard deviation. Then repeated measures analyses of variance (ANOVA) were used to determine significant differences between the pre- and post-test scores.

Measure 2: Engagement Observation Instrument

This instrument was first examined both quantitatively and qualitatively. The quantitative part (Teacher Part-I) was first organized, then studied. Afterwards data were placed into an Excel spreadsheet. Student engagement was rated on a 5-point Likert-type scale ranging from 5 = *very high* to 1 = *very low*. The trend of student engagement with respect to students' body language, consistent focus, verbal participation, confidence, and excitement toward the learning was analyzed cycle-wise. The qualitative part of the student engagement (Student Part-II) was analyzed by inductive coding process.

Measure 3: Thinking Maps

For each cycle, one type of Thinking Map was used. Map accuracy was determined by the cognitive process and concept. Students' understanding of the concept was reflected by the content written in each of the boxes of the Thinking Map (see Figure 6). Thus each box was a representation of an idea related to the concept embedded with the cognitive process.

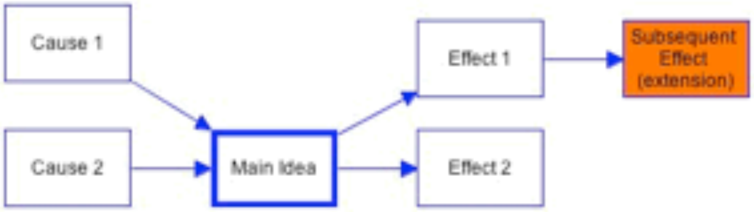


Figure 6. Causation map. This figure illustrates the extension of an idea.

To analyze the Thinking Maps, I tabulated the number of concept boxes created. It was determined that each meaningful concept showed students' conceptual understanding of the science content. Additionally, the number of content boxes placed on the map was taken as an indicator of a student's ability to think deeper and in a connected manner.

Measure 4: Student Discourse Content Analysis

Video recordings were transcribed and read to gain an overall understanding of the data. Open coding was applied in an effort to detect various concepts (categories) embedded in student discourse, followed by axial-coding to find subcategories (Glaser & Strauss, 1967; Patten, 2012).

Measure 5: Researcher Field Notes

Typed field notes were used for triangulation purposes. In an effort to address researcher bias, a journal was used to record reactions and thinking throughout the course of the intervention. This journal provided an opportunity for critical reflection regarding each of the events in the intervention, the method, and the analytical process that occurred, as well as points of clarification throughout the project (Glaser & Strauss, 1967).

Validity and Reliability

Validity refers to the appropriateness, meaningfulness, and usefulness of the inferences made by the researcher (Fraenkel & Wallen, 2005, p. 152). Thus, to ensure validity, I created an audit trail and provide rich description.

The pre-test and post-test questions were selected from the Pearson test bank and because of this, had construct validity. Cycle 1 test questions were selected from the population unit. Similarly, cycle 2 test questions and cycle 3 test questions were from biodiversity and the policy process test bank.

The observation instrument was a modified version of the student engagement tool developed by the International Center for Leadership in Education. This tool has been used and validated by a research team. Multiple users also tested this instrument across the country, though no data were collected

Student notebooks and my own journal provided an audit trail from the beginning to end of the three cycles. Figure 7 shows the strategies utilized by researcher for assessing credibility and dependability of the various qualitative data.

Term	Strategy Utilized
Credibility	Use of peer debriefing Member checks Triangulation
Dependability	Alignment between research questions, data, and analysis Triangulation (Student discourse, exit Questionnaire, pre- and post-test and field notes) Peer examination

Figure 7. Qualitative data rigor.

Throughout the research, a peer who had experience in education research acted as my peer de-briefer. She reviewed my findings and asked questions about my process. Likewise, the students in the study were provided an opportunity to member-check my findings. To do this, I shared the summary of findings and asked students to share their point of view as to their accuracy. Five out of six students affirmed the findings except one. Therefore member checking added credibility to my qualitative findings.

As a researcher, I continuously checked the alignment between various data with the research questions to understand if the questions were being answered. I answered my research questions with the data sources. In other words, assertions were grounded in my data and generated from various sources. The validity of my findings was further enhanced by triangulation, such as the pre- and post-test quantitative data compared with the qualitative student discourse and the exit questionnaire compared to my field notes. Additionally, videotaping added trustworthiness to my engagement data because I could go back and double-check my ratings.

CHAPTER 4 - DATA ANALYSIS AND RESULTS

This study was conducted with students in an Environmental Science class (*N*= 28), and multiple data collection tools were used. These methods included a pre- and post-test, transcripts from student discourse gathered as students worked on projects, an observation instrument designed to measure student engagement from both the teacher's and students' perspectives, and samples of Thinking Maps constructed as students learned and practiced each cognitive processes after it was taught. In this chapter, I present the quantitative and qualitative data analysis process and results from these tools that were designed to answer the following research questions:

1. How, and to what extent, will teaching cognitive processes, prior to teaching content, help my students' conceptual understanding of science content and ability to think scientifically? If I use this innovation will students' achievement improve?
2. How will using Thinking Maps engage my students and encourage them to become scientific thinkers?
3. If my students learn science concepts through cognitive processes and maps, will they be more engaged during class?

Quantitative Data Analysis and Results

Quantitative data included numeric data from pre- and post-test from the three cycles and the Criterion Reference Test (CRT). The second quantitative data source was the Engagement Observation tool. An Excel spreadsheet was used to organize and analyze the above-mentioned quantitative data.

Pre- and Post-tests and CRT

Tests were used to understand if students' conceptual understanding of science content and the ability to think scientifically changed because of teaching cognitive processes prior to learning the content. Each of the pre- and post-tests were based on eleventh grade Environmental Science content. Students were afforded as much time as they needed to complete each test, and most students completed them in 15-20 minutes.

In addition to the short pre- and post-tests, the district's Criterion Reference Test (CRT) was used to gather data on all concepts covered during the cycles. The CRT is not a timed test, usually a class period of fifty minutes is given to students, and most of the students finish the test within the allotted time.

Participants' raw scores for each test were entered into a spreadsheet. The spreadsheet was used to first calculate the mean and standard deviation. Then, repeated measures analyses of variance (ANOVA) were used to determine significant differences between the pre and post test scores. Finally, a test of reliability was performed on the test items of each test prepared by the researcher for the three cycles.

Cycle 1 of the innovation focused on the cognitive process of prediction and the concepts of the population. The pre-test and post-test focused on these and was administered in September 2013. Each test was comprised of 5 multiple-choice items and students could take as long as they needed to finish the test but students finished this test within 15-20 minutes. On the first test, means rose slightly from 1.77 (*SD* 0.70) to 1.82 (*SD* 0.67). Twenty-six percent of the students did better on the post-test. An ANOVA showed no significant difference F (1,53) = 0.56, $p = 0.814$.

The second set of tests were given in November of 2013 and designed to measure students' understanding of biomes and biodiversity and the cognitive process of causation and cause and effect taught in Cycle 2. On this test the means rose from 2.29 (*SD* 1.05) to 3.33 (*SD* 0.75). During this cycle, 77% of the students did better on the post-test. Thus, 51% of the students showed improvement in achievement during cycle 2 as compared to cycle 1. In this cycle, ANOVA showed there was a significant improvement of F (1,53) = 13.39, $p = 0.01$.

Cycle 3 focused on teaching the cognitive process of modeling and the concept of environmental policy. The third set of tests focused on these and was administered in December 2013. On this test ANOVA showed that the mean rose significantly (< 0.01) from 0.88 (*SD* 0.75) on the pretest to 4.17 (*SD* 1.24) on the post-test. In the last cycle, 96% of students did better on the post-test. Scores from Cycle 3 showed high significance of F (1,49) = 133.78, $p = 0.01$. The change in pre- and post-test mean is depicted in Figure 8.

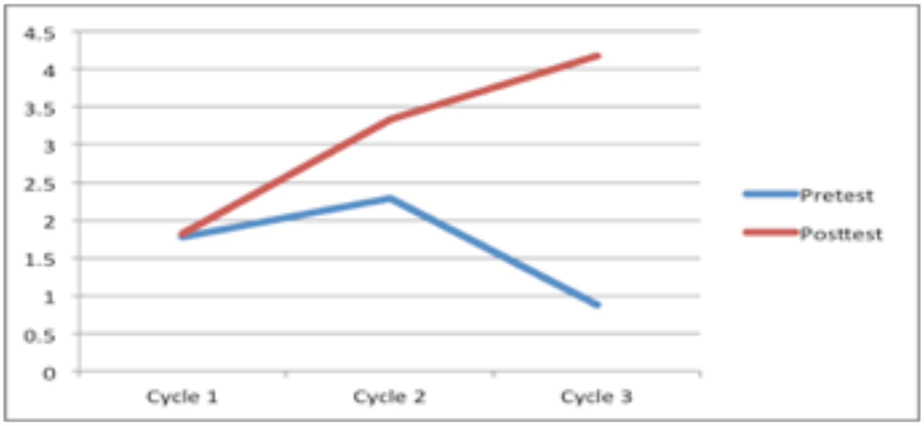


Figure 8. Pre- and post-test mean of each cycle.

As indicated, the district's Criterion Reference Test (CRT) was used as an additional measure to gather data on all concepts covered during the cycles. The CRT was developed by a group of teachers who worked on the environmental curriculum. It had 38 multiple-choice items focused on the curriculum covered during the fall semester, which aligned with each cycle of the innovation. The pre CRT test was administered at the beginning of the semester in August 2013 before the start of the innovation. The post-test was administered at the end of the semester on the last day of school in December 2013. Again, students' scores showed a significant increase ($p < 0.01$). Mean scores, converted into percents, rose from 45.54% (17.52) to 80.32% (11.18). Though it was expected that all students would perform better on the post CRT, higher mean scores with significantly less standard deviation were seen. The significance was $F = (1,54) = 78.49$, $p = 0.01$.

Engagement Observation Instrument – Teacher Part

The second quantitative measure used was an engagement observation instrument which comprised of 2 parts: Teacher Part-I, was an observation checklist based on the teachers' observation of students' body language, consistent focus, verbal participation, confidence, and excitement toward the learning they were doing; and the Student Part-II aimed at understanding students' perceptions of what they were learning and why. This section reports the teacher's rating captured as students worked in teams of three on a project related to the concept and cognitive process being taught in the cycle. The aim of this instrument was to answer the research question: If my students learn science concepts through cognitive processes and maps, will they be more engaged during class?

