Cognitive Structural Change and the Technological Design Process

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ABSTRACT

With increasing challenges from international competition and domestic demands for a technologically literate workforce, pressure is growing on the educational system to produce students that are literate in science, technology, engineering, and mathematics (STEM). Integrative STEM education utilizes design-based pedagogical approaches to teach science/math content and practices concurrently with technology/engineering content and practices (Wells & Ernst, 2012, para. 2). The discipline of technology education has traditionally implemented design-based pedagogical approaches. However, the discipline has not demonstrated through empirical research that its existence and pedagogies are beneficial to student learning and cognition (Lewis, 1999, 2006; Petrina, 1998; Wells, 2008, 2010; Zuga, 1994, 1997, 2001).

The purpose of this study was to demonstrate that the technological design-based approach to teaching biotechnology literacy supports students' connections of science and technology concepts. Grounded in Ausubel's (1968) theory on meaningful learning and Novak's (1980) advanced organizer of concept mapping, this study examined evidence of high school students' cognitive structural change throughout the technological design-based approach to instruction. At three key intervals throughout the technological design process, students developed concept maps to document their understanding of the biology and technology concepts presented within the instructional materials. Data for this study included the students' constructed concept maps. To analyze the concept maps, the researcher used Hay et al.'s (2008) three-method analysis for measuring the quality of students' learning, and a qualitative analysis.

Data analysis across all four methods indicated that all participants experienced a varying degree of growth in biology, technology, and integrative concepts and connections. Collectively this study supports the notion that the technological design-based approach to instruction does indeed (1) encourage meaningful learning, and (2) increase students' use of higher order thinking indicated by their abilities to demonstrate their use of schematic and strategic knowledge within their concept maps. The results of this study have direct implications within the areas of Technology Education, Science Education, classroom practice, and concept mapping. The discussion and implications suggest the need to expand the research conducted within this study, and to improve the methods for concept mapping analysis.

Dedication

“To everyone who helped pave my way

If it weren’t for you, I wouldn’t be here today…

Mom and dad, and all your prayers

And those looking down from up there

I didn’t get here alone

That road’s just too rough and long

I might be the one the spotlight’s on

But, I didn’t get here alone…

I know I didn’t get here alone…”

“I didn’t get here alone” (Thrasher, Chesney, & Dulaney, 2010, track 13)

I would like to dedicate this dissertation to my family, friends, committee, colleagues, students, and especially my teachers. I could not have achieved this goal without the love and support from each of you. Words cannot describe the impact that you have made on my life. I am eternally grateful for everything you have taught me. I only hope that one day I can contribute to the success and happiness of others as you have done for me.

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CHAPTER ONE: INTRODUCTION

Nature of the Problem

Thomas Friedman's widely-read publication *The World is Flat* (2005) captured the attention of policy makers and educational leaders with his call for a scientifically, mathematically, and technologically literate workforce required to meet the needs of our nation within the global economy (Friedman, 2005, p. 272; National Academy of Engineering & National Research Council, 2002; National Science Board, 2007). Globalization and an information-based society have changed the scale of competition within the US from a local to a global market (Friedman, 2005). Due to the competitive nature of the global market, scientific and technological innovations have become increasingly important to the success of our country and industry (Friedman, 2005; National Science Board, 2007).

To have continued prominence within a technologically advanced world, our nation's educational systems need to produce individuals with the knowledge and skills required to contribute to the 21st century workforce (Friedman, 2005; National Science Board, 2006a). Several national publications, *Science and Engineering Indicators, America's Pressing Challenge – Building a Stronger Foundation,* and *Rising Above the Gathering Storm* have supported the need for improved science, technology, engineering and mathematics (STEM) education and teacher quality in hopes of increasing global competitiveness (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2006; National Science Board, 2006a, 2006b, 2007). In response to the demand for an educated workforce, the National Science Board published recommendations to ensure all students graduate with the STEM knowledge and skills required to maintain future success (2007). Five years after its initial publication, The National Academies reassessed the nation's competitive position and the implementation of the National Science Board's recommendations. *Rising Above the Gathering Storm*, *Revisited* found America's ability to compete had grown worse and the educational system showed minimal improvement particularly within math and science (National Academy of Sciences, National Academy of Engineering & Institute of Medicine, 2010).

The growth in awareness from these publications and external pressures from economic competition, many national organizations have increased their demand for improved STEM educational reform for all students (Bybee, 2010; Friedman, 2005; Keller & Pearson, 2012; National Academy of Engineering & National Research Council, 2009; National Research Council, 2011; National Science Board, 2007). The National Academy of Engineering & National Research Council, within *Engineering in K-12 Education*, suggested the traditional separated or "silo" teaching structures of the STEM education disciplines, does not reflect the connectedness of the real-world and has restrained efforts to improve students' performance within science and mathematics (2009, p. 12). Integrative knowledge and skills appear across disciplines, are useful in everyday life, and could improve student performance at all levels (National Academy of Engineering & National Research Council, 2009). Increasing the emphasis on the interconnections between the STEM education disciplines could be important to the development of a scientifically and technologically literate citizenry. The goal of the National Academy of Engineering & National Research Council is to have all students within the United States graduate STEM literate. STEM literacy implies that a person is prepared with sufficient science, mathematics and technology knowledge and skills required to function in a technological society, the workforce, and higher education (Ibid).

Keller & Pearson explained, as students embark on the world beyond K-12 education, the partitions between disciplines begin to collapse, and the need to work in collaboration with other fields becomes the precedent (2012). Regardless of their chosen careers, the future of our nation's students will be stronger if they are able to use and transcend the STEM education disciplines (Keller & Pearson, 2012). The American Association for the Advancement of Science (AAAS) advocated that the connections between science, mathematics, and technology are so close it would be almost impossible to teach one successfully without the others (1993). Many empirical studies have demonstrated that students are successful when integrative pedagogical approaches are implemented (Benenson, 2001; Doppelt et. al, 2008; Fortus et. al., 2004; Fortus et. al., 2005; Hartzler, 2000; Hmelo et al., 2000; Silk et al., 2009; Vars, 1991).

Four national education publications, *Science for All Americans* (AAAS, 1989), *Benchmarks for Science Literacy* (AAAS, 1993), the *National Science Education Standards* (National Research Council, 1996), and the *Standards for Technological Literacy* (International Technology Educators Association, 2000), included standards that emphasized the connections and integration between science, technology and engineering. The reason for emphasizing the links between these disciplines is clearly stated within the *National Science Education Standards*, "…the relationship between science and technology is so close that any presentation of science without developing an understanding of technology would portray an inaccurate picture of science" (National Research Council, 1996, p. 190). The unifying theme throughout all of these documents has been that the STEM education disciplines are closely aligned, students' future achievement relies on their ability to transcend the disciplines, and our nations' success relies on an integrative STEM literate workforce.

The next generation of science standards further encourages integrative practices (National Research Council, 2012). The focus of the *Framework for K-12 Science Education* was to develop students' understanding of core ideas and crosscutting concepts through student participation within science and engineering practices (National Research Council, 2011, p. 1-2). This framework and the 2009 Science National Assessment of Educational Progress (NAEP) framework both included “Using Technological Design” as a science practice (National Research Council, 2011; NAGB, 2009). The technological design-based pedagogical approach to instruction offers a disciplinary bridge to teach integrative STEM education concepts and connections (Wells, in press, p.20). In its most simplified form the technological/engineering design process entails asking questions, imagining possibilities, planning a solution, creating it, and developing improvements (Museum Of Science, 2012).

The cyclical and iterative nature of the design process enables students to refine their understanding to improve their solution (Kolodner, 2002; Puntambekar & Kolodner, 2005). The process of refining one’s conceptions solicits a series of cognitive monitoring strategies, which include questioning, predicting, clarifying, and summarizing (Brown, 1992). Throughout the design process students are also confronted with cognitive demands and must be able to demonstrate their ability to use declarative knowledge (knowing that), procedural knowledge (knowing how), schematic knowledge (knowing why) and strategic knowledge (knowing when and where) (NAGB, 2009; Wells, 2010). These cognitive functions encourage students’ active construction and meaning making, which makes the technological design-based approach to learning valuable (Barlex & Trebell, 2008).

Many experts agree that the technological/engineering design process is a potentially effective method of instruction (Barlex & Trebell, 2008; Cajas, 2001; Hmelo, Holton, & Kolodner, 2000; Puntambekar & Kolodner, 2005). Key researchers within technology education have recognized the lack of empirical evidence to support the benefits of the technological design-based instructional approach (Zuga, 1994, 1997; Petrina, 1998; Lewis, 1999). In Zuga’s

(1994) review and synthesis of the research literature within the field, she suggested seven specific areas in need of further research. Two of these areas were to "explore and demonstrate the inherent value of technology education" and to "research cognition and conceptual attainment with respect to technology education" (Zuga, 1994, p. 67). In 2001, Zuga attempted to address the lack of coherent research on cognition and technology education. She concluded:

> "Yet to be determined and supported by research evidence are the following: technological literacy, problem solving as the technological method, technology as a discipline, and other "truths" that seem to be held by the technology education community. Still technology educators carry on with recommendations that would make one think that technological literacy, problem solving as the technological method, and technology as a discipline are universally accepted concepts outside of the field of technology education with research backing" (Zuga, 2001, p. 2-3)

Zuga's principle argument is the field of technology education needs to provide evidence to demonstrate the benefits of its practices (Zuga, 1994, 1997, 2001).

One way to address this concern is through rigorous empirically based research on the technological design-based pedagogical approach within the context of integrative STEM education. In 2006, Lewis proposed an accommodation between science and technology education. He believed the parallels between design and inquiry provided a natural link between the subject areas, and the classroom was a practical place to study the connections of science and technology within society (Lewis, 2006). With the arrival of the standards movement and the mantra of "literacy for all", he advocated design-based learning would be a more motivating method for teaching all students about science and for introducing them to science careers (Ibid). Lewis recommended that with the union of science and technology, research would be required to answer questions regarding student learning of key concepts using design-based approaches (2006, p. 276).

Rationale for the Study

Given the research recommendations suggested by Zuga (1994, 1997, 2001), Petrina (1998) and Lewis (1999, 2006), technology education needs to demonstrate that the technological design-based approach to instruction is beneficial to students' cognitive abilities. There is growing support that the technological design pedagogy has the potential for addressing cognitive growth (Kolodner, 2002; NAGB, 2009; Wells, 2010). The goal of this study was to address this research need by providing evidence of the connections between technological design and higher-order cognitive growth in student learners.

Purpose of the Study

One way to achieve this goal is by demonstrating that the technological design-based approach to instruction enhances students' cognitive structure of science and technology concepts. Biotechnology, as included within Standard 15 of the *Standards for Technological Literacy*, is a content area that specifically and directly addresses both science and technology concepts (ITEA/ITEEA, 2000, 2002, 2006). In 1998, Wells first published his *Design-based Biotechnology Literacy Teaching Guide* for inclusion within secondary technology education classrooms. This curriculum contained design-based biotechnology literacy content and Problem Scenarios intentionally designed to teach content and practices from both, science and technology disciplines (Wells, 1998). The purpose of this study was to demonstrate that the technological design-based approach to teaching biotechnology literacy develops students' cognitive connections of science and technology concepts. To document these connections, the researcher collected data to answer the following research questions.

Research Questions

The following research questions and sub-questions were the basis for this study:

1. To what extent does the technological design-based approach to teaching biotechnology content result in changes to high school students' cognitive structure, specifically their documented representations of…
    a. biology concepts and connections?
    b. technology concepts and connections?
    c. the connections between biology and technology concepts?
2. In what ways does student documentation of cognitive structure demonstrate their use of strategic knowledge (when, where, and how) while engaged in a Design-Based Biotechnology Literacy Problem Scenario?

Limitations

The limitations of this study included a teacher-researcher perspective, time constraints, sample size, and transferability. Time was a limitation, as the biotechnology course of study lasted only 20-weeks. Previous research suggests that it takes time (possibly up to two years) for students to learn how to be reflexive and articulate their understanding (Novak, 1990). This study contained a small homogeneous sample size (refer to Table 1 within Chapter 3 for demographic information). The researcher had no control over this factor, as the study was limited to the students who chose to enroll within the course. Additionally, this study addressed the learning of students within one particular high school biotechnology course. Therefore, the findings of this study may not apply directly to other courses, as purposive convenience sampling yields a poor rationale and low credibility (Patton, 1990). Due to these limiting factors, the author will not infer any generalizations or transferability from this study.

Operational Definitions

Biotechnology

"Any technique that uses living organisms (or parts of organisms) to make or modify products, improve plants or animals, or to develop micro-organisms for specific uses" (OTA, 1984, 1988, 1991; FCCSET, 1992, 1993; Wells 1992, 1994, 1995, 1998, 1999, 2008; ITEA/ITEEA, 2000, 2002, 2006).

Cognitive demands

Cognitive demands are the four hierarchical levels within a cognitive domain and include declarative, procedural, schematic, and strategic knowledge.

Cognitive domain

A subject domain or central concept from which the learner constructs their understanding, within this study the cognitive domains of focus are "technology" and "biology."

Cognitive structure

Cognitive structure is humans' innate and idiosyncratic mental organizations of information (Ruiz-Primo & Shavelson, 1996). Within an individual's cognitive structure, there are infinite subject domains or central concepts from which the learner constructs their understanding. In its simplest form, cognitive structure consists of concepts and connections.

Declarative knowledge

Declarative knowledge is the most basic. It includes the knowledge of facts and concepts, and reflects an individual's knowledge of "that" (NAGB, 2009; Shavelson et al., 2005).

Design

"An iterative decision-making process that produces plans by which resources are converted into products or systems that meet human needs and wants or solve problems" (ITEA/ITEEA, 2000, 2002, 2006, p. 237).

Integrative Concept

A concept that overlaps the content and practices of science and/or mathematics concurrently with content and practices of technology and/or engineering (i.e., phytoremediation is an integrative concept)

Integrative Meaning Making

A correct connection to an integrative concept, or correct linking line between at least one biology concept and at least one technology concept.

Integrative STEM education

"the application of technological/engineering design based pedagogical approaches to *intentionally* teach content and practices of science and mathematics education concurrently with content and practices of technology/engineering education. Integrative STEM education is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels" (Wells & Ernst, 2012, para. 2).

Meaning Making

Two concepts connected by a linking line make up the most basic unit of meaning.

Procedural knowledge

Procedural knowledge or knowing "how" reflects an individual's knowledge of processes (NAGB, 2009; Shavelson et al., 2005).

Schematic knowledge

Schematic knowledge consists of knowing “why” or the reasoning and relationships between concepts (NAGB, 2009; Shavelson et al., 2005).

S.T.E.M. (separated)

“Each subject is taught separately with the hope that the synthesis of disciplinary knowledge will be applied. This may be referred to as STEM being taught as ‘silos’” (Dugger, 2010, “STEM: Integrated or Separated,” slide 16).

STEM

“…is the integration of science, technology, engineering, and mathematics into a new trans-disciplinary subject in schools” (Dugger, 2010, “What is STEM Education,” slide 5).

Strategic knowledge

An individuals understanding of “when, where and how” to apply their knowledge is considered strategic (NAGB, 2009; Shavelson et al., 2005).

Technological literacy

“The ability to use, manage, assess, and understand technology” (ITEA/ITEEA, 2000, 2002, 2006, p.9).

Technology education

“A school subject specifically designed to help students develop technological literacy” (ITEA/ITEEA, 2000, 2002, 2006, p. 142).

Technological/Engineering design process

“A systematic problem-solving strategy, with criteria and constraints, used to develop many possible solutions to solve a problem or satisfy human needs and wants and to winnow (narrow) down the possible solutions to one final choice” (ITEA/ITEEA, 2000, 2002, 2006, p. 237).

CHAPTER TWO: LITERATURE REVIEW

In preparation for the development of the research design, the author reviewed the related literature concerning the research questions for this study. Several key topics emerged from this analysis including a foundation for integrative STEM education, the design-based pedagogical approach to instruction, cognitive structure and demands, and the theoretical framework. These key topics generated the sections contained within this chapter. The pertinent information presented within each section establishes the justification for the selected research design.

The first section focuses on the foundation of STEM education, its many definitions, the perspectives of each individual discipline, and the significance of integrative STEM education. Section two introduces the foundation for design within learning theory, the technological/engineering design process, integrative design-based instructional approaches, and design-based biotechnology. The third section emphasizes the role of cognitive structure and demands within teaching and learning. The fourth and final section, examines Ausubel's theory of meaningful learning as it relates to Novak's realization of an advanced organizer called concept mapping. The subsection on concept mapping diverges into concept mapping as an assessment tool and the methods for analysis.

Foundations for Integrative STEM Education

As discussed in Chapter One, many state and national organizations have called for the integration of the STEM education disciplines. What exactly is integrative STEM Education? To understand integrative STEM Education, it is best to understand each component independently first. According to a presentation given by Dugger (2010), separated S.T.E.M. refers to "each subject [being] taught separately with the hope that the synthesis of disciplinary knowledge will be applied. This may be referred to as STEM being taught as 'silos'" ("STEM:

Integrated or Separated," slide 16). In this regard, S.T.E.M. education is no different then the traditional disconnected approaches to instruction; it is simply a new acronym to support a shift in emphasis to science, technology, engineering, and mathematics. Each of these disciplines promotes a unique perspective, distinct educational goals and instructional approaches.