In sum, two teams were observed (*n* = 6), and each observation lasted approximately 5 minutes. Student engagement was rated on a 5-point Likert-type scale ranging from 5 = *very high* to 1 = *very low*. Teams consisted of students with varying levels of ability based on the mathematics portions of the Instrument to Measure Standards (AIMS) test. Each team was comprised of a high, medium, and low ability student. It was assumed these mixed groups would contain a representative sample of the class, and both teams were observed after 10 minutes and then again after 20 minutes during a class period of fifty minutes. To understand each group's engagement while they worked on an issues-based project each cycle's Likert item rankings (1= very low, 2= low, 3= medium, 4= high, and 5= very high) were placed in a table and means for each construct were calculated and compared group-wise.

Positive body language. This scale was designed to measure body postures that indicate students were listening and paying attention to others in their group. Observations looked for included eye contact, head position, leaning forward or backward, and positions of arms.

During cycle 1, after 10 minutes, Group A received a rating of 5 (*very high*) and this level continued after 20 minutes. During cycle 2, after 10 minutes, the body language of this group was observed to be a *medium* (3), but after 20 minutes they were rated as *very high* (5). In cycle 3, both ratings were a 4, indicating somewhat high level of body language. Overall, the ratings for Group A consistently went up as they spent more time working and, in all, they listened and paid attention to each other.

Group B showed lower positive body language in all three cycles. During cycle 1, after 10 minutes the body language Group B was observed to display a medium (3) level, and after 20 minutes they were rated as low (2). In cycle 3 after 10 minutes, this group was rated low (2) and then, after 20 minutes, they were rated a little higher medium (3). During cycle 3 the trend of cycle 1 was repeated and they received a rating of medium (3) after 10 minutes and then low (2) after 20 minutes. Group B group displayed lower (64%) positive body language.

Group A members always maintained eye contact with each other as they discussed their project. Their heads were huddled together in front of the computer screen. They sat together in a small tight group, leaning inwards in a semicircle fashion. Overall, both sample teams showed medium to high body language showing positive engagement.

Consistent focus. The purpose of this scale was to measure if students were focused on the learning activity without disruption. The observation looked for students' consistent attention to work without showing lack of interest, frustration, focus on outside distractions, and lack of knowledge as to how to proceed.

Group A, during cycle 1, after 10 minutes, received the rating of *very high* (5), and after 20 minutes continued to show a *very high* (5) focus on the given task. In cycle 2, after 10 minutes, this team was rated *medium* (3) but then changed to *very high* (5) after 20 minutes. During the last cycle, they showed *high* (4) focus after 10 minutes and *medium* (3) focus after 20 minutes. Most of the time Team A showed high focus on their work. They were not influenced by the outside distractions and showed little frustration as they worked together.

During cycle 1 Team B, received a rating of *medium* (3) after 10 working minutes as well as after 20 minutes. In cycle 2, this team, after 10 minutes, was rated *medium* (3), but after 20 minutes, as *high* (4). During cycle 3, after 10 and 20 minutes they were rated *medium* (3). Group B's rating stayed consistently at the *medium* level (60%) as their interest toward work waivered. Overall group A showed more consistent, high focus (86%), on their task as they engaged in their project without much distraction.

Verbal participation. The intent of this scale was to measure students' expression of thoughts, ideas, answers, opinions, and problem solving interactions. During cycle 1, group A's verbal participation was *high* (4) after 10 minutes and 20 minutes of observation. In cycle 2, after 10 minutes, their verbal participation was rated *low* (2) and after 20 minutes they were rated *high* (4). During cycle 3, after 10 minutes, they were rated *very high* (5), and after 20 minutes they were observed to be *high* (4). Team A's verbal participation remained high as this team expressed many ideas and thoughts with each other.

In cycle, 1 Group B received a rating of *medium* (3) after 10 minutes, and their verbal participation was noted *high* (4) after 20 minutes. During cycle 2, after 10 minutes, they were rated *low (*2), and after 20 minutes they received a rating of *medium* (3). Overall group B's verbal participation was slightly less (10%) than group A. Both groups showed a steady rise in their verbal participation. Students' verbal interaction increased, as they got more involved in the project with time.

Student confidence. This scale was designed to measure students' ability to initiate and complete a given project with limited assistance from the teacher. Observations focused on students' active participation in the team toward completion of the project.

During cycle 1 and 3, after 10 minutes, Group A was observed to exhibit *high* (4) levels of confidence and this pattern continued after 20 minutes. In cycle 2, after 10 minutes, this group was rated *medium* (3), and after 20 minutes they received the rating of *high* (4).

On the other hand, group B scored 3 (*medium*) after 10 minutes in cycle 1 and again after 20 minutes. During cycle 2, after 10 minutes they scored *low* (2), but after 20 minutes they were rated *medium* (3). Group B showed *medium* (3) confidence while they worked on all three of the assigned projects. They periodically shared concern with the teacher as to how the task was challenging, and indicated that they were unable to find much information. The students in Group A consistently showed higher confidence (16%) than those in group B, as they engaged with the project with minimum assistance from the teacher. Overall, both sample teams showed confidence in the learning process.

Fun and excitement. This scale was used to measure the affective domain of engagement shown as student interest and enthusiasm toward work. Observations focused on students' positive humor, smiling, laughing, and eagerness to start working.

During cycle 1, group A received a rating of *medium* (3) after 10 and 20 minutes of work. In cycle 2, this team was rated *low* (2) after 10 minutes, and *medium* (3) after 20 minutes of effort. During cycle 3, after 10 minutes, the rating was *very high* (5) and after 20 minutes it was observed to be *high* (4). The rating of this group showed an increase by cycle 3 as their interest increased and they showed more humor and eagerness.

During cycle 1, after 10 minutes, Group B was rated *medium* (3), but after 20 minutes they were rated *low* (2). During cycle 2, after 10 and 20 minutes, they were rated *low* (2). In cycle 3 after 10 minutes, this team received a higher rating of *medium* (3), but after 20 minutes they were again rated as *low* (2). Group A showed an increase in enthusiasm (76%) toward work as compared to Group B (46%). Both teams scored in the medium range for excitement and interest through the period of three cycles. On the average, the sample team members showed high engagement in their work through all three cycles as observed though their body language, verbal participation, confidence, focus, and excitement.

Qualitative Data Analysis and Results

Qualitative data sources included the student portion of the Engagement Observation Instrument (Students part-II), student-created Thinking Maps, an exit interview focused on the use of Thinking Maps, and three cycles of videotaped student discourse as students worked on projects. Data came from both oral and written sources as students wrote their replies on the engagement instrument and the Exit Questionnaire and their discourse, as they worked, was audio recorded and transcribed. Table 1 contains the word count for each data source.

Table 1

Qualitative Data Sources

Data Source	Word Count
Engagement Instrument (student portion)	2,031
Thinking Map Exit Questionnaire	1,564
Student Discourse Cycle 1	2,275
Student Discourse Cycle 2	3,064
Student Discourse Cycle 3	7,869

The corpus of data was analyzed using a constant comparative approach. To do this I employed grounded theory, to read all data and then proceeded to use inductive and deductive reasoning (Corbin & Strauss, 2008; Miles & Huberman, 1994). The first step was open coding of all data using HyperRESEARCH v 3.0.3. Data were read and codes were applied. Open coding lead to 57 codes. After a critical review of the codes, axial coding was used to collapse the codes into themes.

Using a method devised by Miles and Huberman (1994) the corpus of data was analyzed. Based on my hypothesis and on the study's theoretical framework, a list of a priori codes were generated. Line-by-line codes were applied during the data reading process. Subsequently, a second reading of the data was conducted and initial codes were checked and reformulated as needed into new emerging codes. I added, collapsed, or removed codes and then went on to establish themes. Through this process four themes emerged: (1) students' engagement in the activities; (2) students' use of and beliefs about Thinking Maps as learning tools; (3) students' demonstration of deeper level thinking; and (4) use of cognitive process. Thereafter, I examined themes and arrived at assertions based on these. Using a constant comparative approach I use quotes to support my assertions. Figure 9 contains themes, theme-related components, and assertions that arose from the corpus of data.

Themes	Themes related components	Assertions
Students' engagement	Students were engaged in the learning process when the concept and task were interesting. Students were interested in the learning process when the task was involving. Students were engaged in the learning when the task challenged them to think rigorously. Students were engaged in the learning when they had opportunity to be creative and the work was related to the real world.	Students were engaged in the learning process when the science concepts and tasks were interesting, involving, offered an opportunity for them to be creative, to be challenged, and were related to their real world needs.
Students' use of and beliefs about Thinking Maps as learning tools	Creating Thinking Maps helped students categorize and organize their ideas/new learning. Thinking Maps helped students to expand on their ideas. Creating Thinking Maps based on environmental issues helped students gain clarity of the cognitive process scientific thinkers use. Students found Thinking Maps easy to use.	Students found Thinking Maps to be an easy and useful tool to use to categorize, clarify, and organize their thoughts, learn the complexity of science concepts, expand their thinking, correct misconceptions and understand how scientists think.
Students' demonstration of deeper level thinking	As they worked, the students argued and questioned each other for better understanding. Students demonstrated use of learned concepts as they made meaning of new information. Students were able to apply the concepts they learned in real world scenario. Students were able to assess new information	As they worked, students' demonstrated conceptual knowledge taught through cognitive processes by arguing and questioning each other and competently applying the concepts and processes to real world scenarios they were given.
Use of cognitive process	Students were aware of the specific cognitive process taught. The cognitive processes taught helped students understand science content.	Students became aware of cognitive processes and because of this, they corrected errors, thought about science content in new ways, found the work less challenging, and understood the content being taught.

Figure 9. Themes, theme-related components, and assertions.

Students' Engagement

Assertion 1: Students were engaged in the learning process when the science concepts and tasks were interesting, involving, offered an opportunity for them to be creative, to be challenged, and were related to their real world needs.

Data show that students were engaged as they worked on each project during each cycle. Students reflected on their work and noted that their interest piqued when the task and concept were clear. On the Engagement Instrument one student wrote, “I am learning about Arizona's population and yes, it is interesting to me.” One student wrote, “We are learning about invasive species. This is very interesting to me because we get to see how plants and animals affect our ecosystem.” Other noted, “This work is interesting to me because I learned how many threats we have to our biodiversity survival.” Another student working in the same group wrote, “Yes, I find this interesting because I like coming up with ways to solve a problem.” Students found personal meaningfulness in the task that kept them interested in the learning process.

Data from the Exit questionnaire showed similar insight. One student shared, “Thinking Maps allowed me to go deeper and get more involved in the information we are learning.” When students were asked to delve deeper they got more involved. Other student shared, “This work is interesting to me because I learned how many threats we have to our biodiversity survival.” Another student of the same group wrote, “Yes, I find this interesting because I like coming up with ways to solve a problem.” Students found the tasks interesting especially when it allowed them to think about ways to solve problems. Personal meaningfulness in the task kept them interested in the learning process.