Science Education

In its broadest sense, science strives to understand the natural world (National Research Council, 1996). The foundation of science promotes the idea there is a natural order to the universe, and by using systematic observations and investigations, scientists can derive patterns and develop theories to explain phenomena (AAAS, 1993). Scientists presume there to be no absolute truth, but by using scientific inquiry, they are able to gain insights into how the world functions. Scientific inquiry can take on a variety of forms, meaning there is no direct path or set of steps to reach scientific knowledge. Generally, inquiry includes the use of evidence, logic, hypotheses, theories, experimentations, and investigations.

Because science inquiry is central to the study of science and scientific investigation, many believe inquiry should be the fundamental instructional approach within science education (AAAS, 1993; National Research Council, 1996). Although there have been many iterations of the K-12 science content standards since their inception, all of the fundamental science education documents promote scientific literacy for all students (AAAS, 1993; National Research Council, 1996; National Research Council, 2011). Scientific literacy, "is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (National Research Council, 1996, p. 22). The *Framework for K-12 Science Education* has slightly altered this definition to include science practices (National Research Council, 2011). As the field continues to evolve, the focus and definition of scientific literacy may continue to change, but the emphasis on scientific literacy will likely remain a key component of K-12 science education in the foreseeable future.

Technology Education

The definition of technology includes "the innovation, change, or modification of the natural environment to satisfy perceived human needs and wants" (ITEA/ITEEA, 2000, 2002, 2006, p. 242). When compared to the natural world of science, technology includes the man-made world (Dugger, 2010; ITEA/ITEEA, 2000, 2002, 2006). Technology has been changing at an exponential rate, making it increasingly important to understand the positive and negative effects that technology can have on social and economic structures (DeVore, 1980). As technology continues to expand, there is a widening knowledge gap between the creators of technology and the average citizen (ITEA/ITEEA, 1996). Studies have shown that US citizens are interested in but extremely undereducated in modern technology (Rose & Dugger, 2002; Rose, Gallup, Dugger & Starkweather, 2004; National Academy of Engineering & National Research Council, 2002).

Due to our ever changing and technological world, technological literacy for all is crucial (ITEA/ITEEA, 2000, 2002, 2006). Through K-12 general education there is an opportunity for all students to learn about technology (DeVore, 1987; National Academy of Engineering & National Research Council, 2002). At the national level, the *Standards for Technological Literacy* advocate for student understanding of core technological concepts and active student learning through engagement within the technological design process (ITEA/ITEEA, 2000, 2002, 2006). Technological Literacy is a person's ability to "use, manage, assess, and understand technology" (ITEA/ITEEA, 2000, 2002, 2006, p. 7). The National Research Council and National Academy of Engineering within *Technically Speaking* described the need for a citizenry to have adequate technology knowledge, ways of thinking and acting, and capabilities to be technologically literate (2002). To remain competitive in the global market moving forward, the importance of having an informed and educated technological citizenry will likely continue to escalate (Friedman, 2005; National Science Board, 2006a, 2007). Consequently, this will produce a greater demand for technology education within schools.

Engineering Education

The National Academy of Engineering & National Research Council (2009), recognized engineering simply as, “the process of designing the human-made world” (p. 27). The Oxford University Press (OUP) (2012a) considers, the noun, engineering as “the branch of science and technology concerned with the development and modification of engines, machines, structures, or other complicated systems and processes… the profession of an engineer.” For the purposes of this paper, the definition of engineering will comprise a profession focused on the designing of inventions and innovations. The OUP recognized that modern uses of engineering include many distinguishing categories or branches including chemical, civil, electrical, mechanical, and military, among other smaller branches. (2012a).

The American Society for Engineering Education (ASEE) is dedicated to furthering engineering and engineering technology education (ASEE, 2011). The founding of ASEE occurred in 1893, and they currently recognize over 40 divisions (ASEE, 2011). It was not until 2004 that ASEE developed a K-12 and Pre-College Engineering division (Ibid). Hence, K-12 engineering education within the US is in its infancy, and its inclusion within classrooms has been modest, at best (National Academy of Engineering & National Research Council, 2009).

Many believe engineering education should be included in K-12 general education for all students (Bybee, 2010; ITEA/ITEEA, 2000, 2002, 2006).

Similar to technology education, engineer promotes design as a central activity to engineering practice (National Academy of Engineering & National Research Council, 2009). Technology education and its corresponding K-12 curricula incorporate the technological/engineering design process and many overarching engineering concepts (ITEA/ITEEA, 2000, 2002, 2006). Therefore, logic dictates that technology education should be a lead discipline to teach it. In 2010, the International Technology Education Association changed its name to the International Technology and Engineering Educators Association to broaden its scope to become more inclusive of K-12 engineering education.

Mathematics Education

The OUP recognized Mathematics as “the science of space, number, quantity, and arrangement, whose methods involve logical reasoning and usually the use of symbolic notation” (OUP, 2012b). Mathematics includes arithmetic, algebra, geometry, calculus, and analysis to complete mathematical operations and calculations (OUP, 2012b). Mathematics is everywhere, and the need to understand and apply mathematics in everyday life, in other disciplines, and in the workplace to analyze data in an attempt to understand possible relationships between abstractions is of growing significance (NCTM, 2000; Wilkins, 2000).

Students are falling short of quantitative literacy. Wilkins defined quantitative literacy “in terms of mathematical content knowledge, mathematical reasoning, understanding of the social impact and utility of mathematics, understanding the nature and historical development of mathematics, and mathematical disposition” (2000, p. 405). To be quantitatively literate, students need to solve mathematical problems successfully in practical situations they are likely to face in everyday life or a future career (Wilkins, 2000, p. 406; see also NCTM, 2000). By teaching in meaningful ways and placing problems within a practical context, mathematics education can offer opportunities for all students to use diverse strategies, develop their mathematical reasoning, and practice their computational skills (NCTM, 2000).

Integrative STEM Education

The National Academy of Engineering & National Research Council (2009) suggested that the silo teaching of disciplines has been the underlying cause of poor student performance in math and science in the US. The *Benchmarks for Science Literacy* and *Engineering in K-12 Education* suggest the integration of the STEM education disciplines could improve student performance and literacy in all areas (AAAS, 1993; National Academy of Engineering & National Research Council, 2009). Dugger defined STEM education as “the integration of science, technology, engineering, and mathematics into a new trans-disciplinary subject in schools” (2010, “What is STEM Education,” slide 5). In its simplest form, STEM education is about making connections between disciplines. The more connections students’ make, the more they understand (Drake & Burns, 2004).

Instructional methods like critical thinking and problem solving provide occasions for students to see the connections and differences between the disciplines (Huber & Hutchings, 2004). According to Huber and Hutchings (2004), a key to fostering integrative learning is creating self-awareness in the students by making learning more intentional (p. 6). Intentional teaching and learning supports the development of cognitive connections required for integration, and as a result, learning becomes a goal instead of an ancillary effect (Huber & Hutchings, 2004).

The development of integrative connections to intentionally build student understanding is consistent with cognitive science, information processing theory, and psychological constructivism. Informational processing theorists contend that the construction of knowledge occurs internally within a learner's brain (Schunk, 2004). As learners seek out knowledge, the human senses collect perceived information within the sensory memory (Schunk, 2004). If the information is of interest to the individual then, the brain will retrieve prior knowledge from the long-term memory into the individuals working memory (Ibid). Once the development of meaningful connections occurs between the new information and the individual's prior knowledge, the new knowledge may be stored back within the long-term memory (Ibid). All knowledge construction occurs within the schemata of the brain from this basic building block. Psychological constructivism also referred to as cognitive, individual or traditional constructivism, contends that the individual is the sole constructor of his/her learning, which aligns with cognitive science and how the brain processes information (Bransford, Brown & Cocking, 1999). Psychological constructivists believe that due to the nature of each individual's schemata, no two individuals understand the world in the same way because each person has developed their own unique connections (Phillips, 2000). In reality, there are many natural connections between the disciplines (AAAS, 1993). It is the responsibility of education to figure out how to intentionally teach those links through integrative STEM education.

There are different methods and levels of association between integrative teaching approaches. Drake and Burns (2004) delineated three primary levels (multi-, inter-, and trans-) of disciplinary instruction based on the extent of separation between the disciplines. Multidisciplinary approaches to instruction maintain the disciplinary boundaries, and educators incorporate concepts from other disciplines into the curriculum (Drake & Burns, 2004). Fusion, service learning projects, and theme-based units are all examples of multidisciplinary teaching strategies. Interdisciplinary is the next level of integration, at this level teachers collaborate to ensure common concepts are being taught across the disciplines (Ibid). This should not to be confused with intradisciplinary approaches, where the emphasis is on the connections between the sub-disciplines within a single subject area (Ibid). Two interdisciplinary approaches include learning centers and team teaching across parallel disciplines. Within the transdisciplinary approach, a local problem or student-developed questions negotiate the curriculum (Ibid). Drake & Burns consistently found that the integration of content across disciplines was highly correlated with student success; they found it was effective with all learners, and promotes better understanding of connections between concepts and skills (Ibid). Many other research studies have come to similar conclusions on student success when participating within integrative education (Benenson, 2001; Doppelt et. al, 2008; Fortus et. al., 2004; Fortus et. al., 2005; Hartzler, 2000; Hmelo et al., 2000; Silk et al., 2009; Vars, 1991).

As the evidence presented has demonstrated, there is support for integrative STEM education as a method for increasing student connections, literacy, and success. As the demand for a scientifically, technologically, and mathematically literate society grows, so does our dependence on modern advancements (National Academy of Engineering & National Research Council, 2002). Inventions and innovations shape modern life, yet the technology and engineering within these advancements has become invisible to the average citizen (National Academy of Engineering & National Research Council, 2002). One known barrier is the lack of a national mandate for students to learn about technology and engineering within K-12 education (ITEA/ITEEA, 2000, 2002, 2006). Even with the growing national support for STEM education, technology and engineering still lack the visibility and presence required to attain societal demands (Bybee, 2010). The increased visibility of technology and engineering is important to the success of STEM education (National Academy of Engineering & National Research Council, 2009).

For the purposes of this study, the researcher will use the definition for Integrative STEM Education developed by Wells & Ernst (2012):

> "the application of technological/engineering design based pedagogical approaches to *intentionally* teach content and practices of science and mathematics education concurrently with content and practices of technology/engineering education. Integrative STEM education is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels" (para. 2).

Within this definition technology, engineering, and design take on central roles. The status quo of the silo disciplines or the combinations of science and mathematics alone will no longer suffice as STEM education. As the increased emphasis on technology and engineering is important to the success of students and STEM education (National Academy of Engineering & National Research Council, 2009), and the Wells & Ernst definition ensures the T and the E in STEM maintains a strong presence.

National organizations and researchers have demonstrated their support for the implementation of integrative STEM education. However, the future of integrative STEM education relies on teachers' abilities to implement these instructional practices within their K-12 classrooms. Kennedy (1997) demonstrated the long history of disconnections between research and practice. She determined that all of the reasons for this incongruity could be broken down into four hypotheses:

> "…(a) research needs to be more authoritative, (b) research need to be more relevant, (c) research needs to be more accessible, and (d) the education system itself is inherently too stable or too unstable and therefore unable to respond coherently to research findings" (Kennedy, 1997, p. 4).

These hypotheses offer a general explanation for a teachers' hesitation to implement research findings. A more specific reasoning in the context of integrative STEM education is teachers' lack of content knowledge in more than one discipline. Shulman (1986) proposed there were three different types of teacher content knowledge: subject matter content knowledge, pedagogical content knowledge, and curricular knowledge. In some circumstances, a talented teacher can learn the subject matter content and curricular knowledge required to teach a particular subject but pedagogical content knowledge can take years, if not decades to achieve. Pedagogical content knowledge entails an individual's subject matter knowledge for teaching (Shulman, 1986, 2005, p. 9). Most teachers are not prepared with the content knowledge and pedagogical content knowledge needed to teach multiple disciplines concurrently (Wells, 2008).

The Design-Based Pedagogical Approach to Instruction

A central pedagogy within technology and engineering education is the technological/engineering design-based approach to teaching. As emphasized within the Wells & Ernst (2012, para. 2) definition, the technological/engineering design-based learning approach should be the method by which the content and practices of the STEM education disciplines are integrated. A review of the literature on the design-based pedagogical approach to instruction resulted in four sub-sections. The first sub-section presents the related learning theories as a foundation for using design within education. The implementation of design in K-12 education utilizes the technological/engineering design process. Sub-section two, includes the technological/engineering design process model used within this study. A summary of the integrative design-based instructional approaches utilized in previous studies appears in sub-section three. The final sub-section culminates with the pedagogical instructional approach selected for this study, Design-based Biotechnology.

Foundation for Design within Learning Theory

"…with the advent of democracy and modern industrial conditions,
it is impossible to foretell definitely just what civilization will be twenty years from now.
Hence it is impossible to prepare the child for any precise set of conditions."
~ John Dewey, 1897, *My Pedagogic Creed*

This statement by John Dewey justifies the need within education to focus less on the rote learning of facts and more on the problem solving processes that will help students adapt to the challenges of later life. The ITEA/ITEEA (2000, 2002, 2006) regards design as "an iterative process that produces plans by which resources are converted into products or systems that meet human needs and wants or solve problems" (p. 237). Design leads to the development of an invention or innovation through the solution of an ill-defined problem. Ill-defined problems are also known as ill-structured or open-ended, meaning there is no single correct or best answer (Eysenck & Keane, 1990). Instead, there are infinite answers or ways to solve any given problem. Most problems we encounter in life are ill-defined (Ormrod, 2004). The process of designing is unique to each creator and has no prescribed path from the formation of the problem to the completed design (Fortus et al., 2004).

Teaching through design promotes student discovery using novel solutions, integration of subject area knowledge, active construction of understanding, metacognition, and reflexivity. The cyclical and iterative nature of the design process enables students to refine their understanding of a problem to improve their solution (Kolodner, 2002; Puntambekar & Kolodner, 2005). It is this repetitive method of meaning making which requires students to reflect on their existing knowledge in all subject areas in order to construct new knowledge (Barlex & Trebell, 2008). Discovery learning, metacognition, and the constructivist theory of instruction support this method of cognitive development (Tobias & Duffy, 2009).

Discovery learning “is considered an active instructional method because the learner is behaviorally active during the learning process. The intended learning outcome of discovery learning methods is deep learning, as indicated by the ability to use the learned material in new situations” (Mayer, 2009, p. 190). To extend the idea of student constructed knowledge, Roth explained that by using technological design methods it provides students the opportunity to discuss concrete examples, externalize their ideas, and promotes discussion (Roth, 2001). In addition, with physical representations, students are able to use gestures and communicate their interpretations of abstract interdisciplinary concepts in a concrete form (Roth, 2001). Together, these factors make the technological/engineering design process a valuable pedagogical instructional approach (National Academy of Engineering & National Research Council, 2009).

The technological/engineering design process also contains comprehension-monitoring devices that enhance students’ metacognitive abilities. Metacognition is the monitoring of one’s own memory, comprehension, and other cognitive activities (Flavell, 1979, p. 906). Metacognition can be a conscious or unconscious activity. Conscious metacognition can be highly effective as it encourages the learner to reflect constantly on what they know to make connections to new knowledge. Many scholars believe unconscious metacognition occurs frequently and naturally (Flavell, 1979). Making abstract processes, like designing, visible to the learner is necessary for conscious metacognitive activities to occur (Derry, Tookey, & Roth, 1994). Metacognition can be broken down into many constructs, but only one construct self-regulation, is of focus within this study. “Self-regulation refers to the degree that individuals are metacognitively, motivationally, and behaviorally active participants in their own learning process” (Schunk & Zimmerman, 1994, p. 3). A key aspect of self-regulation is providing control and choices to the learner (Zimmerman, 1995). The technological/engineering design process provides a structure, but leaves complete control over the decision-making to the learner. According to Brown (1992) it is difficult to train learners to plan, monitor, and be attentive of their own knowledge. She suggested four comprehension-monitoring devices to enhance students' metacognitive abilities, which include questioning, clarifying, summarizing, and predicting. All four of these activities are present consistently throughout the steps of the design process.

Although, many theorists support design-based instruction as a component of discovery, metacognition, and constructivist theory, there is substantial controversy in regards to discovery learning. According to Brown (1992), "discovery learning, when successful, has much to recommend it. The motivational benefits of generating knowledge cannot be overestimated, and the sense of ownership that this creates is a powerful reward. Successful discovery learning is clearly a desired feature..." (p. 168). However, the main controversy within discovery learning is the amount of guidance (i.e. scaffolding) required by the teacher for students to reach their maximum learning potential (Tobias & Duffy, 2009). The strength of the design process is its inherent steps offer a natural scaffold for learning. However, the design process alone is not sufficient scaffolding for optimal student learning to occur (Putambekar & Kolodner, 2005). Student success relies on the teacher's ability to implement intentional and multiple opportunities (i.e., guided questioning) to develop connections throughout the design process, so that students will understand the new information. This position challenges the traditional "make and take" activities, where students construct artifacts with no accountability for their understanding.

Raizen, Sellwood, Todd & Vickers (1995) have been credited with establishing technological design as a key concept and pedagogy of Technology Education within the US. Since then the role of design within technology education practice and literacy has grown, as it engages learners in realistic problem-solving scenarios (Cajas, 2001; ITEA/ITEEA, 2000, 2002, 2006). Educators and researchers have found that learning improves when the material is relevant to the students (Benenson, 2001; Drake & Burns, 2004; Fennema, 1992; Herbel-Eisenmann et al., 2006; Mehalik et al., 2008; Seiler, Tobin & Sokolic, 2001). Dewey was a strong advocate for situated curriculum that relates to students, their lives outside of school, and the local community (1929). He believed that when students are given the opportunity to run a business, construct a bridge, or transport water, they would not only learn the science, mathematics, and technology, but they would experience it (Dewey, 1929). This is consistent with Jerome Bruner's opinion that, "only through the exercise of problem solving and the effort of discovery that one learns the working heuristics of discovery… I have never seen anybody improve in the art and technique of inquiry by any means other than engaging in it" (1971, p.94).

There are several methods for making learning material relevant: develop real-world scenarios, use student-centered questions, or create authentic problems (Benenson, 2006; Fennema, 1992; Mehalik et al., 2008; Wilkins, 2000). A real-world scenario gives students a practical application or context in which to develop their understanding. Solving real-world problems in order to understand abstract ideas is a highly integrative opportunity for student learning (Fennema, 1992, p. 154; Wilkins, 2000). It allows them to be more analytical of the real-world issues surrounding them (Benenson, 2001; Mehalik et al., 2008). A student-centered question provides students with an opportunity to be independent by developing their own "why" questions that are important to their daily lives. Research has shown when problems were student-centered design-based learning activities were relevant to all students (Mehalik et al., 2008). Authentic problems are usually career-specific and focus on problems students may face within the working world. These problems enable the students to generalize their understanding, connect it to broader culture, and situate it within multiple contexts (Fennema, 1992).

The Technological/Engineering Design Process

There have been many different versions of the technological/engineering design process published over the years (ITEA/ITEEA, 2000, 2002, 2006). Each version has a unique number of steps, titles, and questions, although the underlying concepts are usually similar. In its most basic form the design process is about asking questions, imagining possibilities, planning a solution, creating it, and developing improvements (MOS, 2012). It is important to emphasize that in practice designers do not follow a prescribed path to reach their final solution. Each designer has a unique process of designing, directed by his or her own creativity and past experiences. The goal of technology and engineering education is not to instruct students on design, but to have students engage in design and to enhance content across the disciplines (Fortus et al., 2004).

Figure 1, depicts a unique version of the technological design process model used throughout this study. The purpose of this model was to intentionally teach high school students enrolled within technology education courses about the technological design process. This technological design process model contains eight key steps. These steps include frame the problem, conduct research, develop possible solutions, select a solution, construct the solution, test the solution, redesign for improvements, and reflect and communicate. Although there is an order to the steps within the diagram, the process of designing is cyclical and iterative.

There are many positive benefits to using the technological/engineering design process as a method for instruction. Problem solving and design are integral to technology and engineering practice (National Academy of Engineering & National Research Council, 2002). To be technologically literate students need to learn about these concepts in school. The combination of design-based instruction and integrative curricula has the potential to be a strong learning tool for students (ITEA/ITEEA, 2000, 2002, 2006). It would require students to be both “hands-on” and “minds-on” to connect their knowledge in a more meaningful way (Johnson, 1989).

Figure 1. The Technological Design Process

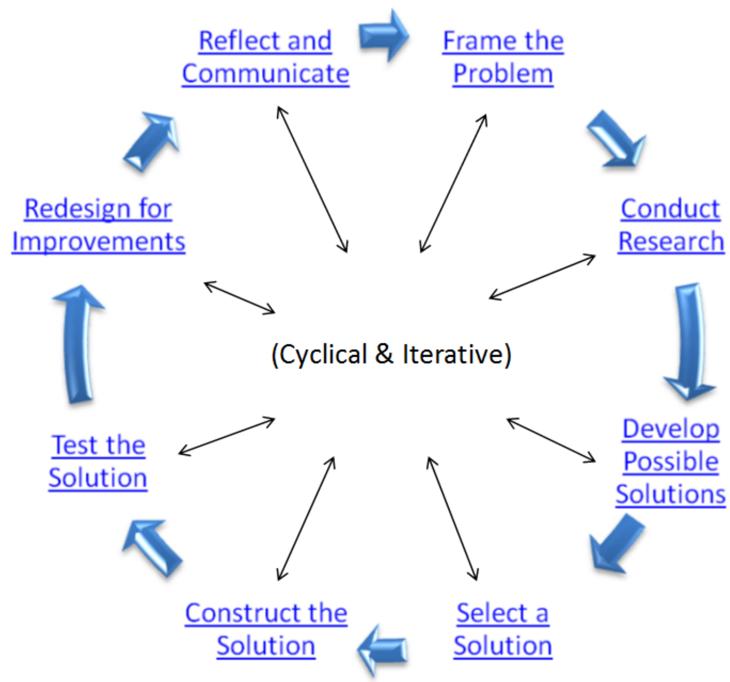


Figure 1. Technological design process model used to teach high school technology education students. Adapted from “The Design Process”, by K. L. Schurr, 2011, presented at the Texas STEM Initiative, San Antonio, Texas, slide 2. Copyright 2011 by Kelly L. Schurr.

Integrative Design-Based Instructional Approaches

A key component of the Wells & Ernst definition for integrative STEM education requires the application of the technological/engineering design based pedagogical approach to integrate the STEM education disciplines (2012). It is the cyclical nature of design, which metacognitively challenges students to confront their understanding and misunderstandings of the content (Puntambekar & Kolodner, 2005). The ultimate goal of integrative learning is to have students understand the connections across all disciplines (not exclusively science, technology, engineering, and mathematics) as a means of reaching literacy (Cajas, 2001).

In the last decade, research on the integration between science, engineering, and technology using design-based pedagogies has become more common (Doppelt, Mehalik, Schunn, Silk & Krysinski, 2008; Fortus, 2004; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005; Ginns, Norton & Mcrobbie, 2005; Hmelo, Holton & Kolodner, 2000; Mehalik et al., 2008; Norton, 2007; Puntambekar & Kolodner, 2005; Silk, Schunn, & Cary, 2009). There are at least three main researchers leading integrative design-based instructional studies with a focus on content in science, engineering, and technology. The first researcher, David Fortus conducts studies at the University of Michigan focused on design-based science. "[Design-Based Science] DBS aims to help students construct scientific understanding and real-world problem-solving skills by engaging them in the design of artifacts" (Fortus et al., 2004, p. 1082). His studies have primarily centered on high school student populations and bringing technological design into the science classroom (Fortus et al., 2004; Fortus et al., 2005). Janet Kolodner is the second researcher located at the Georgia Institute of Technology, where she has developed and studied a curriculum entitled Learning By Design (LBD). The focus of LBD "has been to help middle school students (grades 6 to 8; ages 12 to 14) learn science content in such a way that they can apply it in new situations and engage skillfully in the practices of scientists" (Kolodner, 2002, para. 3). The third set of research titled Design-based Learning (DBL) occurs at the University of Pittsburgh with middle and high school students under the direction of Christian Schunn. "DBL is a form of project-based learning…These units use engineering design processes as a foundational structure for the units–this structure improves the design outcomes and provides an organization of the math/science learning that happens inside the classroom" (Schunn, 2010, para. 1).

The focus for each of these researchers is slightly different. The commonality across all of their studies is the use of technological/engineer design-based instructional approaches as a means to engage students in the design of artifacts as a way to construct scientific and technological content knowledge within real-world scenarios. Creating a physical artifact provides a natural environment for students to confront their knowledge of science concepts by situating them within novel scenarios (Puntambekar & Kolodner, 2005). Since technology does not exist in a majority of schools nationally (ITEA/ITEEA, 2000, 2002, 2006, p. 2), the science curriculum could offer an opportunity for students to learn about content in science, technology, design, engineering, and the interrelationships between them. An alignment of science and technology could provide the additional support required, to establish the role of technology within general education and the core disciplines (Cajas, 2001).

Design-Based Biotechnology

A content area that naturally addresses topics within the disciplines of science and technology and lends itself to integration exists in the *Standards for Technological Literacy.* Within the designed world, standard 15 includes the use of agricultural and related biotechnologies (ITEA/ITEEA, 2000, 2002, 2006). In 1998, Wells first published his *Design-based Biotechnology Literacy Teaching Guide* for inclusion within secondary technology education classrooms. This curriculum contains Design-Based Biotechnology Literacy Problem Scenarios that intentionally incorporate concepts from science and technology content (Wells, 1998).

Biotechnology is defined as "any technique that uses living organisms (or parts of an organism) to make or modify products, improve plants or animals, or to develop micro-organisms for specific uses" (Office of Technology Assessment, 1984; Federal Coordinating Council for Science, Engineering and Technology, 1992; Wells, 1992; ITEA/ITEEA, 1996). In 1994, Wells conducted a research study, which sought to determine key knowledge areas to serve as content organizers within a Biotechnology curriculum geared towards implementation within technology education. The eight content organizers included foundations of biotechnology, environment, agriculture, bioprocessing, genetic engineering, biochemistry, medicine, and bioethics (Wells, 1994). These content organizers became the units within Wells' *Biotechnology Literacy Teaching Guide* for inclusion within secondary technology education classrooms (1998). The guide contained design-based instructional Problem Scenarios structured around the eight content organizers found within the 1994 study. The units used within the Biotechnology course of study were derived from the *Biotechnology Literacy Teaching Guide* (1998).

Cognitive Structure and Demands

A central tenet of education is to increase student understanding. There are many researchers that believe the technological/engineering design-based pedagogical approach to instruction is an effective method for increasing student understanding (Barlex & Trebell, 2008; Cajas, 2001; Hmelo, Holton, & Kolodner, 2000; Puntambekar & Kolodner, 2005). On the contrary, several researchers within technology education have acknowledged the lack of empirical evidence to support such a claim (Zuga, 1994, 1997; Petrina, 1998; Lewis, 1999). In theory, there is some support to suggest that the technological design-based pedagogy has the potential for addressing growth in cognitive structure (Kolodner, 2002; NAGB, 2009; Wells, 2010), but further research in this area needs to be conducted. The purpose of this section is to discuss cognitive structure, the levels of cognitive demand, and the importance of assessing students' schematic and strategic knowledge within the design-based pedagogical approach to instruction.

Cognitive structure is humans' innate and idiosyncratic mental organizations of information (Ruiz-Primo & Shavelson, 1996). Cognitive psychologists suggest that learning occurs as cognitive structure grows due to the acquisition of knowledge (Schunk, 2004). An individual's prior knowledge is the principle determinant of what and how new information will be constructed (Ausubel, 1968). Within an individual's cognitive structure, there are infinite subject domains or central concepts from which the learner constructs their understanding. Shavelson, Ruiz-Primo & Wiley (2005) contend that a subject domain contains a structure and an extent that knowledge is learned. The extent of an individual's subject domain (i.e. science) knowledge is associated with how well they understand the concepts and connections within that domain (Ruiz-Primo, Schultz, Li & Shavelson, 2001). More simply, the extent of a person's knowledge relates to the depth and complexity of their understanding.

Experts tend to have well-structured concepts and extensive connections, while novices understand fewer concepts and may possess misconceptions (Shavelson et al., 2005). Research conducted within the cognitive domain of science has shown that professionals possess complex, and highly integrative knowledge structures (Mintzes, Wandersee & Novak, 1997; Shavelson et al., 2005). Researchers have determined that through experience, learning and training knowledge frameworks grow as does the interconnections between them (Chi, Glaser & Farr 1988; Ruiz-Primo & Shavelson, 1996). Therefore, novices usually have a much smaller knowledge structure within a domain and fewer points from which to connect their understanding (Chi, Glaser & Farr, 1988; Shavelson et al., 2005).

There are four hierarchical levels of cognitive demands within a cognitive domain: declarative, procedural, schematic and strategic. Declarative knowledge is the most basic. It includes the knowledge of facts and concepts, and reflects an individual's knowledge of "that" (NAGB, 2009; Shavelson et al., 2005). Procedural knowledge or knowing "how" reflects an individual's knowledge of processes (NAGB, 2009; Shavelson et al., 2005). Schematic knowledge consists of knowing "why" or the reasoning and relationships between concepts (NAGB, 2009; Shavelson et al., 2005). Finally, an individuals understanding of "when, where and how" to apply their knowledge is considered strategic (NAGB, 2009; Shavelson et al., 2005).

Educational expectations are growing and require that students reach beyond the basics of declarative and procedural knowledge demands to an understanding of how, when and why to apply their knowledge within a global context (NAGB, 2009). Schematic and strategic knowledge requires higher-order thinking operations. The cognitive demands provide a method for assessing student knowledge growth on a continuum from declarative to strategic (Wells, 2010). As an individual's cognitive structure changes to include more concepts and connections, it reflects a growth in their understanding. This demonstrates learning at the schematic knowledge level. By documenting students' cognitive structural changes while they are engaged in the technological design-based approach to instruction, it would provide evidence of their use of schematic knowledge.

According to the National Assessment Governing Board (2009), the use of technological design as a science practice fosters the use of students' schematic and strategic knowledge. Technological design challenges students to question, clarify, summarize, and make predictions to arrive at a solution, demonstrating their reasoning abilities and schematic knowledge (NAGB, 2009). Students use strategic knowledge when negotiating design decisions within novel real-world situations (NAGB, 2009). It is easy to discern the different knowledge demands in theory, but in practice, they are much more difficult to assess (Shavelson et al., 2005). Strategic knowledge is the most challenging to differentiate. Within the context of other knowledge demands, its existence is usually implied (Shavelson et al., 2005).

Theoretical Framework

As previously discussed within the literature on cognitive structure, a subject domain contains a structure and an extent of understanding that domain (Shavelson et al., 2005). The extent of an individual's understanding of new knowledge exists somewhere on a continuum from rote learning to meaningful learning. Meaningful learning is well connected and anchored in concrete ways to existing concepts within the cognitive structure, it is relevant and more easily retainable (Ausubel, 1968). Rote learning does not interact well with the existing cognitive structure, it is factual, literal, or random (Ausubel, 1968). Schematic and strategic knowledge demands encourage meaningful learning and active construction in memory. The goal of this study is to demonstrate that the design-based approach to teaching biotechnology elicits meaningful connections within students' cognitive structure.

Ausubel's hierarchical memory theory on meaningful learning provides the theoretical foundation for this study. Novak developed an advanced organizer called concept mapping that he derived from Ausubel's theory. Concept maps represent the concepts and connections of an individual's cognitive structure in memory. As an assessment tool, concept maps require a task, response format, and scoring method. The response format is the concept map itself, but an extensive variety of tasks and scoring methods exist.

Meaningful Learning

Ausubel's theory for cognitive learning is the theoretical basis for this study. Ausubel focused on the importance of determining students' prior knowledge in order to build upon their understanding (1968). He proposed that "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (Ausubel, 1968, epigraph). To teach him accordingly, Ausubel meant that it was crucial to relate new knowledge to the learner's existing knowledge in memory (1968). The connections between old knowledge and new knowledge promote meaningful learning and the development of cognitive structure.

In its simplest form, cognitive structure consists of concepts and connections. A concept is an idea, event, or object formed by inference within the cognitive structure and designated by a sign or symbol (Novak, 1980). The specific connections between two or more concepts are propositions; a proposition is a unit of meaning (Novak, 1980). Rain is liquid precipitation, is an example of a proposition. As the cognitive structure of an individual grows to include more concepts and propositions, his/her understanding of the cognitive domain becomes more meaningful (Novak, 1980).

Novak extended and refined Ausubel's hierarchical memory theory on meaningful learning (1977, 1979, 1980; Ruiz-Primo & Shavelson, 1996). He revealed how the use of subsumption, integrative reconciliation, superordinate learning, progressive differentiation, and advanced organizers could make learning more meaningful and less rote (Ausubel, 1968; Novak, 1980). Each of these terms denotes an organizational method for relating new information to prior knowledge. Subsumption is the most common and intentionally connects relevant new knowledge to existing concepts and propositions (Ausubel, 1968; Novak, 1980). Integrative reconciliation is the ordering of new knowledge to demonstrate the similarities and differences between concepts (Ibid). Superordinate learning refers to the grouping of multiple related concepts or propositions within new and more-encompassing concepts or propositions (Ibid). Progressive differentiation is a reorganization of concepts and propositions, which occurs over time due to subsumption, integrative reconciliation, or superordinate learning (Ibid). The use of advanced organizers serves as an aid to scaffold new knowledge to existing knowledge and isolates any interfering misconceptions (Ibid). The data collection instrument used for this study included an advanced organizer known as a concept map. Concept mapping provided a method for assessing students' representations of their biotechnology knowledge constructed throughout the technological design process.

Concept Mapping

Meaningful learning is the fundamental process for knowledge attainment and construction in memory (Novak, 1990, p. 32). According to Novak (1980), three conditions must be present for learning to occur:

> "1. The new material must be inherently meaningful; we cannot meaningfully learn non-sense syllables or randomly scrambled textual material.
>
> 2. The learner must have a meaningful learning set; that is s/he must actively try to link new knowledge with existing, relevant knowledge.
>
> 3. The learner must possess relevant concepts" (p.282).

Novak developed concept maps to encourage construction in memory (1980). Concept mapping allows students' to develop graphical representations of their understanding of relevant concepts within a cognitive domain (1980, 1981, 1990). It provides an image of the students' mental organization of key concepts and proposition (Ruiz-Primo et al., 2001).