Moreover, the relevance of the topic to their own lives fueled interest in the task and demanded them to think rigorously. On the Engagement Instrument students shared that the challenging task kept them engaged in their work. One student indicated, “This work was challenging because we had to find causes directly related the invasive species and how they affect native species or the environment. I had the opportunity to be creative by making the PowerPoint.” Other student wrote, “This work is challenging because it takes a long time to find research and I had the opportunity to be creative by making a poster and coming up with different ways to solve the problem.”

On the Exit Questionnaire, one of the students explained how learning through the innovative way was more engaging. She wrote, “If we just learn straight from the book we just learn the basic and we don't challenge ourselves. Things we usually wouldn't consider or think about are brought up so we learn more and expand in knowledge.” Thus students were engaged in the learning process when they were able to relate to the work and were challenged to think deeper.

Students’ Use of and Beliefs About Thinking Maps as Learning Tools

Assertion 2: Students found Thinking Maps to be an easy and useful tool to use to categorize, clarify, and organize their thoughts, learn the complexity of science concepts, expand their thinking, correct misconceptions, and understand how scientists think. The two groups (*N* = 6) created 74 Thinking Maps. There were twenty-three predictions maps, thirty-five causation maps, and sixteen models.

Thinking Maps served as an easy scaffold to organize thoughts with clarity. One of the students reflected, “Another thing that would help with these maps is that they weren't really that difficult to understand” (Exit Questionnaire). The simplicity of

Thinking Maps helped students organize and categorize their ideas. On her Exit Questionnaire a student wrote, “Also you can categorize your ideas and go further in depth in each one.” In contrast, one student thought that Thinking Maps were just an organization tool, as he wrote, “They (to me) are merely a tool to aid in prediction or to organize notes.”

Thinking Maps also helped students expand their ideas and think deeper. One student wrote, “For example using the cause and effect maps we found that it is a lot more complicated than just one thing affecting the environment but a whole bunch of things.” Similarly, another student expressed, “Another thing is that you can create other ideas or thoughts based on the ones you have [and this] forces you to expand and ask yourself more questions.”

The benefits of Thinking Maps were also shown based on individual student differences and needs. One of the lowest achieving students who showed the highest increase on her CRT asserted, “At first I wouldn't really understand the things but after we started using the Thinking Maps, it started making more sense and helped me think more scientifically.” One of the talkative students realized the potential of Thinking Maps and shared, “We had to go deeper and get more involved in the information we were learning.” Students of all abilities and differences were able to use Thinking Maps to make sense of what they were learning and think scientifically. They realized the potential of Thinking Maps as a tool to help them think clearly and deeply about the new information they were learning.

Students' Demonstration of Deeper Level Thinking

Assertion 3: As they worked, students demonstrated conceptual knowledge by arguing and questioning each other and competently applying the concepts and processes to the real world scenarios they were given.

Students learned the cognitive process with Thinking Maps and used those skills while working on their final project. The transcription from the video recording of students on the last days of each cycle provided insight about their use of cognitive process and conceptual knowledge. The three cycles of concepts and cognitive processes were population and prediction, biodiversity and causation, and policy making and modeling.

While working on the invasive species project using causation, a student excitedly said, "So this is an invasive species because it eats a lot of other fishes." Placing this comment within the context of the class data from my field notes, I understand that the student was making sense as to why the Northern Snakehead is treated as invasive species in Arizona. She used the concepts learned in class and also the cognitive process of causation that was taught to her. The words of another student reinforce this idea as she worked with another student on the concept of invasive species.

> Girl: Ecological damage caused by the infestation negatively impacts the desert landscape.
> Boy1: Can we just put cause and effect?
> Girl: Okay yeah the cause negatively affects the native plants.
> Boy1: Damaging the ecosystem.
> Girl: Hold on she is going to ask how is it damaging the ecosystem.
> Boy1: How?
> Girl: Why is it replacing native plants? Because there is less biodiversity.

This part of the transcript shows that these students were engaged in questioning each other to make meaning of the cause, and at the same time used the cognitive processes and concepts learned in class. They applied this knowledge in a real world scenario and this idea was also captured on the Engagement Instrument. One student wrote, “This work is interesting to me because I learned how many threats we have to our biodiversity survival.” Hence students were applying the concept competently in the real world scenario.

During the first cycle in which students learned about cognitive process of prediction and Arizona's population as concept, students capably used the cognitive process with concept while working on their issue-based project. One student suggested, “We can put about the water how the price will increase. And then you can find out how much it is right now and like try to make something that is like right now and then later on it will be double or triple, that amount.”

The same group clarified their prediction about the effects of Arizona’s population increase in future. One conversation was as follows:

> Boy1: Ground water pollution.
> Boy2: Pollution.
> Girl1: Ground water pollution.
> Boy2: Now we have to talk about that for five minutes.
> Boy1: Do you want to look it up?
> Girl1: That is where the water seeps, [crosstalk] isn’t that where the water goes into the ground?
> Boy1: That’s where you are describing it.
> Girl1: Shouldn’t we put the definition of that?
> Boy1: Yeah that is why we are going to describe what ground water depletion is and in the other slide we are going to put ground water depletion’s effect, what effect it is going to have.

It is clear from the above students' discourse that they were working on a prediction cognitive process, in context of Arizona’s population growth, as content. Students were capable of accessing pertinent information to understand the concept at a deeper level and it led them to infer a future condition and make a prediction.

By the last cycle, students had acquired substantial competence in the cognitive process along with conceptual knowledge. In the following student discourse episode, students created a policymaking process for an issue related to Arizona. They were discussing one of the steps in policymaking--gaining access.

> Girl1: Can you find -- since we already have the -- okay where is it at? We have the solution, organize, and access. Okay. Start trying to figure out more things for the evidence.
> Boy2: I don’t know, giving flyers around town for awareness.
> Girl1: Make presentations.
> Boy2: Hold a rally - bulletin boards.
> Girl1: Make a petition.
> Boy1: Service, I just made them up.

Analysis of student discourse shows that they were able to competently apply the concepts and modeling as cognitive process in real world scenario. One of the group members shared his thoughts in the Engagement Instrument, “Yes, I find this interesting because I like coming up with ways to solve a problem.” The same trend was noted on the Exit Questionnaire, “...makes us think in a new way that helps me to better understand more of what we are learning.” Students demonstrated application of both conceptual knowledge and cognitive process for deeper thinking.

Use of Cognitive Process

Assertion 4: Students became aware of cognitive processes and because of this, they corrected errors, thought about the science content in new ways, found the work less *challenging, and understood the science content being taught.* During the innovation students were introduced to the cognitive process of prediction, causation, and modeling through explicit teaching and then practiced and applied each of these processes to learn the science content. The explicit teaching and use of Thinking Maps helped students become aware of the cognitive process and utilize it when needed. Out of 74 Thinking Maps created, only 2 maps made by one student flipped the cause and effect side, but she realized her mistake and fixed it on her own as depicted by the following two figures 10 and 11.

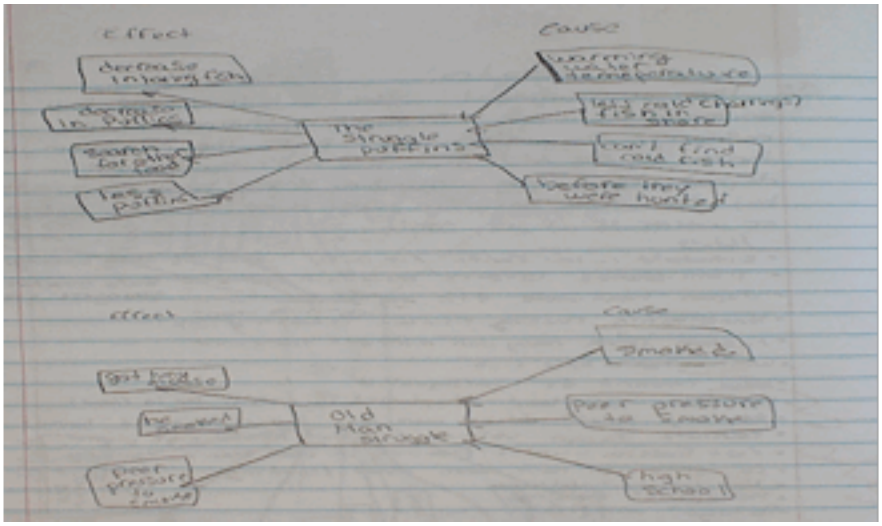


Figure 10. Causation incorrect Thinking Map. Student wrote effect and then cause in reverse fashion.

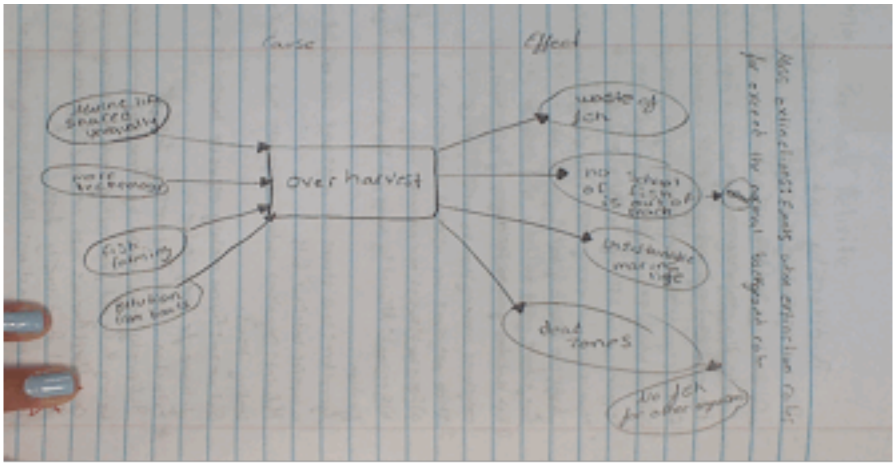


Figure 11. Causation correct Thinking Map. Student fixed the causation map by writing cause and then effect.

This correction shows this student was aware of her error and attempted to use the cognitive process in the right way to process the science content topic introduced in class. One student shared in his Exit Questionnaire, "...influenced my ability to understand science concepts taught in class because it makes us think in a new way that helps me to better understand more of what we are learning." Another student asserted,

> I begin to do more of the work that way and when we are asked questions on what we present it doesn't become as challenging as you would think it would be, I think that learning this way helps all of us in the class.

In a similar vein anther student summarized hew viewpoint as follows,

> The teaching of thinking processes and Thinking Maps does help with my ability to understand science concepts taught in class because they help me sort the information. Also they help me understand what the project is about and how I solve the problem. Plus it helps me know if I my first thought was right or if I should fix it. Another way it helps is expanding. Instead of one plain idea you can change it to a better one that you build off of your original idea.