Concept mapping demonstrates an individual's cognitive structure using hierarchical concept nodes and labeled linking lines for propositions (Novak, 1990, p. 29; see also Shavelson et al., 2005). Within a concept map, a line labeled with a proposition links two or more concept nodes. Propositions are relationships, therefore all of the concepts and links within a domain represent an individuals constructed understanding (Novak, 1990; Ruiz-Primo & Shavelson, 1996). According to Shavelson, Ruiz-Primo & Wiley, "concept and cognitive maps have been said to provide a 'window into students' minds.' Although this might be an overstatement, there is evidence that they *do* seem to provide information on the structure of complex ideas" (2005, p. 416). Because individuals possess their own unique perspective and meanings, all constructed representations are idiosyncratic (Novak, 1990). Since information is infinite, a single concept map cannot contain all of the relevant information that exists, and consequently concept maps are a "work-in-progress" and are never finished (Ruiz-Primo & Shavelson, 1996). To summarize, concept maps are a 'snap shot' in time of an individual's representation of meaning (using concept nodes and linking lines) within a cognitive domain. Within the context of this study, the students will be constructing concept maps at three key intervals to demonstrate how their knowledge grows throughout the technological design process. Due to the integrative nature of Biotechnology, the cognitive domains assessed within this course were biology and technology.

Concept Mapping as an Assessment Tool.

The most common use for concept maps is as an instructional tool, but there is enormous potential for its use as an assessment tool (Ruiz-Primo & Shavelson, 1996). Assessments contain a task, response format, and scoring method. To meet the requirements of an assessment, Ruiz-Primo & Shavelson addressed their conceived ideas of how a concept map is applicable as an assessment (1996). They envision the task as students generated representations of a cognitive domain and the response format as the concept map itself (Ibid). There have been many different methods for scoring concept maps devised by different researchers (Ruiz-Primo & Shavelson, 1996; McClure, Sonak & Suen, 1999; Nesbit & Adesope, 2006; Hay & Kinchin, 2008).

The concept map task can vary based on its requirements of the student, and the teacher. Ruiz-Primo & Shavelson (1996) and Nesbit & Adesope (2006) examined existing studies on concept maps and revealed three types of tasks: construct-a-map, fill-in maps, or expert-generated maps (Nesbit & Adesope, 2006; Ruiz-Primo & Shavelson, 1996). The construct-a-map type requires the student to construct a map from scratch, although the assessor may provide concepts or linking words (Ruiz-Primo et al., 2001). Fill-in maps include fill-in-the-node or fill-in-the-link maps. Fill-in maps require students to add information where it was intentionally omitted (Ruiz-Primo et al., 2001). Expert-generated maps can serve as an assessment tool, but more commonly appear as an instructional tool (Ibid). When used for assessment, a comparison between student and expert-generated maps occurs to determine accuracy and inconsistencies (Ibid). Novak (1990) found that concept maps provide the most benefit to the person who constructs the map. This remains consistent with later findings as well (Shavelson et al., 2005)

The majority of evidence conducted on concept maps has been within the cognitive domain of science (Novak, 1990; Nesbit & Adesope, 2006; Ruiz-Primo, Schultz, Li & Shavelson, 2001). Shavelson, Ruiz-Primo & Wiley (2005) used concept maps as an instrument to assess students' construction of concepts within the cognitive domain of science. Their findings demonstrated that concept maps are beneficial to determining the structure and extent of knowledge students' gain over time (Shavelson et al., 2005). Therefore, changes within student concept maps could represent changes in students' cognitive structure due to instruction (Ibid). These findings demonstrate the benefits of using student-constructed concept maps to assess changes in students' cognitive structure throughout the technological design-based pedagogical approach to instruction.

One implication discussed in Ruiz-Primo & Shavelson (1996) contends that concept maps directly reflect relationships between ideas and do not necessarily account for what students do with the information or how they would use the knowledge to solve a problem (p. 573). As mentioned previously, the technological design-based approach to instruction, used throughout this study, is a method of problem solving. The combination of both, the technological design process and concept mapping, could potentially enhance both learning strategies. Hay, Kehoe, Miquel, Hatzipanagos, Kinchin, Keevil & Lygo-Baker (2008) suggest that "where the same person maps the same topic [cognitive domain] repeatedly, then a comparison of two or more such 'snap-shots' facilitates measurement of cognitive change and the quality of change can be assessed against Novak's original definition of meaningful learning" (Hay et al., 2008, p. 1039). This description illustrates the intent of this study, and facilitates the need to determine a measurement for cognitive change and method of analysis.

Methods for Analysis.

Upon development of the concept map, Novak determined the need to create a scoring method (1980). Novak & Gowin (1984) produced a method for analyzing concept maps, which focused on the number of relationships, hierarchy, branching, general to specific, and cross-links within a given map. An assessor scored student maps against a criterion map, with points awarded based on each of the present components, with a final score totaled. Others have slightly tweaked this method by assigning different values to Novak's components (McClure, Sonak & Suen, 1999)

Since Novak developed his method for analysis, many other methods for analysis followed to accommodate the various goals and many uses for concept mapping. Nesbit & Adesope (2006) conducted an extensive meta-analysis to compile many of these diverse scoring methods. Ruiz-Primo and Shavelson have done extensive research to determine the best ways in which to use and analyze concept maps (Ruiz-Primo & Shavelson, 1996; Ruiz-Primo, Schultz, Li & Shavelson, 2001; Shavelson et al., 2005). They determined that construct-a-maps were best for understanding students' cognitive structure (Shavelson et al., 2005). In Ruiz-Primo et al.'s (2001) article, they studied the validity and reliability of three different methods for analyzing construct-a-map scores: proposition accuracy, convergence, and salience. They determined that of the three, convergence was the most valid and reliable (Ruiz-Primo et al., 2001). Much of Shavelson's research focused on the scoring of linking lines within concept maps.

As concept maps grow in complexity or disarray, concept map scoring methods that examine the number of relationship, concepts, or links become challenging at best. In 1999, McClure, Sonak, & Suen examined the reliability, validity, and logistical practicality of six different assessment methods. These methods included holistic, relational, and structural, the examination of each of these methods occurred twice, with and without a master map (McClure et al., 1999). Holistic involved examining the overall map and assigning a score on a scale of 1-10 (Ibid). Relational dealt with the number of correct linking lines, similar to Shavelson's methods for analyses (Ibid). Structural centered on Novak's hierarchical examination. The highest g-coefficients found were relational with a master map at .76, and holistic without a master map at 0.67.

Kinchin, Hay, and Adams (2000) developed what they originally termed a qualitative approach to concept map analysis. This method categorized concept maps based on its overall structure as a spoke, chain, or net (Kinchin et al., 2000). Hay in 2007 extended this analysis method to describe how knowledge growth or lack there of in the structure of an individual's concept map could be translated into deep, surface, or non-learning. Hay and Kinchin (2008) tied this new analysis back to the importance of prior knowledge, change, and meaningful learning.

Hay et al. (2008) developed a three-method analysis for measuring the quality of knowledge change as a consequence of students' learning. The quality of knowledge change refers to the level in which students are learning, described as either non-learning, rote learning, or meaningful learning. Hay et al's method one included a before and after examination of students concept maps to determine deep (meaningful), surface (rote), or non-learning based on evident structural change and learning quality (Hay et al., 2008). The second method compared the concepts used within the students concept maps to a list of key terms from the instructional materials, a frequency count of these terms was generated (Ibid). The final method incorporated content area experts to rate the student maps in the areas of conceptual richness, linkage and linkage quality, evidence of understanding, and hierarchy and structure (Ibid). There were four items for each of these four categories, the items were rated on a 5-point Likert scale to determine total student gains based on pre and post-student maps (Ibid). Six students participated in the analysis, and the researchers discussed three of the six cases in detail (Ibid).

Hay et al.'s method for measuring the quality of knowledge change as a consequence of students' learning is a logical method for analyzing students' cognitive change within this study because the task and requirements for student assessment are very similar. Hay et al. (2008)

assessed student concept maps as a measurement of students' knowledge growth using an e-learning instructional approach, and this study is focusing on the same except using the technological design-based instructional approach.

Summary of the Literature Review

Increasing pressures to compete within the global economy have challenged the United States to produce a STEM literate citizenry able to solve problems and meet workforce demands. To prepare students for life after K-12 education, it is no longer adequate to teach students within silo disciplines. Students need to be able to apply their knowledge across disciplines and within real-world scenarios. Integrative STEM education utilizes design-based pedagogical approaches to teach science/math content concurrently with technology/engineering content (Wells & Ernst, 2012, para. 2).

Design-based pedagogical approaches challenge students to solve problems using a cyclical and iterative process known as technological/engineering design (Kolodner, 2002; Puntambekar & Kolodner, 2005; Wells, 2008). The cyclical nature of designing requires students to predict, question, clarify, and summarize their understanding (Puntambekar & Kolodner, 2005). Research on integrative design-based instruction has increased within the last decade, particularly within science, engineering, and technology (Doppelt, Mehalik, Schunn, Silk & Krysinski, 2008; Fortus et al., 2004; Fortus et al., 2005; Ginns, Norton & Mcrobbie, 2005; Hmelo, Holton & Kolodner, 2000; Mehalik et al., 2008; Norton, 2007; Puntambekar & Kolodner, 2005; Silk, Schunn, & Cary, 2009). Standard 15 (agriculture and related biotechnologies) in the *Standards for Technological Literacy* (2000) recognized a content area that naturally integrates the disciplines of science and technology. In 1998, Wells first published his high school curriculum guide for teaching *Design-based Biotechnology Literacy* (DBBL™).

Technology education has not been able to demonstrate through empirical research that its existence and pedagogies are beneficial to students' understanding. Since, it is no longer adequate to only assess students' declarative and procedural knowledge, researchers must demonstrate that students are able to achieve the cognitive demands of schematic and strategic knowledge. Schematic knowledge refers to knowing "why" and demonstrates students' understanding of relationships and reasoning within their cognitive structure. Knowledge growth reflects a change in cognitive structure and the extent of an individual's understanding within a cognitive domain.

Ausubel contends that the most important aspect of knowledge growth is what an individual already knows (1968). The extent of an individual's cognitive structure exists on a continuum from rote to meaningful learning. Meaningful learning is well connected to existing knowledge, is relevant and more easily retainable (Ausubel, 1968). Advanced organizers, like concept maps, support construction of new knowledge in memory (Novak, 1980). Concept maps represent a picture of an individual cognitive structure within a domain and are most beneficial to the person who constructs them (Novak, 1990; Shavelson et al., 2005). There are many different tasks and methods for assessing concept maps. Student-constructed concept maps and Hay et al.'s methods for analysis most closely reflect the purpose of this study, which is to demonstrate that the technological design-based approach to teaching biotechnology literacy develops students' connections of science and technology concepts.

CHAPTER THREE: RESEARCH METHOD

This chapter presents the research methods used to investigate the research questions for this study. The sections for this chapter include research design, participants, data collection procedures, and data analysis. The following research questions (RQs) and sub-questions (s-RQs) guided this study:

1. To what extent does the technological design-based approach to teaching biotechnology content result in changes to high school students' cognitive structure, specifically their documented representations of…
   a. biology concepts and connections?
   b. technology concepts and connections?
   c. the connections between biology and technology concepts?
2. In what ways does student documentation of cognitive structure demonstrate their use of strategic knowledge (when, where, and how) while engaged in a Design-Based Biotechnology Literacy Problem Scenario?

The researcher used primarily quantitative methods developed by Hay et al. (2008) to analyze student's concept map data and address all of the sub-questions within RQ 1. A qualitative case study analysis of student's concept maps generated the data necessary to address RQ 2.

Research Design

The purpose of this study is to investigate the development of students' cognitive connections between science and technology concepts while implementing a technological design-based approach to teaching biotechnology literacy. This study utilizes a case study research design focused on the use of student-generated concept maps as a tool for assessing changes within their cognitive structure. The independent variable for this study is the technological design-based approach to teaching biotechnology used within a Problem Scenario on Biorestoration. The dependent variable for this study are the three concept maps generated by the students at selected times throughout the technological design process. The researcher collected and analyzed each student's concept maps using Hay et al. (2008) scoring methods to answer RQ 1. A qualitative case study analysis of the concept maps established the evidence for RQ 2.

Prior to collecting data, the researcher submitted an Institutional Review Board (IRB) proposal to the Board of Human Subjects at Virginia Tech and received approval for conducting this research with high school students (refer to Appendix A and B for the IRB approval letters). The researcher provided the students enrolled in the biotechnology course with a study recruitment document, parental permission form, and student assent form. Only the data submitted by those students that returned their IRB approved forms (parental permission and student assent), and completed all three concept maps were included within this study. Their work was collected, analyzed and will be discussed.

A pilot study was conducted during the spring of the 2011-2012 school year to guide and inform the current research design. The pilot study served as a trial for collecting data, analyzing those data, to develop findings and to come to conclusions on the research design. The methods used within this study are reflective of the information learned throughout the pilot study.

Participants

The participants within this study were students enrolled in a Biotechnology course located within a large public high school in Western New York. The district serves approximately 2,700 children, 900 of which are high school students. All students entering grades nine through twelve have the option to enroll in this elective course. Given the variety of grade levels represented, the students' prior knowledge and experiences were diverse. The maximum student enrollment for hands-on, laboratory courses is restricted to 20 students per section, with the potential for multiple sections. All students enrolled within the biotechnology course during the fall semester of the 2012-2013 school year were eligible to participate. Thirty-nine percent (seven out of 18) of the students in the course volunteered to participate within the study, and these students constituted the convenience sample of the student population used in this study.

The researcher gathered and reported all of the participating student's demographic information within Table 1 below. These data included each participant's grade level, gender, ethnicity, grade point average in the course, overall grade point average, and access to learning support services. As depicted in Table 1, six students participating in the study were males, one student was a female, all students were Caucasian, five were in grade ten, two were in grade twelve, and none of the students received learning support services from the school district.

Table 1

Participant demographic data

	Participant							
Characteristics	1	2	3	4	5	6	7	Totals
Grade level	10	10	12	12	10	10	10	(2)12 (0)11 (5)10 (0)9
Course GPA	87	82	89	95	91	85	91	88.57, 85.78
Overall GPA	76.91	82.38	83.13	96.44	84.13	79.11	81.38	83.35
Gender	Male	Male	Male	Male	Female	Male	Male	(6)Male, (1)Female
Ethnicity	C	C	C	C	C	C	C	(7)Caucasian
LSS	No	No	No	No	No	No	No	(0)Yes, (7)No

Note. Course grade point average (GPA) totals were for all participants in the study, and all students enrolled in the course during the fall 2012 semester. Overall grade point average (GPA) total was for the participants in the study only. C = Caucasian. LSS = Learning support services.

Data Collection Procedures

The data collection procedures section is divided into two sections, one on concept mapping and the other on the phases of the study. This study incorporated student-generated concept maps to capture their cognitive structure at three different points during the technological design-based approach to instruction. The phases of the study occurred in three segments including pre-treatment, mid-treatment, and post-treatment. The sub-sections that follow present the pertinent information on these topics.

Concept Mapping

The main tool for data collection and analysis was the student generated concept maps. As mentioned in Chapter Two, there are many different types of tasks, and response formats when using concept maps as an assessment tool. Ericsson and Simon (1993, 1998) had students use a think aloud protocol while they were concept mapping to determine their patterns of thinking. They determined that student generated construct-a-maps elicited explanations from the students on known concepts and their links, and encouraged self-regulation (Ericsson & Simon, 1993, 1998). Whereas, fill-in maps did not encourage student explanations, instead students monitored their maps to ensure every blank was answered (Ericsson & Simon, 1993, 1998). While both map types elicit students' understanding of declarative knowledge, the construct-a-map method provides insight into students' cognitive structure, and fill-in maps do not (Shavelson et al., 2005). For this reason, the researcher chose to use construct-a-maps for this study (Shavelson et al., 2005).

Since construct-a-maps have the potential to provide insight into students' cognitive structure, they offer the best opportunity to generate data to answer the RQs and therefore establish evidence that the technological design-based approach to instruction targets students' higher-order cognitive demands (i.e., schematic and strategic knowledge). To exhibit gains at the schematic knowledge level, students must demonstrate their understanding of the reasoning and relationships between concepts. This means that within the concept maps, the students' new knowledge should be well connected and anchored to their prior knowledge demonstrating meaningful conceptual connections, as opposed to rote or non-learning connections. To demonstrate gains at the strategic level, students would demonstrate an understanding of "when, where, and how" to apply their knowledge. In the context of this study, evidence of their strategic understanding is most likely to be apparent within their design decisions. Within the concept maps, changes to the concepts utilized within student solutions and between maps should demonstrate some of their design decisions. As discussed in Chapter Two, strategic knowledge is the most difficult to differentiate in practice, and it is usually implied when other cognitive demands are present (Shavelson et al., 2005).

Phases

The data collection procedures for this study occurred in phases categorized as pre-treatment, treatment, and post-treatment. Figure 2 presents these three distinct treatment phases, and the 14 stages of the study, including activities that took place during each stage, and the approximate time dedicated to each phase. The pre-treatment phase included one stage, which was devoted to teaching the students the technological design and concept mapping processes. The first two Problem Scenarios ("Enzymes in the Wash" and "Bioremediation") were dedicated to familiarizing the students with both of these processes. The treatment phase contained stages two through 12, with eight of these stages (2, 4, 5, 6, 8, 9, 10, and 11) representing steps of the technological design process, and the other three stages include the instances of student concept mapping (stages 3, 7, and 12). The Problem Scenario on "Biorestoration" was the topic of study throughout the treatment and data collection phase. The post-treatment phase contained the final requirements for the “Biorestoration” Problem Scenario that were not included within the treatment, stage 13 (class discussion) and stage 14 (conclusion questions). As mentioned previously, all of the Problem Scenarios used within the high school Biotechnology course of study were variations derived from Wells’ *Biotechnology Literacy Teaching Guide* (1994-2011). This curricula was intentionally selected because it contains both biology and technology objectives for each Problem Scenario.