Thus explicit teaching of cognitive processes prior to teaching science content helped students to understand the science concept taught in class in better way. The use of Thinking Maps acted as a scaffold to concretize students’ thinking and ease to bring depth and clarity while processing new information.

In Chapter 5, I will compare and contrast the quantitative and qualitative data results described in this chapter to integrate and interpret the data. From there, I will use the results to present assertions that respond to my research questions.

CHAPTER 5 - DISCUSSSION AND CONCLUSION

The purpose of this action research study was to investigate students' conceptual understandings when thinking processes were taught in an explicit fashion prior to teaching concepts. In prior chapters, I identified the need for this way of teaching in my own context, provided literature as a means to support my ideas, and explained my methodology. In this chapter I converge and triangulate the various data sources I used to answer each of my research questions. A quick glance of my findings is supplied in Figure 12.

Research Questions	Assertions
How, and to what extent, will teaching cognitive processes prior to teaching content help my students' conceptual understanding of science content and ability to think scientifically and will students' achievement improve?	As they worked, students' demonstrated conceptual knowledge taught through cognitive processes by arguing and questioning each other and competently applying the concepts and processes to real world scenarios they were given. Students became aware of cognitive processes and because of this, they corrected errors, thought the science content in new ways, found the work less challenging, and understood the science content being taught. Students found Thinking Maps to be an easy and useful tool to use to categorize, clarify, and organize their thoughts, learn the complexity of science concepts, expand their thinking, correct misconceptions and understand how scientists think.
How will using Thinking Maps engage my students and encourage them to become scientific thinkers?	Students found Thinking Maps to be an easy and useful tool to use to categorize, clarify, and organize their thoughts, learn the complexity of science concepts, expand their thinking, correct misconceptions, and understand how scientists think.
If my students learn science concepts through cognitive processes and maps, will they be more engaged during class?	Students were engaged in the learning process when the science concepts and tasks were interesting, involving, offered an opportunity for them to be creative, to be challenged, and were related to their real world needs.

Figure 12. Research questions and assertions.

Integration of Qualitative and Quantitative Data

This action research study used an integrated mixed methods design for the purpose of complementarity. Greene (2007) defines integrated mixed methods as a means to have both quantitative and qualitative data intentionally interact with one another during and after the course of a study to validate results. Integrated mixed methods allowed me to maximize the strength and minimize the weaknesses of each data type. Complementarity helped me understand the connections that existed between my quantitative and qualitative data.

Quantitative data were collected from 28 participants in one of the Environmental Science classes. The quantitative data were comprised of pre- and post-test scores and the teacher part of the Engagement Observation Instrument. Qualitative data were comprised of the student part of the Engagement Observation Instrument, Thinking Maps, an exit questionnaire, student discourse gathered as students worked in teams on an issue-based project, and my field notes. These data sources were complemented and triangulated in the following ways:

- The quantitative teacher part of the Engagement Observation Instrument and qualitative student part of the same instrument were triangulated to understand students' level of engagement.
- Thinking Maps created by students and the students' responses to the Exit Questionnaire were also triangulated to understand if students thought scientifically and engaged in the learning process.
- Quantitative data pre- and post-test scores were used to assess students' achievement. Qualitative data students' discourse transcripts and my field

notes complemented the pre- and post-test scores to better understand conceptual understanding shown by students.

Triangulation and complementarity of data indicated an increase in student engagement and achievement. The next sections provide evidence for this claim.

Research Question 1

How, and to what extent, will teaching cognitive processes prior to teaching content help my students' conceptual understanding of science content and ability to think scientifically? If I use this innovation, will students' achievement improve? A couple of decades back when I entered the teaching profession armed with a masters degree in science, I thought teaching concepts were all I needed to do as a science teacher. However, through the years I found this method did not lead to the results I wanted to achieve. Therefore, I planned to use action research to innovate and investigate if I could improve my teaching and my students' engagement and achievement. After researching several possibilities, I came upon Schank's (2011) ideas and wondered if the explicit teaching of cognitive processes would impact my students' engagement and thinking and ultimately increase their understanding of science concepts and achievement. Through my data, I now have evidence that my innovation accomplished these goals.

Students demonstrated a deeper level of thinking. *Assertion 1 - As they worked, students demonstrated that they understood the conceptual knowledge taught through cognitive processes by arguing and questioning each other and competently applying the concepts and processes to real world scenarios they were given.* Data show that when students learned concepts through cognitive processes, they started to question each other rather than be passive learners. Students' discourse showed signs of conceptual change through dissatisfaction, intelligibility, plausibility, and fruitfulness (Piaget, 1977; Posner et al., 1982). When students realized their prior knowledge could not help them with the environmental issue, they showed dissatisfaction and dug deeper into the topic. Students kept questioning each other until the new information made sense to them. When the new information made sense (intelligibility), then students were able to accommodate it with their prior knowledge (plausibility; Piaget, 1977). They accommodate new learning in a way that allowed them to use it on the issue-based project (fruitfulness). The episode below provides an example of this:

> Girl: Ecological damage caused by the infestation negatively impacts the desert landscape.
> Boy 1: Can we just put cause and effect.
> Girl: Okay yeah the cause negatively effects the native plants.
> Boy 1: Damaging the ecosystem.
> [boy 1 reads under breath]
> Girl: Hold on she is going to ask how is it damaging the ecosystem.
> Boy 1: How?
> Girl: Why is it replacing native plants? Because there is less biodiversity. Okay we will do that. [Girl reads under breath] What is foliage?
> Boy 1: Ms. Singh what is foliage?
> [Teacher explanation]
> Girl: This is connected to this one and we could have an arrow to it. Wouldn't that go backwards though like eliminating the native plants would remove the preferred plants causing the damage in the ecosystem? So wouldn't these be backwards?
> Boy 2: It doesn't really matter cause aren't they the same thing
> Boy 1: Damaging the ecosystem.
> Girl: By eliminating, wouldn't it be like replacing native plants which is eliminating the preferred plants so by the preferred plants going away it is damaging the ecosystem.
> Boy 2: Yeah.
> Girl: I am going to switch the arrow.

This episode shows students were grasping new information but students also needed me. As explained in Chapter 2, social constructivism (Vygotsky, 1978) promotes the idea that learning proceeds from the interpsychological plane between the individual and others to the intrapsychological plane (within an individual) plane when a more knowledgeable person scaffolds learning. My role in the innovation served this purpose. I provided information about the process and concept as students worked and asked questions.

Students used cognitive process. *Assertion 2 - Students became aware of cognitive processes and because of this, they corrected errors, thought the science content in new ways, found the work less challenging, and understood the science content being taught.* Classroom discourse provided an opportunity for students to test the validity of their ideas and develop meaning of complex concepts (Aufschnaiter & Aufschnaiter, 2007). One student shared that cognitive processes helped him, “think deeper.” Another student noted that once she learned a cognitive process, she was able to apply it to a different environmental issue. Data from the Exit Questionnaire aligned and confirmed that the teaching of cognitive processes prior to the content helped students understand concepts.

Interestingly the way students used the cognitive processes and concepts changed over time. During the first cycle, students showed excitement and enthusiasm and took the new ways of learning as a challenge to their own intellectual capabilities. During the second cycle, students faced many challenges. They showed frustration and asked many questions but still continued trying to think in new ways. By the third cycle, students were familiar with the process. By the third cycle, cognitive processes were quickly becoming students’ habits of mind (Jäncke et al., 2002)

Students used Thinking Maps as learning tools. *Assertion 3 - Students found Thinking Maps to be an easy and useful tool to use to categorize, clarify, and organize their thoughts, learn the complexity of science concepts, expand their thinking, correct misconceptions and understand how scientists think.* Another data source, Thinking Maps, showed clarity of cognitive process and understanding of concepts. Given this, Thinking Maps became a representational scaffold that helped students learn and think scientifically. Thinking Maps helped students integrate and refine their thinking. Most students shared that learning cognitive process with the aid of Thinking Maps helped them think scientifically. As one student wrote in the Exit Questionnaire:

> We had to go deeper and get more involved in the information we were learning. For example using the cause and effect maps we found that it is a lot more complicated than just one thing effecting the environment but a whole bunch of things. In a whole, I have learned to think more scientifically because of these thinking maps.

Tytler and Prain (2010) confirm that representation offers more active and engaging approach to science learning. Developing a representation of a concept allows students to see the world in a scientific way.

Research Question 2

How will using Thinking Maps engage my students and encourage them to become scientific thinkers? In chapter 1 explained that my students were used to the regiment of worksheets and concrete products. So when I began thinking of ways to teach cognitive processes, I knew I had to use a scaffold. I chose Thinking Maps because they had recently been adopted in my district, and I had received training in their use. For each cognitive process, one type of Thinking Map was developed. I introduced the one-sided Multi-Flow Map for prediction, Multi-Flow Map for causation, and Flow Map for modeling. Data suggests that students found Thinking Maps to be a useful tool to share their scientific thinking and integrate their thinking with the content knowledge they learned.

Students believed Thinking Maps were learning tools. *Assertion 3 - Students found Thinking Maps to be an easy and useful tool to use to categorize, clarify, and organize their thoughts, learn the complexity of science concepts, expand their thinking, correct misconceptions and understand how scientists think.* Tytler and Prain (2013) view visual representations as a means to support students' thinking processes. To them representations function as both a process marker of one's learning and product of understanding. All of the 74 Thinking Maps analyzed showed that students were able to produce information, sort that information, and make associations among concepts. Thinking Maps helped students interrelate ideas and this led to more organized thinking and learning. Pre-and post-test scores indicate students were able to retrieve facts easily and apply them as needed (Anderson, 1993; Bedard & Chi, 1992; White & Rumsey, 1994). There was only one instance where a student misconstrued a cognitive process on a Thinking Map. However, as she worked with others, she self-corrected her mistake and redefined her map. Neuroscientist Willingham (2009) stresses practice enables further learning, improves transfer, and increase memory. Working on Thinking Maps provided practice for students and gave them time to discuss concepts and their thinking among themselves.

Research Question 3

If my students learn science concepts through cognitive processes and maps, will they be more engaged during class? In the past, asking students to think and to do projects was a challenge for me. I wanted my classroom to be alive with meaningful discussion among students as well as students and me. My innovation of explicit teaching of cognitive process with Thinking Maps enabled students to take charge of their own learning after I introduced the concepts.

Students' engagement increased. *Assertion 4 - Students were engaged in the learning process when the science concepts and tasks were interesting, involving, offered an opportunity for them to be creative, to be challenged, and were related to their real world needs.* Students worked to solve a local environmental problem at the end of each cycle of the innovation. Data show that they effectively applied their learning of the concepts and cognitive processes to their Thinking Maps. My observations and students' perceptions of engagement confirm that they found that learning in my class to be interesting, involving, challenging, and meaningful. On the Engagement Instrument, one student wrote, "I'm learning about Arizona's population and yes it is interesting to me. Yes to be more careful with things we do." This brief excerpt shows that this student was interested in the project because it was related to his real world needs. It also shows that he understood that he has a role to play in Arizona's environment. Insights like these made him more engaged in my class and aware of what he could do.

Newmann et al. (1992) theorize that engagement in learning is enhanced when a task is authentic, provides an opportunity for enjoyment, utilizes diverse talents, and when students take ownership of it. The above scenario shows students' engagement and interest, but my challenge was to stretch their thinking beyond concepts and help them think of ways to apply what they were learning to a real world scenario in a reasonable fashion. Teaching cognitive process and concepts through authentic local problems encouraged students to think creatively and understand that real world problems do not have linear solutions. I observed agentic engagement, or students' constructive contributions to the flow of instruction (Ainley, 2012; Assor, 2012; Brooks et al., 2012; Hipkins, 2012). Students actively shared their thoughts, opinions, and ideas on local scenarios affecting their lives.

Limitations to this Study

The first limitation of the study was the novelty effect. Explicit learning of cognitive process and concepts with Thinking Maps was new to all participants and this may have affected how hard they worked.

The second limitation was time and number. This action research was conducted for one semester with a small group of students. More time and more classes will allow findings to be validated.

Another limitation was the Hawthorne effect. The six students who were chosen to be video recorded may have felt special to be chosen by their teacher. One of the weakest students showed the highest improvement in achievement and this may have been due to the extra attention.

Finally, I as a teacher presented a potential threat through my researcher bias. To decrease this threat, I documented my thoughts and reactions throughout the innovation in a research journal. I also used peer debriefing and peer examination. I could have also used an outside observer for the Engagement Instrument to mitigate researcher bias.

Implications for Practice

Arizona is considering adopting the New Generation Science Standards (NGSS) and if they do this will change the course of K-12 science teaching. NGSS standards are not based on merely learning content, but also include science and engineering practices and crosscutting concepts that are embedded in cognitive processes. Furthermore, students will need to apply what they learn. Thus explicit teaching of cognitive processes with core ideas will need to be emphasized in science education and my innovation shows a place to begin. My innovation enabled students to understand new information quickly and effectively solve issue-based projects. Explicit teaching and practice of cognitive processes not only helped students understand how to think with content matter, but also placed less demand on their working memories. Cognitive load theory (CLT) is based on the assumption that working memory is limited (Miller, 1956).

NGSS urges that science should be taught not just as a discrete packet of information, but in a progressive way with application. These changes will necessitate science teaching be focused on both conceptual understanding and cognitive processes. The NGGS state:

> The Framework and the NGSS provide a more coherent progression aimed at overall scientific literacy with instruction focused on a smaller set of ideas and an eye on what the student should have already learned and what they will learn at the next level. (p. 3)

If the science standards become part of our nation’s science education, then teaching with worksheets will no longer due. Teachers will need to help students think deeply and become engaged in their own learning. Given these goals the teaching of cognitive process before teaching of concepts along with time for students to engage in discourse may be a good strategy to teach content and new ways of thinking.

The Common Core Standards emphasize that cognitive processes are part of scientific literacy, and because of this, the innovation in this study could be beneficial to introduce cognitive processes explicitly before asking students to perform high order thinking with texts. For example, one student stated, “No one has ever taught us like the way you teach.”

Additionally, the use of Thinking Maps, diagrams, and concepts maps can be used as an assessment tool because they capture what students think and know. Research in science learning and teaching suggests that visual representation of any kind is a powerful tool for scientific thinking and conceptual understanding (Tytler & Prain, 2010). Inclusion of visual representation to support science learning and teaching should be emphasized in science classrooms.

Implications for Research

Stringer (2007) suggests that action research is strengthened when it is replicated in various contexts. The innovation in this study should be tried and investigated in various contexts with various students.

Further research may also be done on engagement. The Engagement Observation Instrument used in this study was a modified version adopted from the International Center for Leadership in Education. The three aspects of engagement posed were cognitive, affective, and behavioral, and these were used in this study. However, for further research, I would recommend exploration into different aspects of engagement such as voice. Voice may be a better means to understand students’ engagement as they work on in real world scenarios because students’ discourse shows their passion for what they are learning and can be used in place of conventional testing. The work on conceptual understanding in the last decade emphasizes the importance of student discourse.

Another area a researcher should consider is inequality in STEM majors and what can be done about it. In the U.S., 71.8% of STEM professionals are White. Hispanic and African Americans are not well represented. This is problematic because the increasing minority population in the U.S. necessitates more students be encouraged to go into this field. Given this, more studies need to be conducted to understand what works for these students to be successful.

A further area of research could focus on the science curriculum. The theory of conceptual change has been in focus for the last three decades, but the science standards are more than six decades old. Moreover, science is one of the fastest evolving subject areas and the idea of conceptual change and scientific thinking needs to be brought into each subject area such as biology, chemistry, and physics. Though the road map provided by NGSS solves the problem of direction, there is still a need for more insight as to just how to create an effective science curriculum for conceptual understanding and science practices with cross cutting concepts.

Conclusion

In our hyper-competitive global marketplace, there is a demand for STEM majors. Consequently, the need for high school students to choose STEM majors when they attend college is becoming more important. Research suggests that high school students who are proficient and interested in science are the ones who graduate with STEM majors or choose STEM careers. Thus, one of the challenges for urban high school science teachers is to get students with limited backgrounds in science interested and engaged. Teaching science concepts to adolescents can be an arduous task especially if their early experiences in the classroom focused on paper and pencil tasks. Another factor adding to the challenge is the urgency to teach the new NGSS standards to engage all students in three dimensions of framework, disciplinary core ideas, scientific and engineering practices, and crosscutting concepts. This is difficult when students are not prepared or interested.

Action research gives practitioners, like myself, an opportunity to work towards effective solutions to local problems (Stringer, 2007). Thus, in my personal context, finding creative ways to teach science core ideas, science, and engineering practices and crosscutting concepts will come from teaching strategies that balance cognitive processes with concepts. My innovation of the explicit teaching of cognitive process prior to concepts brought significant student achievement and increased student engagement. Not a single student failed the district's final CRT test.

Closing Thoughts From Researcher's Perspective

Through this action research, I evolved as an educator, leader, and researcher. First, the whole idea of qualitative research was alien to me. I always had difficulty communicating ambiguous ideas because of my strong background and training in science. My personal challenge was to break my mindset of cause and effect thinking and understand a social phenomenon from the perspective of all stakeholders. In other words I had to listen to their voices and analyze their discourse and writing. Moreover, the variables were numerous and ever changing which perplexed me at times and hindered my focus on the very aspects I was studying. In these three years, my mind and practices as an educator have transformed. My focus is no longer just on content, strategies, or student achievement. I now listen to my students to understand what they are not saying and what they are coming to know. This understanding has led to a positive relationship with my students in ways that allowed me to personalize their learning and challenge them to be independent learners at the same time. Through this action research, my linear vision expanded to 360^o. The journey of three years of hard work has strengthened my potential to be a leader from my classroom.

References

Achieve Inc. (2013). *New generation science standards.* Retrieved from http://www.nextgenscience.org/next-generation-science-standards

ACT. (2006). *Developing the STEM education pipeline.* Iowa City, IA: ACT.

Ainley, M. (2012). Students' interest and engagement in classroom activities. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 283–302). New York, NY: Springer.

Alliance for Excellent Education. (2007). *High school teaching for the twenty-first century: Preparing students for college.* Washington, D.C.: author.

Anderson, L. M. (1993). Auxillary materials that accompany textbooks: Can they promote "higher order" learning? In B.K. Britton, A. Woodward, & M. Binkley (Eds), *Learning from textbooks: Theory and practice.* Mahwah, NJ: Erlbaum

Appleton, J. J., Christenson, S. L., & Furlong, M. (2008). Student engagement with school: Critical conceptual and methodological issues of the construct. *Psychology in Schools*, *45*, 369–386. doi:10.1002/pits.20303

Assor, A. (2012). Allowing choice and nurturing an inner compass: Educational practices supporting students' need for autonomy. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 421–440). New York, NY: Springer.

Aufschnaiter. C. (2003). Interactive processes between university students: Structures of instructions and related cognitive development. *Research in Science Education,* 33, 341-374.

Aufschnaiter, C. Von, & Aufschnaiter, S. Von. (2007). University students' activities, thinking and learning during laboratory work. *European Journal of Physics*, *28*(3), S51–S60. doi:10.1088/0143-0807/28/3/S05

Ausubel, D. (2000). Theories of learning in educational psychology. Retrieved from http://tip.psychology.org/ausubel.html

Bedard, J., & Chi, M. T. H. (1992). Expertise. *Current Direction in Psychological Science, 1,* 135-139.

Beeth, M. E., & Hewson, P. W. (1999). Learning goals in an exemplary science teacher's practice: Cognitive and social factors in teaching for conceptual change. *Science Education, 83*(6), 738-760.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn.* Washington, DC: National Academy Press.

Brooks, R., Brooks, S., & Goldstein, S. (2012). The power of mindsets: Nurturing engagement, motivation, and resilience in students. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 541–562). New York, NY: Springer.

Business-Higher Education Forum (BHEF). (2010). *Increasing the number of STEM graduates: Insight from the U.S. STEM education and modeling project.* Washington, DC: Author.

Bybee, R. W. (1995). Science curriculum reform in the United States. *Redesigning the science curriculum,* 12-20.

Chi, M. T. H., Roscoe, R. D., Slotta, J. D., Roy, M., & Chase, C. C. (2012). Misconceived causal explanations for emergent processes. *Cognitive Science*, *36*(1), 1–61. doi:10.1111/j.1551-6709.2011.01207.x

Cleary, T. J., & Zimmerman, B. J. (2012). A cyclical self-regulatory account of student engagement: Theoretical foundations and applications. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 237–258). New York, NY: Springer.

Commission on Professionals in Science and Technology (CPST). (2007). *Is US science and technology adrift?* Washington, DC: Author.

Corbin, J., & Strauss, A. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory.* Thousand Oaks, CA: Sage Publications, Inc.

Corno, L. (1993). The best-laid plans: Modern conceptions of volition and educational research. *Educational Researcher*, *22*(2), 14–22. doi:10.3102/0013189X022002014

Creswell, J. W., & Plano Clark, V. L. (2007). *Designing and conducting mixed methods research.* Thousand Oaks, CA: Sage

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks, CA: Sage.