Figure 2. Treatment Phases Flow Chart

Pre-treatment	Treatment	Post-treatment
Stage 1. Teach the Processes of Technological Design & Concept Mapping		
a. **"Enzymes in the Wash"** Whole Class Concept Map (Continuous)		
b. **"Bioremediation"** Three Concept Maps in Pairs		
~ 9 weeks	**"Biorestoration"**	
	Stage 2. Frame the Problem	
	Stage 3. Individual Concept Map (1 - Pre)	
	~2 days	
	Stage 4. Conduct Research	
	Stage 5. Develop Possible Solutions	
	Stage 6. Select a Solution	
	Stage 7. Individual Concept Map (2 - Mid)	
	~ 1 1/2 weeks	
	Stage 8. Construct the Solution	
	Stage 9. Test the Solution	
	Stage 10. Redesign for Improvements	
	Stage 11. Reflect and Communicate	
	Stage 12. Individual Concept Map (3 - Post)	
	~2 weeks	Stage 13. Class Discussions
		Stage 14. Conclusion Questions
		~ 2 days

Figure 2. The data collection flow chart is broken down into phases, stages, and procedures.

A more detailed description of what occurred within the classroom on a given day of the study is provided in Appendices C and D. These appendices contain audit logs describing the classroom activities that took place, technological design process steps followed, metacognitive skills, and New York State (NYS) Learning Standards of focus for each day. The technological design process steps and NYS learning standards highlighted in bold lettering were the primary emphasis for that day and the others were secondary. The metacognitive skills listed in the right column of Appendices C and D demonstrate the cognitive-monitoring devices (predict, summarize, clarify, or question) used by the students throughout the technological design process to encourage their self-regulation (Brown, 1992).

Phase 1: Pre-Treatment.

The purpose of the pre-treatment phase (stage 1) of the study was to teach the students how to concept map and solve problems using the technological design process. The first two Problem Scenarios of the semester “Enzymes in the Wash” and “Bioremediation” were used to scaffold student learning and desensitize them to these two processes. Throughout the first Problem Scenario (“Enzymes in the Wash”) the class developed one concept map on the board together on a continuous basis. This incorporated concept mapping into daily instruction and provided students an opportunity for guided practice.

During the second Problem Scenario (“Bioremediation”) students created their concept maps in pairs. By working in pairs students were able to be more independent of the teacher by using each other for guidance throughout the concept mapping process. All of the instructional and data collection procedures used throughout the “Bioremediation” and the “Biorestoration,” Problem Scenario three, were consistent. The students developed their concept maps at the same three intervals as specified in the treatment phase of the study. Again, the purpose of the pre-treatment phase was to mitigate confounding variables by intentionally scaffolding student learning of the technological design process and concept mapping, and to prepare them for data collection within the third Problem Scenario.

Phase 2: Treatment.

The purpose of phase two (treatment) was to collect the data required to answer the research questions for the study. The treatment phase of the study contained the third Problem Scenario, which was derived from ProbScen 2E on "Biorestoration" within the "Environment" chapter (Wells, 2010, p. 144-155). The modified context and design challenge used within this study was:

> "**Context:** We are pleased to announce that we are partnering with Green Technology and Personal Touch Food Services to design a bioremediation system that will help to reduce the amount of water wasted in the preparation of food in the school cafeteria. The biotechnology system must be in the form of an enclosed Green House that utilizes hydroponics and phytoremediation to clean the grey water from the cafeteria. As an added benefit to scrubbing the grey water, you must design a system to supply the fruits, vegetables, and/or herbs to the cafeteria as an integral part of the healthy meals plan currently in place at [the school district].
>
> The space available for the Green House hydroponics system is 25'x15'x15'. The system must operate in the limited space provided, incorporate appropriate light and nutrients for plant growth, and allow for the increase in plant size as they mature. In addition, the system must allow for plant care within the hydroponic environment.
>
> **Challenge:** Develop a proposal/presentation to share with school officials. Your proposal should include a floor plan of the green house (including a minimum of three different plant types and two different hydroponics systems), a phytoremediation system for scrubbing the grey water, and a working model of one of your hydroponics systems."

Using the technological design process model previously described, students were asked to develop a technological design solution to the real-world scenario illustrated. They began by framing the problem (stage 2), which included describing the problem, the importance of the problem, the context of the scenario, the resources available, any requirements/constraints provided, what they already knew, and what they needed to know. Each of the students had time to frame the problem individually, then the class came together to discuss their thoughts and generate areas of research.

After the students framed the problem they developed their first concept map individually (stage 3). The purpose of this concept map within the study was to determine the students' prior knowledge of the concepts related to the problem scenario. This concept map formed the baseline data used to gauge students' cognitive structure at the start of the challenge. Each student received a blank sheet of paper and the researcher projected the prompt below on the board in the front of the room.

> "Develop a concept map that includes what you already know and what you think you need to know in regards to the problem scenario.
> - You should have two central nodes on your map; one labeled, *Biology* and the other should be labeled *Technology*.
> - Please be sure to clearly label all concepts and linking lines."

Students were allowed as much time as they needed to develop their concept maps, but most of them finished within twenty minutes. Once complete, the teacher collected the students' concept maps. The teacher made copies of each of the participants' maps for use as data.

After the students completed their first concept map, the students found out the name of their partners for the project and began conducting research (stage 4). The students mostly worked individually while conducting their research, but consulted their partner often to compare notes. The students spent approximately five days researching information in a computer lab at the school. The researcher provided students with a handout, which included the big ideas and some possible websites to guide their investigation. The big ideas included the concepts of phytoremediation (phytoextraction, phystostabilization, & phytotransformation), hydroponics (systems & vertical farming), plant (growth requirements & nutrients), grey water recycling, plant tolerances, and green houses. When needed, the researcher would conduct brief whole-class discussions using guided questioning to help direct the students to desired information.

When the students exhausted their resources and believed they possessed adequate information, they developed possible solutions (stage 5) to the design problem. Each of the students independently brainstormed and produced at least five different ideas through sketching. The front side of an 8 ½" x 11" sheet of paper read:

> "Directions: Sketching is the great way to generate new ideas for a project; it allows you to map out your thoughts graphically and mathematically so that your ideas can be communicated clearly to others.
> Brainstorm: Draw five (5) basic sketches of possible solutions to the given design challenge" (Schurr, 2011).

The backside of the same document stated:

> "Choose two (2) of your basic sketches to develop further. Re-draw these sketches in more detail using annotations and dimensions. Please include as much information as possible. Anyone that looks at your sketches should be able to construct your idea without needing verbal clarification" (Schurr, 2011).

Once each individual student completed their seven drawings, then each pair of students discussed their designs together to select a design solution (stage 6) for construction. The students' presented their selected design solution to the teacher for approval. Once approved, the students completed their second (mid-treatment) concept map (stage 7).

The students developed their mid-treatment concept map in response to the second prompt. The prompt for the second concept map changed slightly to account for what the students had learned and to determine which concepts were important to their selected design solution. Determining which concepts were important to the students design solutions was critical to gaining evidence to account for students strategic knowledge (knowledge of when, where and how). The second prompt stated:

> "Develop a concept map that includes what you already knew, what you have learned, and what you think you need to know in regards to the problem scenario.
> - You should have two central nodes on your map; one labeled, *Biology* and the other should be labeled *Technology*.
> - Please be sure to clearly label all concepts and linking lines.

- Once you have finished your concept map, please place a check mark in the concept nodes that you plan to or have already incorporated into your design solution."

The students received a blank piece of 11x17 inch paper and as much time as needed to complete their concept maps. All students finished within a single class period. When the students were finished, the researcher collected the concept maps and made copies for later analysis.

In pairs, each team worked to construct a design solution (stage 8) for their operational hydroponics system and a floor plan drawing of their greenhouse. All of the teams completed their final design within five days. Each team created a PowerPoint presentation to share with the class as a reflection of the information learned and to communicate their design proposals (stage 9). The researcher provided each team with a list of questions that needed to be answered within their final presentation to the class (refer to Appendix E for the list of Presentation Questions). Each group presented their completed design (including their drawing of their green house floor plan and working hydroponics model) to the class.

Following the team presentations, students completed their third (post-treatment) concept map. The prompt for the third map was:

"Develop a concept map that includes what you already knew, and what you have learned throughout the process of designing your solution to the problem scenario.

- You should have two central nodes on your map; one labeled, *Biology* and the other should be labeled *Technology*.
- Please be sure to clearly label all concepts and linking lines.
- Once you have finished your concept map, please place a check mark in the concept nodes that you plan to or have already incorporated into your design solution."

The prompt changed slightly again to include all of the information the students learned throughout the process of designing their solution to the Problem Scenario. Otherwise, the procedures for the third concept map remained the same as the second. The students received a blank piece of 11x17 inch paper, and worked individually to complete their map. When finished, the researcher collected and copied all of the maps for analysis.

Phase 3: Post-Treatment.

The post-treatment phase of the study included a class discussion (stage 13), and the conclusion questions (stage 14) for the Problem Scenario. The purpose of the teacher-led class discussion was to reinforce the important concepts within the Problem Scenario, and to eliminate any remaining misconceptions uncovered within the presentations and concept maps. Conclusion questions are a requirement at the end of every Problem Scenario. For this Problem Scenario there were five primary questions used to target and expand students understanding of the challenge, all of which the students completed individually.

Data Analysis

To answer the research questions and sub-questions the researcher collected the students' three individually generated concept maps. The data analysis methods used within this study included Hay's et al. (2008) three methods for measuring the quality of students' e-learning using concept maps, and a qualitative case study analysis of each participant's concept maps. The three raters for this study were experts within science or technology education. Criteria for selecting raters were: (a) at least five years teaching experience, (b) held a NYS professional teaching certificate, and (c) had a master's degree within their designated content area. Two of the raters held professional teaching certificates in science education and one was within technology education.

Concept Map Scoring Methods

To answer research question number one, the researcher followed a three-method analysis approach based on a study by Hay, Kehoe, Miquel, Hatzipanagos, Kinchin, Keevil & Lygo-Baker (2008). This method of analysis included three different approaches to scoring student constructed concept maps focusing on changes within student's cognitive structure. Hay et al. (2008) referred to Method One as an analysis of structural change and learning quality. Method Two was a frequency count of the concepts, words, and terms used in the student maps compared to a list of relevant terms used in the instructional materials. Method Three used expert raters to score student maps using a 16-item Likert-scale instrument. The following sections present detailed descriptions of how each of these methods was employed in the analysis of concept map data collected for this study.

Method One.

The raters used Method One to categorize student's learning quality. Learning quality was determined based on a typology classification of students' pre, mid and post-treatment concept maps, and comparisons of the frequency of concepts and linking lines used in each map. Table 2 is a variation on the table used within Hay et al.'s study (2008). To add clarity and account for having two cognitive domains (i.e., science and technology) instead of one, and three concept maps instead of two, the researcher altered Hay et al's original version of the table (2008).

Table 2

Method One: Measures of student learning for example participant

Concept map typologies		Participant # 1		
		Categorizations		
		(Non, Rote, Meaningful)		
Concept map 1	Prior-knowledge	Chain		
Concept map 2	Mid-treatment	Chain		
Concept map 3	Post-treatment	Chain		
		Categorizations		
		(Yes, No)		
Typology change		No		
Structural growth		Yes		
Concept comparisons		*Frequency*		
			Mid	Post
Biology concepts				
Frequency of retained concepts			6	4
Frequency of new concepts			5	8
Technology concepts				
Frequency of retained concepts			8	13
Frequency of new concepts			7	15
Total concepts				
Frequency of retained concepts			12	15
Frequency of new concepts			12	15
Meaning making		*Frequency*		
		Pre	Mid	Post
Frequency of correct linking lines		11	13	12
Categorization of learning quality		*Categorizations*		
		(Non, Rote, Meaningful)		
Learning quality		Meaningful		
Integrative meaning making		*Frequency*		
		Pre	Mid	Post
Frequency of correct linking lines between biology and technology concepts		3	6	6

Note. This measurement of student learning quality is Method One of the Hay et al.'s (2008) three-method analysis approach for recording participant's concept mapping data. Adapted from “Measuring the quality of e-learning,” by Hay et al., 2008, *British Journal of Educational Technology, 39*, p. 1045-1046. Copyright 2008 by Hay et al.

The modified table includes the categories of concept map typologies, concept comparisons, meaning making, categorization of learning quality, and integrative meaning making. Concept map typologies included spoke, chain, or net structures, and the instructional goal is for all students to reach a net structure by their third concept map, which includes many new concepts with links to their prior knowledge. A comparison of the typology classifications for all three maps determined whether (yes or no), the student experienced structural change within their cognitive structure. A second comparison of all three maps determined if each participant demonstrated a growth (yes or no) in the structure of their maps. Raters compared the concepts used within each of the student's maps to determine the use and frequency of retained and new (biology, technology, and total) concepts. They recorded numerical values reflecting the frequencies of concepts. Increased frequencies demonstrated growth in student's knowledge of concepts. Two concepts connected by a linking line make up the most basic unit of meaning. Therefore, a frequency count of correct linking lines was included to demonstrate growth in meaning across all concept maps. An overall assessment of the information contained within the table determined the learning quality designation as non-learning, rote, or meaningful. Integrative meaning making includes all correct linking lines connected to integrative concepts, or correct linking lines between biology and technology concepts. A frequency count designated the number of integrative connections used by the participants in each concept map. The following paragraphs describe in detail the learning quality designations as well as the process taken by the raters to assess the concept maps and complete Table 2.

To begin, the raters examined each participant's concept maps for incorrect concepts/links or misconceptions as determined by the teaching materials and their expert knowledge. Any incorrect concepts or links, the raters crossed off with red colored pencil, and did not include within the analysis. The raters then classified each map into its typology. Kinchin et al. (2000) and Hay (2007) developed concept map typologies described as spoke, chain, or net. Figure 3 depicts the characteristics of each of these typologies. The goal is for participants' constructed concept maps to resemble a net structure with many correct concepts and connections. After classifying the typology of each map, the raters documented the status of the participant's structural change and structural growth in Table 2. Yes, if there was a change in the typologies of the participant's maps, and no, if there was not. Similarly, yes if there was a growth in concepts and connections between the participant's maps, and no, if there was not.

Figure 3. Concept Map Structural Typologies

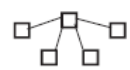
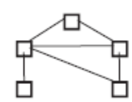
	SPOKE	CHAIN	NET
Structure			
Hierarchy	Single level	Many levels, but often inappropriate	Several justifiable levels
Additions	Additions to central concept do not interfere with associated concepts	Cannot cope with additions near the beginning of the sequence	Additions / deletions may have varying influence as 'other routes' are often available through the map
Deletions	Have no effect on overall structure	Disrupt the sequence below the deletion	
Links	Often simple	Often 'compound', only making sense when viewed in the context of the previous link	Often employ technical terminology to enhance meaning

Figure 3. Illustration of the three different concept map structures as discussed in Kinchin, Hay & Adams (2000) and depicted in Hay et al. (2008, p. 1042).

Table 2 contains participant 1 from the study. All three of this participant's concept map typologies resembled a chain structure, meaning it had many hierarchical levels, but was linear and would not make sense with concept additions or deletions. Unfortunately, this participant's concept map typology never reached a net structure. Specifically, it lacked the complex connections required in a network typology. Based on an overall evaluation of this participant's concept maps, the raters concluded that there was no structural change due to the consistency in the chain typology, but there was growth in the knowledge structure demonstrated in the concept maps.

Raters compared the concepts in each of the participant's maps to determine the number of retained and new concepts (biology, technology, and total). These numbers were ascertained by comparing the prior knowledge (pre-treatment) concept map to the mid and post-treatment maps. All overlapping concepts that were retained from the first concept map to the mid and post concept maps were highlighted in green colored pencil. The same technique but in blue was used between the mid and post-treatment concept maps. Raters took a frequency count for each concept comparison category specified in Table 2, and recorded their findings accordingly.

Considering the participant in Table 2, to determine how many retained biology concepts he had within his mid-concept map, the rater counted all of the concepts highlighted in green and determined he had six retained biology concepts. The rater took a frequency of new (the blue and non-highlighted) concepts within the mid-treatment concept map and documented five new biology concepts. The same process occurred for the post-treatment concept map, except the rater counted both the green and blue highlighted concepts as retained biology concepts and found four retained concepts. In the post-treatment concept map, the participant added eight new biology concepts. The same process occurred for the technology, and total concepts. Because some concepts fit under both cognitive domains, the total number of correct concepts does not always equal the number of biology concepts plus the number of technology concepts.

As mentioned previously, two concepts connected by a linking line symbolizes the most basic unit of meaning within a concept map. Therefore, having correct linking lines within a concept map is crucial as it demonstrates student understanding. Table 2 included a frequency count of the total correct linking lines as demonstrated within each concept map. The example participant had eleven correct linking lines in his first concept map, 13 correct links in his second map, and 12 in his third concept map. This demonstrates a growth in meaning in the second concept map, but a slight loss in the third.

To make a determination on the learning quality of each student, the raters examined the student's pre and post-treatment concept maps, based on the data contained within the table. Raters compared this data to Hay et al.'s (2008) categorizations of learning quality as non-learning, surface learning (rote), or deep learning (meaningful), and made a determination for each participant based upon Figure 4 (excerpt from Hay et al., 2008, p. 1040) and the following description:

> "The criteria used for learning quality measures were as follows:
> (1) Non-learning: defined by an absence of cognitive change. Non-learning was therefore measured by the lack of new concepts in the second map and by an absence of new links in the extant prior-knowledge structure.
> (2) Rote learning [Surface]: defined in two ways: first, by the addition of new knowledge, and second, by the absence of links between the newly acquired concepts and those parts of the prior knowledge repeated in the second map.
> (3) Meaningful learning [Deep]: defined by a substantial change in the knowledge structure. Thus, evidence of deep learning comprised the emergence of new links in parts of the prior-knowledge structure developed in the course of learning or the meaningful linkage of new concepts to parts of the pre-existing understanding" (Hay et al., 2008, p. 1042-1043).