Crick, R. D. (2012). Deep engagement as a complex system: Identity, learning power, and authentic enquiry. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 675–694). New York, NY: Springer.

Davis, M. H., & McPartland, J. M. (2012). High school reform and student engagement. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 515–540). New York, NY: Springer.

Dockter, J., Haug, D., & Lewis, C. (2010). Redefining rigor: Critical engagement, digital media, and the new English/language arts. *Journal of Adolescent and Adult Literacy*, *53*, 418–420. doi:10.1598/JAAL.53.5.7

Driver, R., Guesne, E., & Tiberghien, A. (1985). *Children's ideas in science*. Milton Keynes, England: Open University Press.

Dykstra, D. I., Boyle, C. F., & Monarch, I. A. (1992). Studying conceptual change in learning physics. *Science Education,* 76, 615.

Eccles, J. S., & Wang, M. (2012). Part I commentary: So what is student engagement anyway? In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 133–145). New York, NY: Springer.

Feinstein, S. G. (2009). *Secrets of the teenage brain: Research-based strategies for reaching and teaching today's adolescents* (2nd ed.). Thousand Oaks, CA: Corwin Press.

Feinstein, N.W., Allen, S., & Jenkins, E. (2013). Outside the pipeline: Re-imagining science education for nonscientists. *Science, 340*(6130), 314-317. doi:10.1126/science.1230855

Fensham, P. J., Gunstone, R. F., & White R. T. (1994). *The content of science: A constructivist approach to its teaching and learning,* London: Falmer.

Finn, J. D., & Zimmer, K. (2012). Student engagement: What is it? Why does it matter? In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 97–132). New York, NY: Springer.

Fox, M. A., & Hackerman, N. (Eds.). (2003). *Evaluating and improving undergraduate teaching in science, technology, engineering, and mathematics*. Washington, DC: National Academies Press.

Fraenkel, J. R. & Wallen, N. E. (2005). Validity and reliability. In J. R. Fraenkel & N. E. Wallen, *How to design and evaluate research in education with PowerWeb*. (pp. 152-171). Hightstown, NJ: McGraw Hill Publishing Co.

Fredericks, J. A., Blumenfeld, P., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research, 74*(1), 59–109.

Furlong, M. J., & Christenson, S. L. (2008). Engaging students with school and academics: A relevant construct for all students. *Psychology in Schools*, *45*, 365–368. doi:10.1002/pits.20303

Gelo, O., Braakmann, D., & Benetka, G. (2008). Quantitative and qualitative research: beyond the debate. *Integrative psychological & behavioral science*, *42*(3), 266–90. doi:10.1007/s12124-008-9078-3

Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., Zijdenbos, A., T. Paus, A. C. Evans & Rapoport, J. L. (1999). Brain development during childhood and adolescence: A longitudinal MRI study. *Nature neuroscience*, *2*(10), 861-863.

Glaser, B.G., & Strauss, A L. (1967). *The discovery of grounded theory: Strategies for qualitative research*, Chicago, IL: Aldine Publishing Company

Greene, J. C. (2007). *Mixed methods in social inquiry*. San Francisco, CA: Jossey-Bass.

Greene, J. C., Caracelli, V. J., & Graham, W.F. (1989). Toward a conceptual framework for mixed-method evaluation designs. *Educational Evaluation and Policy Analysis, 11*(3), 255-274.

Griffiths, A., Liles, E., Furlong, M. J., & Sidhwa, J. (2012). The relations of adolescent student engagement with troubling high-risk behaviors. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 563–584). New York, NY: Springer.

Guthrie, J. T., & Wigfield, A. (2000). Engagement and motivation in reading. In M. Kamil, R. Barr, P. Mosenthal, & D. Pearson, *Handbook of reading research*, (Vol. 3, pp. 403-422). New York: Longman.

Guthrie, J. T., Wigfield, A., & You, W. (2012). Instructional contexts for engagement and achievement in reading. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 601–634). New York, NY: Springer.

Hall, C., Dickerson, J., Batts, D., Kauffmann, P., & Bosse, M. (2011). Are we missing opportunities to encourage interest in STEM fields? *Journal of Technology Education*, 23 (1), 32-46.

Hendricks, C. (2006). *Improving school through action research: A comprehensive guide for educators.* Boston, MA: Allyn & Bacon.

Herr, K., & Anderson, G. L. (2005). *The action research dissertation: A guide for students and faculty*. Thousand Oaks, CA: Sage.

Hewson, P. (1981). A conceptual change approach to learning science. *European Journal of Science Education, 3*(4), 383-396.

Hinchey, P. H. (2008). *Action research primer*. New York, NY: Peter Lang.

Hipkins, R. (2012). The engaging nature of teaching for competency development. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 441–456). New York, NY: Springer.

Howard-Jones, P. (2007). *Neuroscience and education: Issues and opportunities.* London, England: Teaching and Learning Research Programme.

Hyerle, D. (1996). *Visual tools for constructing knowledge*. Alexandria, VA: Association for Supervision and Curriculum Development.

Jäncke, L., Wüstenberg, T., Scheich, H., & Heinze, H.J. (2002). Phonetic perception and the temporal lobe. *Neuroimage, 15*, 733-746.

Johnson, B. J., & Onwuegbuzie, A. J. (2004). Mixed method research: A research paradigm whose time has come. *Educational Researcher,* 33(7), 14-26.

Kang, H., Welcher, A. A., Shelton, D., & Schuman, E. M. (1997). Neurotrophins and time: different roles for TrkB signaling in hippocampal long-term potentiation. *Neuron*, *19*(3), 653-664.

Kaplan, P.S. (1998). *The human odyssey* (3rd ed.). Pacific Grove, CA: Brooks/Cole.

Knox, R. (Writer). (2010). *The teen brain: It's just not grown up yet* [Audio program]. National Public Radio. Retrieved from http://www.npr.org/templates/story/story.php?storyId=124119468

Kuhn, T.S. (1970). *The structure of the scientific revolution* (2nd ed.). Chicago, IL: University of Chicago Press

Lam, S., Wong, B., Yang, H., & Liu, Y. (2012). Understanding student engagement with a contextual model. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 403–420). New York, NY: Springer.

Lawson, M. A., & Lawson, H. A. (2013). New conceptual frameworks for student engagement research, policy, and practice. *Review of Educational Research*, *83*(3), 432-479.

Lieberman, A., & Miller, L. (2005). Teachers as leaders. *The Educational Forum*, *69*(2), 151-162.

Lowell, B. L., & Regets, M. (2006, August). *A half-century snapshot of the STEM workforce, 1950-2000*. Washington, D.C.: Commission on Professionals in Science and Technology.

Mahatmya, D., Lohman, B. J., Matjasko, J. L., & Farb, A. F. (2012). Engagement across developmental periods. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 45–64). New York, NY: Springer.

Marzano, R. J., & Arrendondo, D. E. (1996). Restructuring schools through the teaching of thinking skills. *Educational Leadership*, *43*(8), 20-26.

McNiff, J., & Whitehead, J. (2006). *Action research for teachers: A practical guide.* Abingdon, UK: David Fulton.

Meloth, M. S., & Deering, P. D. (1994). Task talk and task awareness under different cooperative learning conditions. *American Educational Research Journal*, *31*(1), 138-165.

Mercer, N. (2002). *Words and minds: How we use language to think together.* London: Routledge.

Miles, M., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Thousand Oaks, CA: Sage.

Miller, G.A. (1956). The magical number seven plus or minus two: some limits on our capacity for processing information, *Psychological Review,* 63, 81-97.

Mills, G. (2006). *Action research: A guide for the teacher researcher* (3rd ed.). Columbus, OH: Merrill/Prentice Hall.

Mitra, D., & Serriere, S. (2012). Student voice in elementary school reform: Examining youth development in fifth graders. *American Educational Research Journal*, *49*, 743–774. doi:10.3102/0002831212443079

Morse, J. M., & Niehaus, L. (2009). *Mixed method design: Principles and procedures*. Walnut Creek, CA: Left Coast Press.

National Research Council. (2000). *Inquiry and the National Science Education Standards: A guide for teaching and learning.* Washington, D.C.: National Academy Press.

National Science Board. (2010). *Science and engineering indicators 2010*. Arlington, VA: Author.

National Science Foundation (NSF). (2010). *Science and engineering indicators 2010.* Arlington, VA: Author.

Newmann, F. M. (1992). *Student engagement and achievement in American secondary schools*. New York, NY: Teachers College Press.

Newmann, F. M., Wehlage, G. G., & Lamborn, S. D. (1992). The significance and sources of student engagement. In *Student engagement and achievement in American secondary schools* (pp. 11-39). New York, NY: Teachers College Press.

Noffke, S., & Stevenson, R. (1995). *Educational action research: Becoming practically critical.* New York: Teachers College Press.

O'Conner, K., Hanny, C., & Lewis, C. (2011). Doing "business as usual": Dynamics of voice in community organizing talk. *Anthropology and Education Quarterly*, *42*, 154–171. doi:10.1111/j.1548-1492.2011.01122.x

Ormrod, J.E. (2008). *Educational psychology: Developing learners* (6th ed). Upper Saddle River, NJ: Prentice Hall.

Patten, M. L. (2012). *Understanding research methods: An overview of the essentials* (8th ed.). Glendale, CA: Pyrczak.

Patton, S. (2013, September 12). Influx of foreign students drives modest increase in graduate-school enrollments. *The Chronicle of Higher Education.* Retrieved from https://chronicle.com/article/Graduate-School-Enrollments/141577/

Pekrun, R., & Linnenbrink-Garcia, L. (2012). Academic emotions and student engagement. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 259–282). New York, NY: Springer.

Pfundt, H., & Duit, R. (1985). *Bibliography: Students' alternative frameworks and science education*. Kiel, United Kingdom: IPN.

Piaget, J. (1977). *Equilibrium of cognitive structure.* New York, NY: Viking Press.

Pintrich, P. R., & De Groot, E. (1990). Motivated and self-regulated learning components of academic performance. *Journal of Educational Psychology*, *82*, 33–40. doi:10.1037/0022-0663.82.1.33

Pintrich, P. R., & Garcia, T. (1991). Student goal orientation and self-regulation in the college classrooms. In M. L. Maehr, & P. R. Pintrich (Eds.), *Advances in motivation and achievement: Goals and self-regulatory processes* (pp. 371–402). Greenwich, CT: JAI Press.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, *63*(2), 167-199.