Figure 4. Categorization of Learning Quality

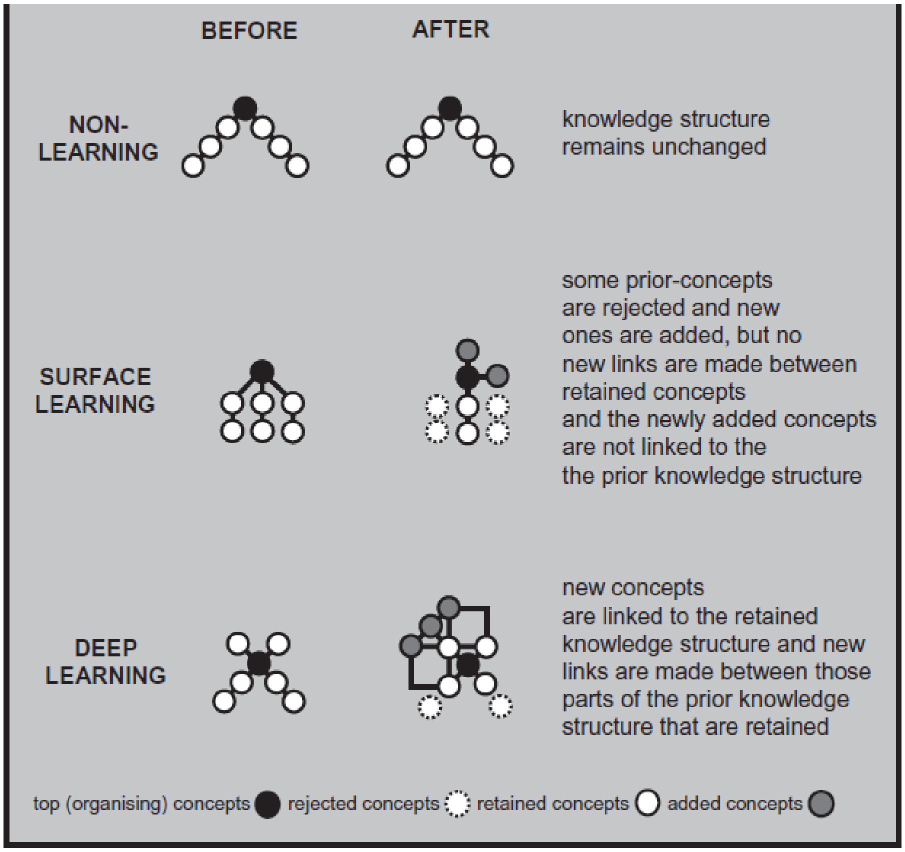


Figure 4. From Hay et al. (2008, p. 1040).

Ideally, the goal is for each student to have many new well-connected concepts that branch off their prior knowledge, demonstrating a meaningful level of learning quality. In Table 2, the participant showed a chain structure across all three concept maps. His maps demonstrated many retained concepts that were well-connected to many new concepts, and a growth in linking lines. Even though, the typology of his maps did not change he still attained a meaningful level of learning. Reaching a meaningful level of knowledge demonstrates substantial growth in the student's cognitive structure, and provides evidence that students are achieving the higher-order cognitive demand of schematic knowledge.

Method Two.

The second method of construct-a-map analysis focused on the participant's use of concepts within their concept maps compared to a list of key concepts, words, and terms targeted in the instructional materials (Hay et al., 2008). The researcher compiled a list of each of the concepts, words, and terms important for students' understanding of the content (biology and technology) addressed within the Problem Scenario. For Method Two, the raters simply highlighted each of the concepts, words, or terms within the list of instructional terms that were present within the participants' post-treatment concept maps (Appendix F, p. 92). This analysis resulted in a list and frequency count of the instructional concepts contained within the participant maps. Table 3 includes an example analysis for participant 1. This participant self-reported 27 out of the possible 65 concepts on the list of key concepts, words, and terms.

Table 3

Method Two: Participant's use of concepts, words, and terms

	Participant #1	D
Frequency of concepts words, and terms The instructional materials consisted of 65 concepts, words, and terms. By examining the students' post-treatment concept maps, the following concepts, words, and terms were evident.	1) Tools	T
	2) Materials	T
	3) Process(es)	T
	4) Living Organisms	B
	5) Phytoremediation	I
	6) Clean the Environment	I
	7) Plants	B
	8) Hydroponics	T
	9) Growing Plants without Soil	T
	10) Vertical Framing	T
	11) Drip System	T
	12) Ebb & Flow	T
	13) Deep Water Culture	T
	14) Aeroponics	T
	15) Nutrient Film Technique	T
	16) Polyvinyl Chloride (PVC)	T
	17) Wick System	T
	18) Water Pumps	T
	19) Air stones	T
	20) Oxygen	B
	21) Growth Requirements	B
	22) Water	B
	23) Root System	B
	24) Contaminants	T
	25) Salt	T
	26) Grey Water	T
	27) Barley	I

	Total	Maximum
Biology concepts, words, & terms	6	14
Technology concepts, words, & terms	18	37
Integrative concepts, words, & terms	3	14
Total concepts, words, & terms	27	65

Note. This measurement is Method Two of Hay et al.'s (2008) three-method analysis approach for recording the rater's documentation of the frequency of participants' use of key concepts, words, and terms used in their post-treatment concept maps. D = Subject domain; T = Technology, B = Biology, I = Integrative. Adapted from "Measuring the quality of e-learning," by Hay et al., 2008, *British Journal of Educational Technology*, *39*, p. 1045-1046. Copyright 2008 by Hay et al.

Method Three.

For Method Three the rater's provided scores for each of the participants' concept maps based on four constructs: conceptual richness, linkage quality, evidence of understanding, and hierarchy and structure (Hay et al., 2008) The raters assessed all of the participants' maps using a 16-item, five-point Likert scale scoring instrument and rubric (Hay et al., 2008). Refer to Appendix G to examine the instrument developed by Hay et a. (2008), and Appendix H to examine the rubric criteria developed for this study. The five-point Likert scale ranged from strongly agree to strongly disagree (Hay et al., 2008). After each rater scored the participants' maps, the researcher totaled each of the categories to calculate a gain score across all concept maps. The researcher averaged the raters' total scores for each participant. The researcher modeled Table 4 after a table used within Hay et al.'s (2008) study, but was adapted slightly to account for the three concept maps. A graph generated from these scores demonstrates participants' knowledge and understanding as a function of the quality of their prior knowledge. Hay et al. (2008) tested and confirmed the face validity, reliability, and item analysis of the instrument (p. 1043).

Table 4

Method Three: Rater scores for student's pre, mid, and post concept maps

	Concept map scores				Participant #1			
Constructs	Pre	Mid	Post	Gain	Pre	Mid	Post	Gain
Conceptual richness	0-20	0-20	0-20	+0-20	10	16	16	+6
Linkage quality	0-20	0-20	0-20	+0-20	16	17	11	-5
Evidence of understanding	0-20	0-20	0-20	+0-20	11	15	13	+2
Hierarchy and structure	0-20	0-20	0-20	+0-20	10	14	16	+6
Total	0-80	0-80	0-80	+0-80	47	62	56	+9

Note. This measurement is Method Three of the Hay et al.'s (2008) three-method analysis approach for recording rater scores for participant's pre, mid, and post concept maps based on a 16 item, five-point likert scale instrument. Adapted from "Measuring the quality of e-learning," by Hay et al., 2008, *British Journal of Educational Technology, 39*, p. 1045-1046. Copyright 2008 by Hay et al.

Validity.

Several researchers have supported the validity of using construct-a-maps to measure student's cognitive structure (Hay et al., 2008; Ruiz-Primo et al., 2001; Shavelson et al., 2005). Ruiz-Primo et al. (2001) determined that the construct-a-map method was the most valid and accurate measurement of students' cognitive structure. In 2005, Shavelson et al.'s findings coincided with this research, and concluded that this method of concept mapping yielded "high estimates" of students' cognitive structure (p. 421). They also suggested that the changes in an individual's concept maps at two different points offers evidence of cognitive structural change due to instruction (Shavelson et al., 2005). Hay et al. applied this idea within their 2008 study on the quality of students' e-learning. Both groups of researchers agree the construct-a-map method of concept mapping analysis can provide insights into changes in students' cognitive structure as a result of instruction (Hay et al., 2008; Shavelson, et al., 2005).

Interrater Reliability.

The purpose of establishing interrater reliability is to demonstrate consensus that other experts agree with the findings derived from the evidence. Researchers have shown that raters can reliably score construct-a-map concept maps (McClure et al., 1999; Ruiz-Primo et al., 2001; Shavelson et al., 2005). They found that multiple raters could consistently score concept maps even in the event that complicated decisions were required. Concept maps have generated strong interrater reliabilities around 0.90 or above on a scale of 0 to 1.0 (Shavelson et al., 2005, p. 419).

The raters for this study received training during the pilot study. Once all of the data was collected, the researcher made copies of all the students' concept maps, and a detailed list of instruction. The researcher conducted a meeting with the raters to go over the procedures and to answer any remaining questions. Each of the raters analyzed their data separately. Once each rater finished their analysis, they returned all forms to the researcher. The researcher calculated the interrater reliability using a percent agreement for Hay et al's Methods One, Two, and Three. A percent agreement is a ratio of the number of items the raters agreed upon divided by the total number of criteria, and then multiplied by 100. An overall percent agreement equal to or higher than 80% is considered reliable and preferred, for research within social science disciplines a 70% agreement is acceptable (Howell, 2007). Analyses of the interrater reliabilities for this study are presented in Chapter Four.

Qualitative Analysis

To answer RQ2, the researcher used a qualitative analysis method. In this study, the researcher focused on the phenomena of conceptual knowledge growth as evidenced within student-generated concept maps. The intent of the qualitative analysis is to determine in what ways student concept maps demonstrate their use of strategic knowledge (when, where and how) while engaged within the technological design process. A careful analysis of each of the concept maps resulted in the discovery of emerging themes from across the maps to generate a rich holistic description. Specifically, the raters were examining each participants' mid-treatment concept map in comparison to his/her post-treatment map looking for commonalities or inconsistencies between the concepts used strategically within the students' design solutions. The mid-treatment and post-treatment concept mapping prompts included the following bullet, "once you have finished your concept map, please place a check mark in the concept nodes that you plan to or have already incorporated into your design solution." These check marked concepts represented student design solutions within their concept maps and were the focus of the qualitative analysis.

Throughout the qualitative analysis, the raters wrote analytical memos to document emergent themes, possible categories, methodological questions and associations between the developing information (Rossman & Rallis, 2003). The initial stage of analysis was open coding, in which topics and possible themes of overlap were freely generated (Berg, 1989). Each rater examined the mid and post-treatment concept maps for each participant individually, they color-coded and created notes on any topics or emergent themes apparent across the check marked concepts. A detailed thematic analysis was the second stage that followed (Boyatzis, 1998), in which the raters conducted a systematic exploration to search for themes across all participants concept maps. Raters compared the topics and possible themes found in participant 1's concept maps to participant 2's, then they compared participant 1's to participant 3's, etc… until a comparison of the topics and themes across all participants was complete. Each rater generated a list of themes uncovered within all of the participants' concept maps. A constant comparative method was used to evaluate the list of themes and classify them within emerging categories. All three of the raters came together to discuss, adjust and come to a consensus on the found categories and their characteristics. Finally, the researcher defined and wrote the description based on the agreed upon categories and their designated themes (Glaser, 1965; Lincoln & Guba, 1985).

Trustworthiness.

The qualitative approach utilized in this study, established trustworthiness through credibility, dependability, and confirmability (Guba, 1981; Patton, 2002). Credibility refers to establishing the accuracy of the research findings. The researcher addressed credibility through prolonged participation within the classroom, and the use of peer debriefings (Guba, 1981). Prolonged participation within the classroom provides the researcher with more evidence and confidence in their data to substantiate their findings. Scheduled peer debriefings allowed the researcher to consult colleagues for impartial views and feedback on the design of the study. The researcher met formally and informally with a committee throughout the research process to gain insight, and suggestions for improvements to strengthen the research. Dependability refers to the stability of the data. The researcher maintained daily audit logs throughout the study to document the procedures and provide transparency to the reader. To achieve confirmability, and reduce possible bias introduced by having only one teacher researcher (Lincoln & Guba, 1985; Patton, 2002), three raters crosschecked and verified the dependability of the discovered themes and categories through data-category checking (Guba, 1981; Patton, 2002).

CHAPTER FOUR: DATA ANALYSIS AND FINDINGS

The purpose of this study was to demonstrate that the technological design-based approach to teaching biotechnology literacy develops students' cognitive connections of science and technology concepts. To provide evidence to support this purpose, the researcher collected participants' concept maps at three key intervals throughout the technological design process. Three raters analyzed the concept maps to answer the following research questions:

1. To what extent does the technological design-based approach to teaching biotechnology content result in changes to high school students' cognitive structure, specifically their documented representations of…
   a. biology concepts and connections?
   b. technology concepts and connections?
   c. the connections between biology and technology concepts?
2. In what ways does student documentation of cognitive structure demonstrate their use of strategic knowledge (when, where, and how) while engaged in a Design-Based Biotechnology Literacy Problem Scenario?

The remainder of this chapter will present the analysis and findings from the concept mapping data. The sub-questions for research question one will be presented in order using Hay, Kehoe, Miquel, Hatzipanagos, Kinchin, Keevil & Lygo-Baker's three methods for concept mapping analysis (2008). Results of a qualitative analysis will follow addressing research question two. The chapter will conclude with the interrater reliability and a summary of findings.

Research Question-1a

Research question one (RQ-1) contained three sub-questions (RQ-1a, RQ-1b, and RQ-1c). RQ-1a was, "To what extent does the technological design-based approach to teaching biotechnology content result in changes to high school students' cognitive structure, specifically their documented representations of biology concepts and connections?" To answer this question, the raters used three methods for scoring participants' concept maps developed by Hay et al. (2008). Method One included measures of student learning. Method Two was a frequency count of the concepts, words, and terms used in the participant maps compared to a list of relevant terms used in the instructional materials. Method Three used expert raters to score student maps using a 16-item Likert-scale instrument and rubric. Raters received copies of the concept maps for each participant, directions, the table for Method One, the list of terms for Method Two, the instrument and rubric for Method Three. Each rater examined the concept maps separately, completed the corresponding tables and then submitted their data to the researcher for each of the three methods of analysis.

Method One: Biology

Concept mapping analysis Method One focused on Measures of student learning as represented by Concept Map Typologies, Concept Comparisons, Meaning Making, Categorization of Learning Quality, and Integrative Meaning Making. Table 5 contains a summary of the data resulting from this analysis. To review the information according to each participant refer to Appendix I. Concept Map Typologies and Categorization of Learning Quality data are presented first, as this data applies to all of the sub-questions of RQ-1. Data specific to the biology concepts and connections specified in RQ-1a will follow.

The data presented in Table 5 demonstrates that from the pre to post-treatment four participants had a structural Typology Change and three did not. The four participants (2, 3, 4, and 7) that demonstrated this Typology Change had a chain knowledge structure for their pre-treatment concept map, but reached a network structure by their post-treatment map. The two participants (5 and 6) not demonstrating a Typology Change achieved network knowledge structures throughout all three of their concept maps. The remaining student (participant 1) maintained a chain structure throughout all of the concept maps. None of the participant's concept maps resembled a spoke structure typology. All seven participants demonstrated Structural Growth, and attained a meaningful level of Learning Quality across all of their concept maps.

RQ-1a focused on students' documented representations of biology concepts and connections. The data demonstrated that the participants retained six Biology Concepts from their pre-treatment to mid-treatment concept map. They added an average of eight new Biology Concepts to their mid-treatment map. They retained approximately 10 of the Biology Concepts used previously in their post-treatment concept map, and added nine new ones. Data contained within Table 6 shows the Mean Gain Scores for Concept Comparisons, Meaning Making, and Integrative Meaning Making. On average, the participants' used 38 Total Concepts in their post-treatment map, demonstrating a gain of 11 concepts from the mid-treatment map. This indicated an average of 19 Biology Concepts used in the participants' post-treatment concept maps, which was a gain of five Biology Concepts over the mid-treatment map.

Table 5

Method One: Measures of student learning quality

Concept map typologies		Totals		
			Categorizations	
		Spoke	Chain	Net
Concept map 1	Prior-knowledge	0	5	2
Concept map 2	Mid-treatment	0	2	5
Concept map 3	Post-treatment	0	1	6
			Yes	No
Typology change			4	3
Structural growth			7	0
Concept comparisons			Mean scores	
			Mid	Post
Biology concepts				
Frequency of retained concepts			6	10
Frequency of new concepts			8	9
Technology concepts				
Frequency of retained concepts			8	16
Frequency of new concepts			10	13
Total concepts				
Frequency of retained concepts			12	22
Frequency of new concepts			15	16
Meaning making		Mean scores		
		Pre	Mid	Post
Frequency of correct linking lines		10	15	20
Categorization of learning quality		Totals		
			Categorizations	
		Non	Rote	Meaningful
Learning quality		0	0	7
Integrative meaning making		Mean scores		
		Pre	Mid	Post
Frequency of correct linking lines between biology and technology concepts		2	6	11

Note. This measurement of student learning quality is Method One of the Hay et al.'s (2008) three-method analysis approach for recording participant's concept mapping data. Adapted from “Measuring the quality of e-learning,” by Hay et al., 2008, *British Journal of Educational Technology, 39*, p. 1045-1046. Copyright 2008 by Hay et al.

Table 6

Method One: Measures of student learning quality mean gain scores

Concept comparisons	Mean Scores		Mean Gain Scores
	Mid	Post	Mid to Post
Biology concepts			
Frequency of total concepts	14	19	5
Technology concept			
Frequency of total concepts	18	29	11
Total concepts			
Frequency of total concepts	27	38	11
Integrative concepts			
Frequency of total concepts	5	10	5

Meaning making	Mean Scores			Mean Gain Scores	
	Pre	Mid	Post	Pre to Mid	Mid to Post
Frequency of correct linking lines	10	15	20	5	5

Integrative meaning making	Mean Scores			Mean Gain Scores	
	Pre	Mid	Post	Pre to Mid	Mid to Post
Frequency of correct linking lines between biology and technology concepts	2	6	11	4	5

To gauge student understanding and Meaning Making, participants' linking lines between concepts were examined. Participants used an average of 10 correct connections in their first concept map, 15 in their second, and 20 in their third. Overall, the data demonstrates that the number of correct linking lines for all participants increased by five links between each concept map. As a whole, the data shows structural knowledge growth and that students achieved a meaningful level of learning quality with a growth in Biology Concepts and Meaning Making across the concept maps.

Method Two: Biology

Hay et al.'s (2008) Method Two of concept mapping analysis was used to compare the concepts, words, and terms used in the participant post-treatment concept maps to a list of relevant terms used in the instructional materials. Table 7 includes the data analysis results for Method 2, and the complete data set can be found in Appendix J. The teaching materials for this problem scenario contained 14 key Biology concepts, words, and terms. Of the 14, the analysis revealed the students used an average of six (43%) of the Biology concepts, words, and terms in their post-treatment concept maps. There was proportionally fewer key Biology concepts, words, and terms used by the participants for Method Two, than any other category (technology or integrative).

Table 7

Method Two: Participant's frequency for use of concepts, words, and terms

Frequency of concepts, words, and terms used by each participant per category	Participant #							Mean	Max.
	1	2	3	4	5	6	7		
Biology concepts, words, and terms	6	6	9	4	7	6	5	6	14
Technology concepts, words, and terms	18	17	15	20	20	19	21	19	37
Integrative concepts, words, and terms	3	7	11	12	9	12	12	9	14
Totals	27	30	35	35	36	37	38	34	65

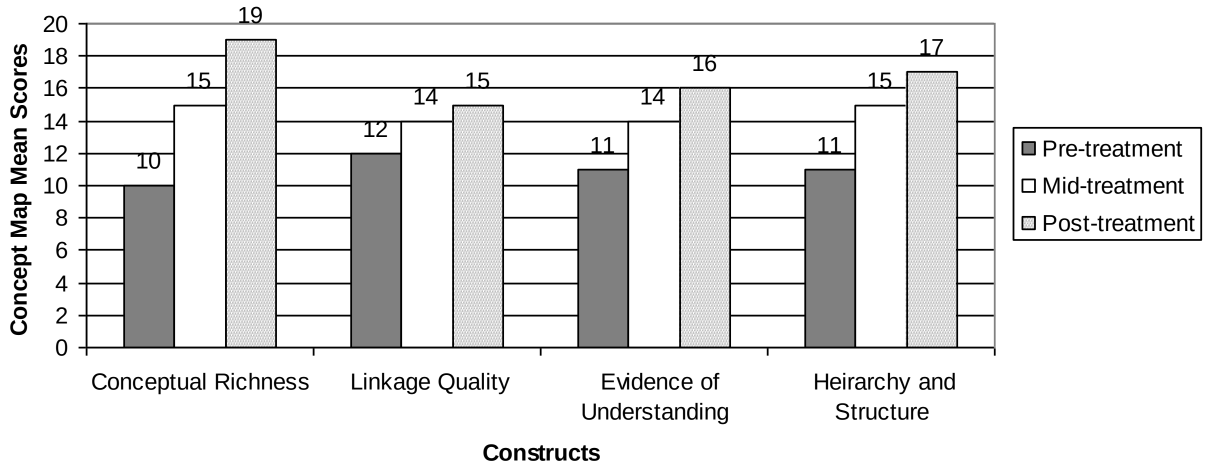
Note. This measurement is Method Two of Hay et al.'s (2008) three-method analysis approach for recording the rater's documentation of the frequency of participants' use of key concepts, words, and terms used in their post-treatment concept maps. Adapted from "Measuring the quality of e-learning," by Hay et al., 2008, *British Journal of Educational Technology, 39*, p. 1045-1046. Copyright 2008 by Hay et al.

Method Three: Constructs

The third method of Hay et al.'s analysis employs expert raters to score student maps using a 16-item Likert-scale instrument. This method of analysis does not concentrate specifically on biology, technology, or integrative concepts and connections. Instead, Method Three demonstrates student growth based on constructs in the areas of Conceptual Richness, Linkage Quality, Evidence of Understanding, and Hierarchy and Structure. Therefore, this section will focus on participants' mean concept map scores by construct. The data within Method Three of RQ-1b will be organized according to each participant's pre, mid, and post-treatment concept maps. Method Three for RQ-1c will contain data to demonstrate the gain scores for each participant based on each construct.

Figure 5 illustrates participants' mean concept map scores by construct. The data demonstrate that the participants achieved the highest mean scores (19 out of 20) and largest gain scores (+eight) in the category of Conceptual Richness. Note that rounding of all values to the nearest whole number accounted for any discrepancies between the pre and post treatment scores, and the gain score. Hierarchy and Structure and Evidence of Understanding followed Conceptual Richness, with mean post-treatment scores of 17 (+six gain score) and 16 (+five gain score) respectively. The lowest post-treatment score (15) overall and smallest gain score (+3) appeared in the Linkage Quality category.

Figure 5. Participant Mean Concept Map Scores by Construct



Within the Conceptual Richness construct participants showed a mean gain of five points between their pre and mid-treatment maps, and four gain points between their mid and post. The mean six-point gain score reported within the Hierarchy and Structure construct indicated a four-point gain for the mid-treatment map and a two-point gain for the post-treatment. The Evidence of Understanding construct revealed a gain of three points in the mid-treatment and two points in the post-treatment concept map for a total of five points. The construct for Linkage Quality showed the lowest mean growth scores, revealing a two-point gain between the pre and mid scores, and a one-point gain between the mid and post-treatment scores. The trend showed increases occurred for all constructs with the greatest gain scores demonstrated in Conceptual Richness, and lowest in Linkage Quality.

Research Question-1b

RQ-1b asked, "to what extent does the technological design-based approach to teaching biotechnology content result in changes to high school students' cognitive structure, specifically their documented representations of technology concepts and connections?" Due to the similarity between RQ-1a and RQ-1b, some of the findings already presented apply to both questions. Therefore, only new data specific to the participants' representations of technology concepts and connections are included in the sections for Methods One and Two. Method Three will contain a reexamination of the raters' scores for each participant's concept maps to demonstrate growth in the quality of their learning between maps.

Method One: Technology

Data analysis Method One included measures of student learning. Technology Concept Comparisons occurred between the frequency of retained concepts and those that were new. Table 8 indicates that students retained an average of eight Technology Concepts in their mid-treatment maps, and 16 in their post-treatment maps. Participants demonstrated an average addition of 10 new Technology Concepts to their mid-treatment and 13 to their post-treatment concept maps. The complete data set contained in Appendix I shows a growth in Technology Concepts across all participant concept maps. The average growth in Technology Concepts between mid and post-treatment maps for all participants was 11.

Table 8

Technology concept comparisons – Excerpt from Tables 5 & 6: Method One

Concept comparisons	Mean Scores		Mean Gain Scores
	Mid	Post	Mid to Post
Technology concepts			
Frequency of retained concepts	8	16	
Frequency of new concepts	10	13	
Frequency of total concepts	18	29	11

Note. Adapted from "Measuring the quality of e-learning," by Hay et al., 2008, *British Journal of Educational Technology, 39*, p. 1045-1046. Copyright 2008 by Hay et al.

Method Two: Technology

Table 9 contains data on participant's frequency for using Technology concepts, words, and terms specifically targeted within the instructional materials. On average participants' used 51% (19 out of 37) of the Technology concepts, words, and terms specified in the instructional list. Of the three categories, the participants used the most technology concepts, words, and terms contained in the instructional list. Appendix I contains the full data set for Method One, and Appendix J for Method Two. The data demonstrates fluctuations between each participant's growth in concepts, between subject domains, and analysis methods.

Table 9

Participant's frequency for use of technology concepts, words, and terms – Excerpt from Table 7

Frequency of concepts, words, and terms used by each participant per category	Participant #								
	1	2	3	4	5	6	7	Mean	Max.
Biology concepts, words, and terms	6	6	9	4	7	6	5	6	14
Technology concepts, words, and terms	18	17	15	20	20	19	21	19	37
Totals	27	30	35	35	36	37	38	34	65

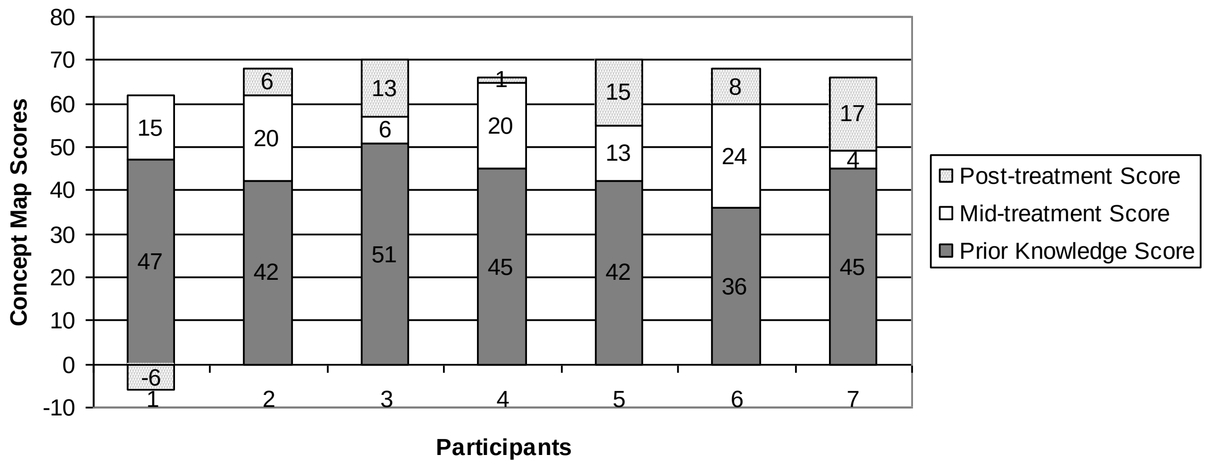
Note. This measurement is Method Two of Hay et al.'s (2008) three-method analysis approach for recording the rater's documentation of the frequency of participants' use of key concepts, words, and terms used in their post-treatment concept maps.

Method Three: Individual Participants

Method Three involved demonstrating the quality of student learning within each of their concept maps. Figure 6 presents raters' scores for each participant pre, mid and post-treatment concept maps. The graph summarizes the data in Appendix K and provides evidence that each of the participants began the design challenge with considerable prior knowledge (mean score of

44). Most of the participants (with the exception of participant 1) demonstrated growth in their scores across all of the concept maps, but to a varying degree.

Figure 6. Rater Scores for Participant Concept Maps



Data in Table 10 included the mean concept map scores for all participants. It showed that the average pre-treatment score (44), mid-treatment score (59), and post-treatment score (66) for all participants resulted in an average gain score of +22. This data indicates a mean gain score of 15 points between the pre and mid concept maps, and a gain of seven points between the mid and post maps. Appendix K contains the raw data collected and categorizes each of these scores based on the construct and participant. Analysis of data reveals that all participants demonstrated some degree of growth between each concept map, except for Participant 1. Participant 1 documented a deficit (-6 points) in total points between the mid and post-treatment concept maps.

Table 10

Method Three: Mean scores for participants' concept maps

	Concept map scores				Mean Scores			
Constructs	Pre	Mid	Post	Gain	Pre	Mid	Post	Gain
Conceptual richness	0-20	0-20	0-20	+0-20	10	15	19	+8
Linkage quality	0-20	0-20	0-20	+0-20	12	14	15	+3
Evidence of understanding	0-20	0-20	0-20	+0-20	11	14	16	+5
Hierarchy and structure	0-20	0-20	0-20	+0-20	11	15	17	+6
Total	0-80	0-80	0-80	+0-80	44	59	66	+22

Note. This measurement is Method Three of the Hay et al.'s (2008) three-method analysis approach for recording rater scores for participant's pre, mid, and post concept maps based on a 16 item, five-point likert scale instrument. Adapted from "Measuring the quality of e-learning," by Hay et al., 2008, *British Journal of Educational Technology, 39*, p. 1045-1046. Copyright 2008 by Hay et al.

Research Question-1c

The data generated from the use of Hay et al's three-method concept mapping analysis provided evidence to answer RQ-1c. This question asked, "to what extent does the technological design-based approach to teaching biotechnology content result in changes to high school students' cognitive structure, specifically their documented representations of the connections between biology and technology concepts?" The question addresses the connections between biology and technology concepts, or the integrative concepts and connections within the data. Integrative Concepts overlap the content and practices of science and/or mathematics concurrently with content and practices of technology and/or engineering. Integrative Meaning Making (or connections) are correct linking lines to an Integrative Concept, or correct linking lines between at least one Biology Concept and at least one Technology Concept. Results of the data analysis from Methods One and Two demonstrate the participants' use of integrative concepts and connections. Addressed in Method Three is the quality of student learning according to each participant's gain score per construct.

Method One: Integrative

Table 11 contains excerpts from Tables 5 and 6, which includes the data on participants' use of retained and new Integrative Concepts within their concept maps. The Integrative Concepts contained in the participants' concept maps were not documented directly within Method One. When the raters examined the participants' concept maps, they counted the Biology, Technology, and Total Concepts. The Integrative Concepts within the maps were included in the frequency counts for both Biology and Technology Concepts. Therefore, the frequency of Integrative Concepts can be determined by the overlap in the number of Biology and Technology Concepts. By adding the frequency of retained Biology and Technology Concepts in Table 5 and subtracting the frequency of Total retained concepts, the number of retained Integrative concepts can be determined.

Table 11

Integrative concept comparisons – Excerpt from Tables 5 & 6: Method One

Concept comparisons	Mean Scores		Mean Gain Scores
	Mid	Post	Mid to Post
Biology concepts			
Frequency of retained concepts	6	10	
Frequency of new concepts	8	9	
Frequency of total biology concepts	14	19	5
Technology concept			
Frequency of retained concepts	8	16	
Frequency of new concepts	10	13	
Frequency of total technology concepts	18	29	11
Total concepts			
Frequency of retained concepts	12	22	
Frequency of new concepts	15	16	
Frequency of total concepts	27	38	11
Integrative concepts			
Frequency of retained concepts	2	4	
Frequency of new concepts	3	6	
Frequency of total integrative concepts	5	10	5

Note. Adapted from "Measuring the quality of e-learning," by Hay et al., 2008, *British Journal of Educational Technology, 39*, p. 1045-1046. Copyright 2008 by Hay et al.

Data in Table 11 revealed the average number of Integrative Concepts using this method. The data demonstrates participants' retained an average of two Integrative Concepts in their mid-treatment map and added three new Integrative Concepts. Participants' retained four of the Integrative Concepts in their post-treatment map, and they included six additional Integrative Concepts. The data from Method One indicates an average of five Integrative Concepts used in the participants' mid-treatment concept map and 10 in their post-treatment map for a gain of five integrative concepts between the maps.

The data presented in Table 12 includes the Method One categories of Meaning Making, and Integrative Meaning Making. The data indicates an average increase in the Frequency of correct linking lines between Biology and Technology Concepts across all of the participants' concept maps. The participants documented a mean of two integrative linking lines out of 10 correct links (20%) in the pre-treatment concept map. On average in the mid-treatment map, 6-15 of the correct linking lines were integrative (40%), and the post-treatment map included 11 integrative links out of 20 (55%). This data revealed that all students demonstrated some degree of growth in Integrative Concepts and Meaning Making from the pre to post-treatment concept maps.

Table 12

Integrative meaning making – Excerpt from Table 6: Method One

Meaning making	Mean Scores			Mean Gain Scores	
	Pre	Mid	Post	Pre to Mid	Mid to Post
Frequency of correct linking lines	10	15	20	5	5
Integrative meaning making	**Mean Scores**			**Mean Gain Scores**	
	Pre	Mid	Post	Pre to Mid	Mid to Post
Frequency of correct linking lines between biology and technology concepts	2	6	11	4	5

Note. Adapted from "Measuring the quality of e-learning," by Hay et al., 2008, *British Journal of Educational Technology, 39*, p. 1045-1046. Copyright 2008 by Hay et al.

Method Two: Integrative

Data analysis Method Two focused on participant's use of key concepts, words, and terms. The data within Table 13 demonstrates that the students used an average of nine out of a possible 14 Integrative concepts, words, and terms within their post-treatment concept maps.

This accounts for 64% of the Integrative concepts, words, and terms on the instructional list. The percentage of Integrative concepts, words, and terms used by the participants was higher than the subject domains (biology or technology). In total, the participants data revealed a mean of 34 out of the 65 (52%) of the relevant concepts, words, and terms on the instructional list.