Pintrich, P. R., Wolters, C., & Baxter, G. (2000). Assessing metacognition and self regulated learning. In G. Schraw, & J. Impara (Eds.), *Issues in the measurement of metacognition* (pp. 43–97). Lincoln, NE: Buros Institute of Mental Measurement.

Polman, J. L., & Miller, D. (2010). Changing stories: Trajectories of identification among African American youth in a science outreach apprenticeship. *American Educational Research Journal*, *47*, 879–91. doi:10.3102/0002831210367513

Posner, G.J., Strike, K.A., Hewson, P.W., and Gertzog, W. A. (1982). Accommodation of scientific conception: Towards a theory of conceptual change. *Science Education, 66*(2), 211-227.

Reeve, J. (2012). A self-determination theory perspective on student engagement. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 149–172). New York, NY: Springer.

Rogoff, B. (2003). *The cultural nature of human development*. New York, NY: Oxford University Press.

Ross, P. E. (2006). The expert mind. *Scientific American*, *295*(2), 64–71. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23592253

Rumberger, R. W., & Rotermund, S. (2012). The relationship between engagement and high school drop-out. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 491–514). New York, NY: Springer.

Rutherford, F. J. (2005). The 2005 Paul F-Brandwein lecture : Is our past our future ? Thoughts on the next 50 years of science education reform in the light of judgments on the past 50 years. *Journal of Science Education and Technology. 14*(4), 367–386. doi:10.1007/S10956-005-8082-3

Sagor, R. (2004). *The action research guidebook: A four-step process for educators and school team.* Thousand Oaks, CA: Corwin Press.

Schank, R. (2011). *Teaching minds: How cognitive science can save our schools.* New York, NY: Teacher College Press

Schnotz, W., Vosniadou, S., & Carretero, M. (Eds.). (1999). *New perspectives on conceptual change*. New York, NY: Pergamon.

Scott, P. (1998). Teacher talk and meaning making in science classrooms: A Vygotskian analysis and review. *Studies in Science Education*, *32*(1), 45–80. doi:10.1080/03057269808560127

Skinner, E. A., & Pitzer, J. R. (2012). Developmental dynamics of student engagement, coping, and everyday resilience. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 21–44). New York, NY: Springer.

Spillane, J. P., Diamond, J. B., Walker, L. J., Halverson, R., & Jita, L. (2001). Urban school leadership for elementary science instruction: Identifying and activating resources in an undervalued school subject. *Journal of Research in Science Teaching, 38*(8), 918–940.

Spinks, S. (2000). Adolescent brains are works in progress, here's why. *Nature, 404.* Retrieved from http://www.pbs.org/

Stenhouse, L. (1981). What counts as research? *British Journal of Educational Studies, 29,* 103-113.

Stringer, E. T. (2004). *Action research in education*. Upper Saddle River, NJ: Pearson/Merrill/Prentice Hall.

Stringer, E. T. (2007). *Action research*. Thousand Oaks, CA: Sage.

Teddlie, C., & Tashakkori, A. (2009). Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences. Thousand Oaks, CA: Sage

Treagust, D. F., & Duit, R. (2008). Conceptual change: A discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education, 3*(2), 297-328. doi: 10.1007/s11422-008-9090-4

Tressel, G. W. (1994). Thirty years of "improvement" in precollege math and science education. *Journal of Science and Technology, 3*(2), 77–88.

Tucker. M. (2011). *Standing on the shoulder of giants: An American agenda for education reform*. Washington, D.C.: National Center on Education and the Economy.

Turcotte, S. (2012). Computer-supported collaborative inquiry on buoyancy: A discourse analysis supporting the "pieces" position on conceptual change. *Journal of Science Education and Technology*, 21(6), 808-825. doi:10.1007/s10956-012-9368-x

Tytler, R., & Prain, V. (2010). A framework for re-thinking learning in science from recent cognitive science perspectives. *International Journal of Science Education, 32*(15), 2055-2078.

Tytler, R., & Prain, V. (2013). International handbook of research on conceptual change. In Vosniadou, S. (Ed.). *Representation construction to support conceptual change* (pp, 560-579). New York, NY: Routledge.

U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics. (2008). *Digest of education statistics, 2007* (NCES 2008-022). Washington, DC: author.

U.S. Department of Labor (DOL). (2007). *The STEM workforce challenge: The role of the public workforce system in a national solution for a competitive science, technology, engineering, and mathematics (STEM) workforce.* Washington, DC: Author.

Voelkl, K. E. (2012). School identification. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 193–218). New York, NY: Springer.

Vygotsky, L. (1962). *Thought and language.* Cambridge, MA: MIT Press.

Vygotsky, L. S. (1978). *Mind and society: The development of higher mental processes.* Cambridge, MA: Harvard University Press.

Wang, X. (2013). Why students choose STEM majors: Motivation, high school learning, and postsecondary context of support. *American Educational Research Journal*, *50*(5), 1081–1121. doi:10.3102/0002831213488622

Wells, G. (2000). Dialogic inquiry in education. In C. D. Lee & P. Smagorinsky (Eds.),*Vygotskian perspectives on literacy research: Constructing meaning throughcollaborative inquiry* (pp. 51-85). New York, NY: Cambridge University Press.

West, L., & Pines, A. (Eds.). (1985). *Cognitive structure and conceptual change*. Orlando, FL: Academic Press.

White, J. J., & Rumsey, S. (1994). Teaching for understanding in a third-grade geography lesson. In J. Brophy (Ed.), *Advances in research on teaching: Case studies of teaching and learning in social studies* (Vol. 4). Greenwich, CT: JAI Press.

Willingham, D. T. (2007, Summer). Critical thinking. *American Educator,* 8-19. Retrieved from https://www.aft.org/newspubs/periodicals/ae/subject.cfm

Willingham. D.T. (2009). *Why don't students like school?* San Francisco, CA: Jossey-Bass

Willis, J. (2006). *Research-based strategies to ignite student learning: Insights from a neurologist and classroom Teacher.* Alexandria, VA: Association for Supervision and Curriculum Development.

Woolfolk, A. (2007). *Educational psychology*. New York: Pearson.

Yurgelun-Todd, D. A., Killgore, W. D., & Young, A. D. (2002). Sex differences in cerebral tissue volume and cognitive performance during adolescence. *Psychological Reports, 91*(3), 743-757. doi:10.2466/pr0.2002.91.3.743

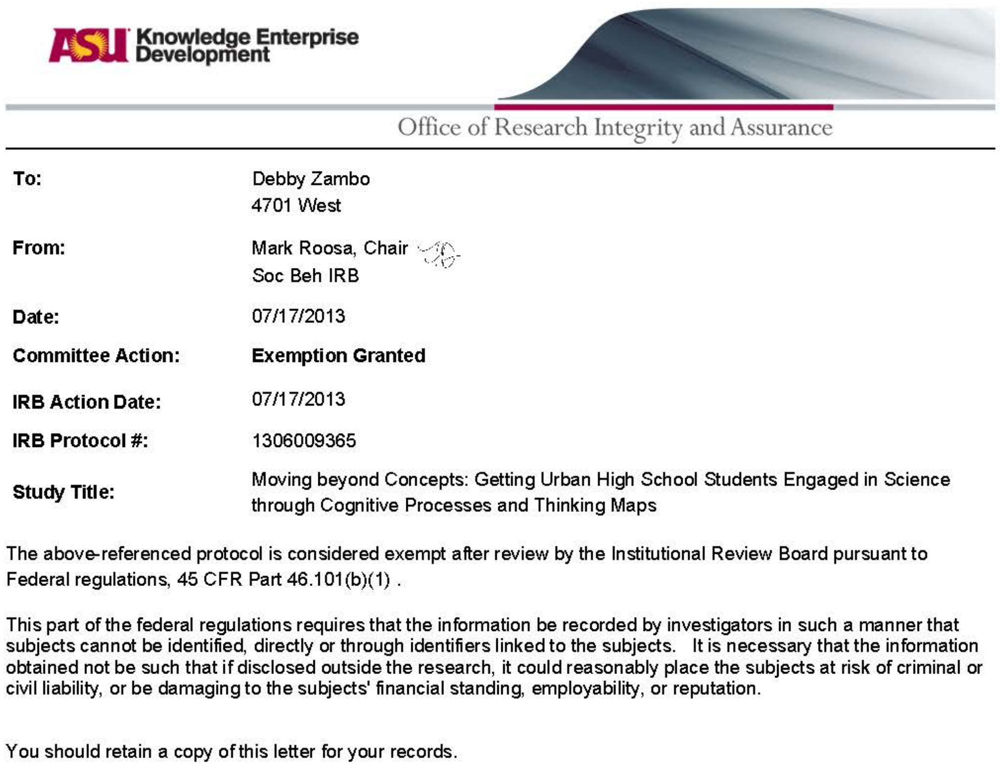
Ziechner, K., & S. Noffke. (2001). Practitioner research. In V. Richardson (Ed.), *Handbook of research on teaching* (pp. 298-330). Washington DC: American Educational Research Association.

Zirbel, E. L. (2004). Framework for conceptual change. *Astronomy Education Review*, *3*(1), 62. doi:10.3847/AER2004007

Zirbel, E. L. (2006, December). Teaching to promote deep understanding and instigate conceptual change. *Bulletin of the American Astronomical Society, 38,* 1220.

APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL



ASU Knowledge Enterprise Development
Office of Research Integrity and Assurance

To:	Debby Zambo 4701 West
From:	Mark Roosa, Chair Soc Beh IRB
Date:	07/17/2013
Committee Action:	**Exemption Granted**
IRB Action Date:	07/17/2013
IRB Protocol #:	1306009365
Study Title:	Moving beyond Concepts: Getting Urban High School Students Engaged in Science through Cognitive Processes and Thinking Maps

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(1) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

APPENDIX B

PARENT'S PERMISSION FORM

Moving beyond Concepts: Getting Urban High School Students
Engaged in Science through Cognitive Processes and Thinking Maps

Parent Letter of Permission

Dear Parents,

I am your child's Environmental Science teacher and also a graduate student at Arizona State University under the direction of Dr. Debby Zambo. I am conducting a research study to understand the effect of teaching cognitive processes with scientific concepts on students’ understanding and interest in science.

I am inviting your child's participation. The teaching in this project will be a normal part of the school day and a part of my class. All ideas presented align with the district's Environmental Science standards and overarching New Generation Science Standards. My study will involve collecting the Thinking Maps students develop, videotaping and observing students while they are learning to solve environmental issues, and testing students to ensure they are learning. Student discourse from the videotape will be transcribed without students' name to understand students' understanding of the content.

Your child's participation in this study is voluntary. If you or your child chooses not to participate, there will be no penalty. Participation will not affect your child’s grade. At any point, you or your child may opt out of the study.

The result of the research study may be published, but your child’s name will not be used. All student responses and information will remain confidential. Your child's name will not appear to any report, presentations or publication that may come out of this study.

If you have any questions about your child's rights as a subject/participant in this research, or if you feel your child have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the Office of Research Integrity and Assurance, at (480) 965-6788.

Sincerely,

Renu Singh
Science Teacher

Parent's Permission Slip

By indicating YES and signing below, you are giving your permission for your child

To participate in the videotaping process:

PARENT SIGNATURE	PRINTED NAME	DATE

For use of your child's schoolwork in research data:

PARENT SIGNATURE	PRINTED NAME	DATE

APPENDIX C

STUDENT ASSENT FORM

Moving beyond Concepts: Getting Urban High School Students
Engaged in Science through Cognitive Processes and Thinking Maps

Student Letter of Notification & Assent

Dear Student,

I am your Environmental Science teacher and also a graduate student at Arizona State University under the direction of Dr. Debby Zambo. I am conducting a research study to understand the effect of teaching cognitive processes with scientific concepts on students' understanding and interest in science.

I am inviting your participation. The teaching in this project will be a normal part of the school day and a part of my class. All ideas presented align with the district's standards and New Generation Science Standards. My study will involve collecting the Thinking Maps students develop, videotaping and observing students while they are learning to solve environmental issues, and testing students to ensure they are learning. Student discourse from the videotape will be transcribed without students' name to understand students' understanding of the content.

Your participation in this study is voluntary. If you choose not to participate, there will be no penalty. Participation will not affect your grade. At any point, you may opt out of the study.

The result of the research study may be published, but your name will not be used. All student responses and information will remain confidential. Your name will not appear to any report, presentations or publication that may come out of this study.

Your parent must also give you permission to participate.

Sincerely,

Renu Singh
Science Teacher

By signing below, I ____am expressing my willingness to participate in the videotaping while students are engaged in solving environmental issue during the class period.

For use of schoolwork as research data: ______________________ ___________
STUDENT SIGNATURE DATE

For videotaping: ______________________ ___________
STUDENT SIGNATURE DATE

APPENDIX D

ISSUE-BASED PROJECT - 1

Population Issue in Arizona

The latest US census bureau estimate, from 2011, puts the population of Arizona at 6,482,505. This follows on from the official 2010 census results, which recorded a population of 6,392,017. Assuming consistent growth, the Arizona population in 2012 is likely to increase well past 6.5 million. From 1990 to 2000, Arizona was the second fastest growing state, increasing it's population by nearly 40 percent. (Source: http://worldpopulationreview.com/population-of-arizona/)

Based on the given scenario, predict all possible implications of population growth both directly and indirectly. Your final product will be a PowerPoint presentation. Your presentation will be graded based on the rubric provided.

During the research process, jot down your findings in the notebook. Make all thinking maps on the left hand-side of the notebook and notes on right hand-side. Please follow the steps given below:

1. Brainstorm all possible aspects of population impact. Use Bubble Map for this activity.
2. Research and make the prediction with specific details. Use half-Multi-Flow Map for this activity.
3. After each prediction, provide the evidence as well as source of the evidence.
4. Summarize your findings.

APPENDIX E

PRE-TEST AND POST-TEST -2

Biomes & Biodiversity

Multiple Choice

Identify the choice that best completes the statement or answers the question.

____ 1. Tigers living in warm climates have thinner coats of fur than tigers living in cool climates. This is a result of

a. genetic diversity.
b. species diversity.
c. ecosystem diversity.
d. general diversity.

Explain your answer:

____ 2. Which is the most direct way in which biodiversity can provide a source of income?

a. medicines
b. ecotourism
c. research
d. agriculture

Explain your answer:

____ 3. What global phenomenon has caused some organisms to move toward the poles or to higher altitudes?

a. habitat fragmentation
b. pollution
c. invasive species
d. warming temperatures

Explain your answer:

____ 4. Why do shorter trees and plants that make up the understory in tropical rain forests have large, flat leaves?

a. to shade themselves from excessive sunlight
b. to create habitat for forest insects
c. to offer protection from rain
d. to allow maximum surface for light absorption

Explain your answer:

____ 5. To help them survive in the tundra, caribou have various adaptations, such as

a. thin coats of fur to prevent overheating.
b. wide hooves for travel on mud and snow.
c. a diet that consists mostly of deciduous tree leaves.
d. the ability to hibernate.

Explain your answer:

APPENDIX F

ENGAGEMENT OBSERVATION INSTRUMENT

Student Engagement Instrument (Part One - TEACHER)

OBSERVATIONS**:** ***Circle one***

Positive Body Language

After 10 minutes: Very High High Medium Low Very Low

After 20 minutes: Very High High Medium Low Very Low

Students exhibit body postures that indicate they are paying attention to the teacher and/or other students.

Consistent Focus

After 10 minutes: Very High High Medium Low Very Low

After 20 minutes: Very High High Medium Low Very Low

All students are focused on the learning activity with minimum disruptions.

Verbal Participation

After 10 minutes: Very High High Medium Low Very Low

After 20 minutes: Very High High Medium Low Very Low

Students express thoughtful ideas, reflective answers, and questions relevant or appropriate to learning.

Student Confidence

After 10 minutes: Very High High Medium Low Very Low

After 20 minutes: Very High High Medium Low Very Low

Students exhibit confidence and can initiate and complete a task with limited coaching and can work in a group.

Fun and Excitement

After 10 minutes: Very High High Medium Low Very Low

After 20 minutes: Very High High Medium Low Very Low

Students exhibit interest and enthusiasm and use positive humor.

STUDENT PERCEPTIONS

(Part Two - Student)

Circle one

Clarity of Learning

Very High High Medium Low Very Low

Students can describe the purpose of the lesson or unit. This is not the same as being able to describe the activity being done during class.

Questions to Ask: What are you working on? What are you learning from this work?

Meaningfulness of Work

Very High High Medium Low Very Low

Students find the work interesting, challenging, and connected to learning.

Question to Ask: What are you learning? Is this work interesting to you? Do you know why are you learning this?

Rigorous Thinking

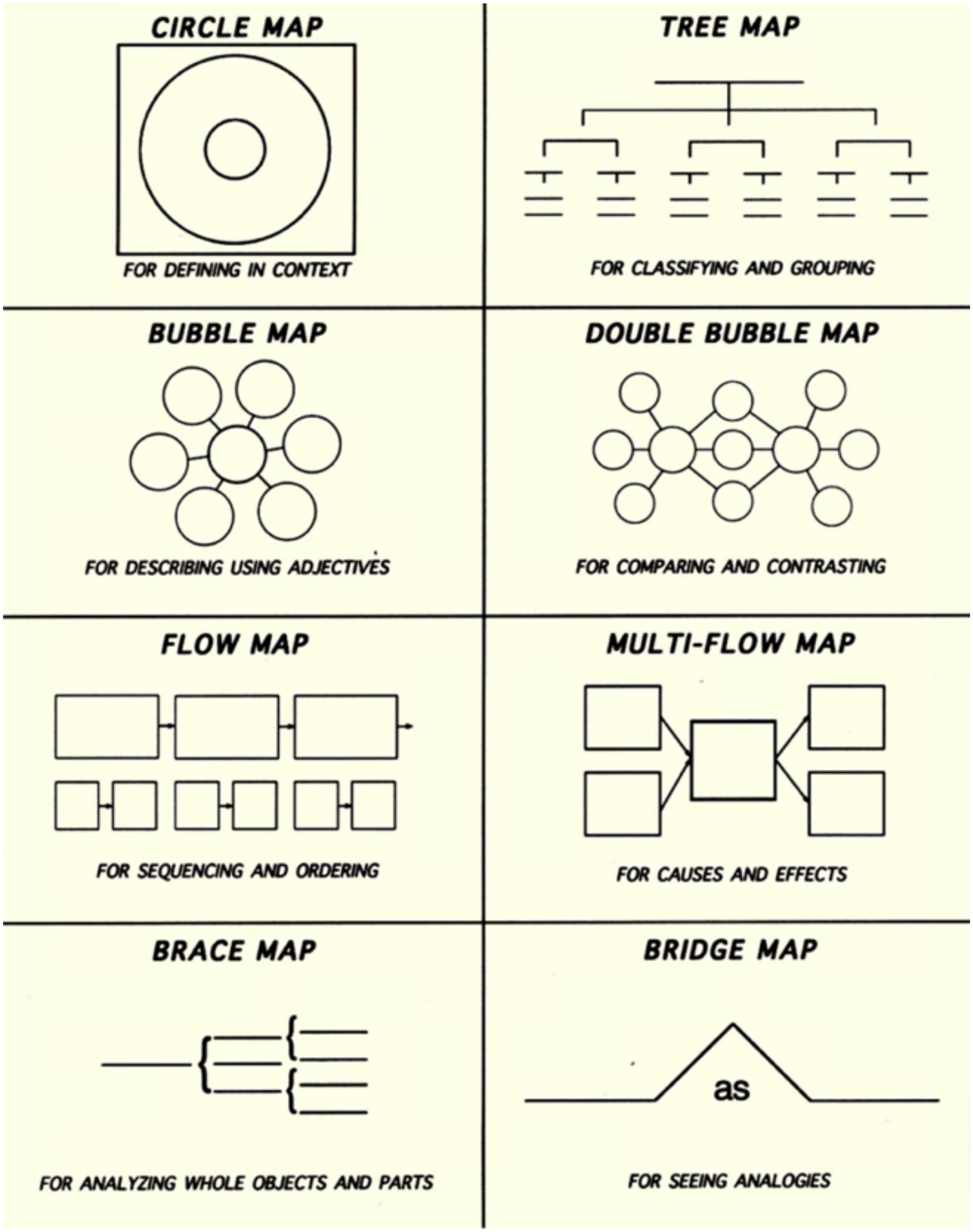
Very High High Medium Low Very Low

Students work on complex problems, create original solutions, and reflect on the quality of their work.

Question to Ask: How challenging is this work? In what ways do you have the opportunity to be creative?

APPENDIX G

TYPES OF THINKING MAPS


CIRCLE MAP
FOR DEFINING IN CONTEXT
TREE MAP
FOR CLASSIFYING AND GROUPING
BUBBLE MAP
FOR DESCRIBING USING ADJECTIVES
DOUBLE BUBBLE MAP
FOR COMPARING AND CONTRASTING
FLOW MAP
FOR SEQUENCING AND ORDERING
MULTI-FLOW MAP
FOR CAUSES AND EFFECTS
BRACE MAP
FOR ANALYZING WHOLE OBJECTS AND PARTS
BRIDGE MAP
as
FOR SEEING ANALOGIES