Table 13

Participant's frequency for use of integrative concepts, words, and terms – Excerpt from Table 7

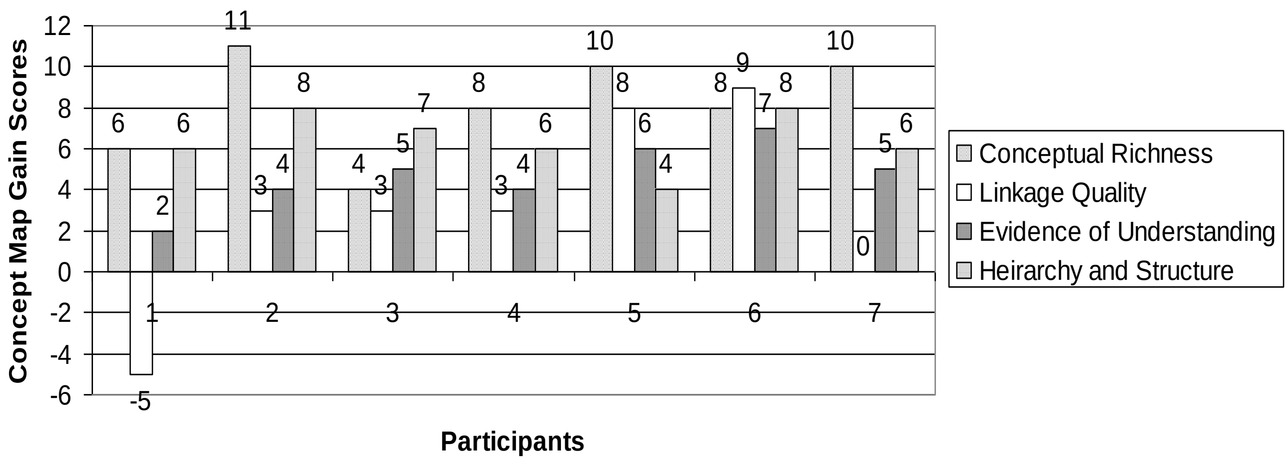
Frequency of concepts, words, and terms used by each participant per category	Participant #								
	1	2	3	4	5	6	7	Mean	Max.
Biology concepts, words, and terms	6	6	9	4	7	6	5	6	14
Technology concepts, words, and terms	18	17	15	20	20	19	21	19	37
Integrative concepts, words, and terms	3	7	11	12	9	12	12	9	14
Totals	27	30	35	35	36	37	38	34	65

Note. This measurement is Method Two of Hay et al.'s (2008) three-method analysis approach for recording the rater's documentation of the frequency of participants' use of key concepts, words, and terms used in their post-treatment concept maps. Adapted from "Measuring the quality of e-learning," by Hay et al., 2008, *British Journal of Educational Technology, 39*, p. 1045-1046. Copyright 2008 by Hay et al.

Method Three: Individual Participants by Construct

Once again, Method Three does not address integrative concepts and connections specifically, but instead addresses the overall quality of the students' concept maps based on rater scores. Participants' gain scores by construct were depicted in Figure 7. The gain scores in Figure 7 refer to the amount of growth in a particular construct from the participants' pre-treatment map to their post-treatment concept map. Figure 7 demonstrated that the participant's largest gain scores occurred in order of the following constructs: Conceptual Richness, Hierarchy and Structure, Evidence of Understanding, and Linkage Quality. It is apparent in the graph that the concept map scores for participants 1 and 7 had an impact on the low average gain scores in Linkage Quality. Participant 1 received a negative five and participant 7 received a zero gain score for Linkage Quality. The rest of the individual construct gain scores demonstrated growth, but the extent of growth varied noticeably between participants. All participants achieved a positive total gain score, between nine and 32.

Figure 7. Participant Concept Map Gain Scores by Construct



Research Question 2

Research Question 2 (RQ-2) asked, “in what ways does student documentation of cognitive structure demonstrate their use of strategic knowledge (when, where, and how) while engaged in a Design-Based Biotechnology Literacy Problem Scenario?” Strategic knowledge is a higher-order cognitive demand, which targets an individual’s understanding of when, where, and how to apply their knowledge (NAGB, 2009). A Design-Based Problem Scenario continually challenges students to make informed design decisions to arrive at a solution to a given problem. Within this study, students’ received the following prompt for the mid and post-treatment concept maps: “please place a check mark in the concept nodes that you plan to or have already incorporated into your design solution”. This prompt was developed to elicit data on students design decisions and target their strategic knowledge. To answer research question 2, the raters examined the participants mid and post-treatment concept maps for checked concept nodes using a qualitative analysis.

Throughout the qualitative analysis, the raters refined their investigation by reviewing the data to identify themes. Based on the commonalities among the themes, the raters organized the data into three main categories: strategic knowledge questions, pathways, and meaningful learning. Holistic descriptions for each category were developed to present the identified themes. The category on strategic knowledge questions examined in what ways the participants demonstrated their understanding of when, where, and how to apply their knowledge within their design solution. The second category on pathways describes the themes surrounding the pathways revealed within the data. The final category describes the refined themes on students' meaningful learning.

Strategic Knowledge Questions

Raters examined the participants' mid and post-treatment concept maps to find evidence of each participant's design decisions. During the first consensus meeting held by the raters, they determined the students made informed choices in regards to the types of hydroponics systems used, methods of phytoremediation, plant selection, growth requirements of the plants, and cleaning the grey water. Each rater generated a list of when, where and how questions to describe the decisions made by the participants as evidenced by the data within the concept maps. Then, another consensus meeting was held to compare and refine the list of when, where, and how questions. The raters reexamined the questions a third time to ensure each question targeted strategic demands and to refine the language between questions to avoid repetition. For each iteration, the raters examined the data separately to develop their own questions. Then, they discussed their questions as a group until they reached consensus.

Raters used the same process to determine and refine the data required to support each question. They determined that "when" questions focused on *time* and student data should indicate an *event or occasion* in which to use a particular method. Raters determined that "where" questions indicated a *place, situation, or direction*. Therefore, to address a "where" question, the participants' concept maps needed to account for a *place, situation, or direction*. To demonstrate data to support a "How" question students' concept maps had to explain their *reasoning or methods* for selecting their design decisions. The raters held a fourth meeting to confirm their earlier decisions. The resulting list included two "when," two "where," and six "how" questions. Table 14 presents the list of all ten strategic knowledge questions.

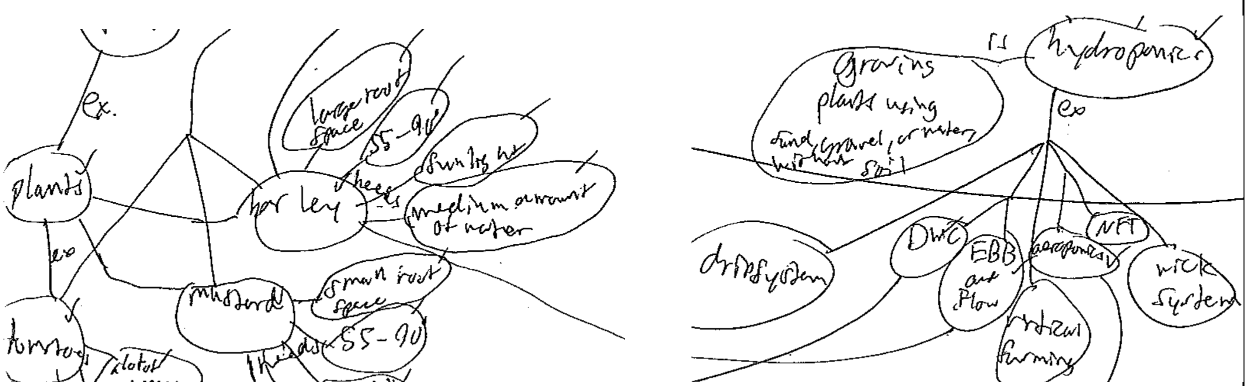
Table 14

Strategic knowledge questions

"When"
1. When would you use a hydroponics system?
2. When would you use barley or sugar beets to phytoremediate grey water?
"Where"
1. Where can you use plants to phytoremediate toxins?
2. Where in your designed system do you account for the plants needs?
"How"
1. How did you select which hydroponics system to use?
2. How are you going to clean the grey water?
3. How did you select which phytoremediation system to use?
4. How did you determine which plants to grow?
5. How does your design meet human needs and wants (i.e., clean water and food for the cafeteria)?
6. How did you select a plant to remove the salt from the grey water?

Raters reanalyzed the concept maps, but this time to examine the data to document evidence for each question. Individually, each rater examined the mid and post-treatment concept maps of each participant. If the rater determined the data in a concept map addressed a question, then they documented the corresponding participant and concept map number (2 indicated the mid-treatment concept map, and 3 the post). For example, “Where” question two asked, “Where in your designed system do you account for the plants needs?” Raters determined evidence to address this question should include “a *place, situation, or direction* in which the student’s design decisions accommodated the plants growth requirements (i.e., light, nutrient needs, root size, ph level, and temperature).” Figure 8 includes two excerpts from Participant 3’s Post-Treatment Concept Map. Participant 3 demonstrated evidence to address this question by including the needs of the plants, and connecting the plants to a hydroponics system that would support the plants needs (i.e., barley was linked to the ebb and flow hydroponics system). To document this data under the second “Where” question the raters recorded Participant 3, and Concept map 3 (3 indicated the post-treatment map). The researcher compiled the data from all raters. Table 15 contains the data documenting participants’ concept maps addressing the “when” questions. Table 16 reveals the evidence for the “where” questions, and Table 17 presents the “how” questions.

Figure 8. Excerpts from Participant 3’s Post-Treatment Concept Map



When Questions.

Raters identified two "when" questions within the participant's concept maps. Table 15 reveals the first question, "When would you use a hydroponics system?" Raters analyzed student concept maps for data demonstrating the use of hydroponics in an occasion when there is a need to grow plants without the use of traditional soil. Participants 1, 3, and 5 provided such evidence within their third concept map. The data in Table 15 indicates the second "when" question was "when would you use barley or sugar beets to phytoremediate grey water?" Participants 1, 4, 6, and 7 addressed this question within their post-treatment maps. These participants' concept maps described the use of barley or sugar beets in the event that water is contaminated with sodium chloride.

Table 15

Strategic knowledge: Data to support "when" questions

Question	A response to this question should include a *time, event, or occasion* in which…	Participant	Concept Map	
			Mid	Post
1. When would you use a hydroponics system?	there is a need to grow plants without traditional soil	1		3
		3		3
		5		3
2. When would you use barley or sugar beets to phytoremediate grey water?	water is contaminated with sodium chloride (barley and sugar beets are hyperaccumulators of sodium chloride)	1		3
		4		3
		6		3
		7		3

Note. The data within the Concept Map column indicates in which of the participants' concepts maps the "when" questions were addressed. The number 2 signifies the mid-treatment map, and 3 signifies the post-treatment concept map.

Where Questions.

Participants' concept maps revealed two "where" questions as indicated within Table 16. The first "where" question was, "where can you use plants to phytoremediate toxins?" Raters determined a justifiable response would infer, “any place in which toxins need to be removed from a contaminated site, and there is a plant able to hyperaccumulate the toxin.” Participants 1 and 4 included data to address this question within both the mid and post-treatment concept maps. Participants 3, 6, and 7 also addressed this question within their post-treatment maps. “Where in your designed system do you account for the plants needs?” was the second “where” question. Data to address this question required the students to identify a situation in which their designed system accommodated the plants growth requirements (i.e., light, nutrient needs, root size, ph level, and temperature). The post-treatment concept maps of participants 1, 2, 3, 5, 6, and 7 included such evidence, in addition to the mid-treatment maps of participants 3, 5, and 7.

Table 16

Strategic knowledge: Data to support "where" questions

Question	A response to this question should include a *place, situation, or direction* in which…	Participant	Concept Map	
			Mid	Post
1. Where can you use plants to phytoremediate toxins?	toxins need to be removed from a contaminated site, and there is a plant able to hyperaccumulate the toxin (i.e., barley/sugar beets will hyperaccumulate sodium chloride from grey water)	1	2	3
		3		3
		4	2	3
		6		3
		7		3
2. Where in your designed system do you account for the plants needs?	the student's design decisions accommodated the plants growth requirements (i.e., light, nutrient needs, root size, ph level, and temperature)	1		3
		2		3
		3	2	3
		5	2	3
		6		3
		7	2	3

Note. The data within the Concept Map column indicates in which of the participants' concepts maps the "where" questions were addressed. The number 2 signifies the mid-treatment map, and 3 signifies the post-treatment concept map.

How Questions.

Table 17 contains the data to support the six “how” questions revealed within the participants’ concept maps. The first question addressed was “how did you select which hydroponics system to use?” Raters determined that the participants needed to establish reasoning for the selection of the hydroponics systems based on the growth requirements of the plants (i.e., light, nutrient needs, root size, ph level, and temperature). Participant 3 addressed this question within the mid-treatment concepts maps, and Participants 2, 3, 5, and 7 addressed it in their post-treatment. The second “how” question was “how are you going to clean the grey water?” A response to this question required the participants to include a method for using plants and phytoremediation to remove the contaminant from the grey water. All of the participants’ post-treatment concept maps included data to support this question. Participants 1, 4, and 7 also included data to support this question within their mid-treatment concept map. Question three of the “how” questions asked, “how did you select which phytoremediation system to use?” The participants had to determine which method of phytoremediation to use based on the plant selected. Since, barley and sugar beets phytoextract sodium chloride from grey water, a decision should have been evident within their concept maps. Participant 3, 4, 6, and 7 included this information in the post-treatment map, and Participant 4 included it in the mid. The fourth “how” question was, “how did you determine which plants to grow?” An acceptable response included at least one plant (barley or sugar beets) for phytoremediation, and two plants to supply food for the school cafeteria. All of the participants included this information within their mid-treatment concept map, and Participants 3, 4, 6, and 7 included it within the post-treatment map. Question five asked, “how does your design meet human needs and wants (i.e., clean water and food for the cafeteria)?” To address this question the participants had to select barley or sugar beets to clean the grey water, and plants to supply food for the school cafeteria. The mid-treatment concept map for Participant 4, and post-treatment concept maps of Participants 3, 4, 6, and 7 revealed evidence to support question five. The final "how" question was, "how did you select a plant to remove sodium chloride from the grey water?" The participants had to select the most beneficial plant for their design, barley or sugar beets, and explain its use as a method to phytoextract sodium chloride from the grey water to justify a response to question six. Raters determined that Participants 3 and 4 addressed question 6 within their mid-treatment concept map, and Participants 1, 3, 4, 6, and 7 addressed it in their post-treatment map.

Table 17

Strategic knowledge: Data to support "how" questions

Question	A response to this question should include a *reasoning or method* for…	Participant	Concept Map	
			Mid	Post
1. How did you select which hydroponics systems to use?	selecting a hydroponics systems based on the growth requirements of the plants (i.e., light, nutrient needs, root size, ph level, and temperature)	2		3
		3	2	3
		5		3
		7		3
2. How are you going to clean the grey water?	using plants and phytoremediation (specifically phytoextraction) to remove the contaminant (sodium chloride) from the grey water	1	2	3
		2		3
		3		3
		4	2	3
		5		3
		6		3
		7	2	3
3. How did you select which phytoremediation system to use?	determining the phytoremediation system used based on the plant selected (barley and sugar beets will phytoextract sodium chloride from grey water)	3		3
		4	2	3
		6		3
		7		3
4. How did you determine which plants to grow?	selecting one plant (barley or sugar beets) for phytoremediation, and two plants as nutrition for the school cafeteria	1	2	
		2	2	
		3	2	3
		4	2	3
		5	2	
		6	2	3
		7	2	3
5. How does your design meet human needs or wants (i.e., clean water and food for the cafeteria)?	selecting barley/sugar beets to clean the grey water, and plants to provide food for the school cafeteria	3		3
		4	2	3
		6		3
		7		3
6. How did you select a plant to remove the sodium chloride from the grey water?	selecting a plant (barley or sugar beets) to hyperaccumulate the sodium chloride from the grey water	1		3
		3	2	3
		4	2	3
		6		3
		7		3

Note. The data within the Concept Map column indicates in which of the participants' concepts maps the "where" questions were addressed. The number 2 signifies the mid-treatment map, and 3 signifies the post-treatment concept map.

To summarize the findings collected on the "when," "where," and "how" questions, the data was compiled into a frequency table organized by participant. Table 18 contains the frequency of strategic knowledge questions addressed within each participants mid and post-treatment concept maps. The data within the participants' concept maps addressed an average of three strategic knowledge questions within the mid-treatment concept map, and six questions within the post-treatment concept map. This demonstrated that the participants addressed an average of three additional strategic knowledge questions between their mid and post-treatment concept maps. The data revealed from this analysis suggests that the technological design-based approach to instruction challenged students to make design decisions. This provided some indication that the Design-Based Biotechnology Literacy Problem Scenario demands a higher level of cognitive knowledge, which was the focus of RQ-2.

Table 18

Strategic knowledge: Frequency of questions addressed by each participant

	Concept Map		
Participant	Mid (2)	Post (3)	Total
1	3	5	8
2	1	3	4
3	4	9	13
4	6	7	13
5	2	4	6
6	1	8	9
7	3	9	12
Total	20	45	65
Mean	2.86	6.43	9.29

Note. A frequency count (*f*) was used to represent the strategic knowledge questions addressed by each of the participants.

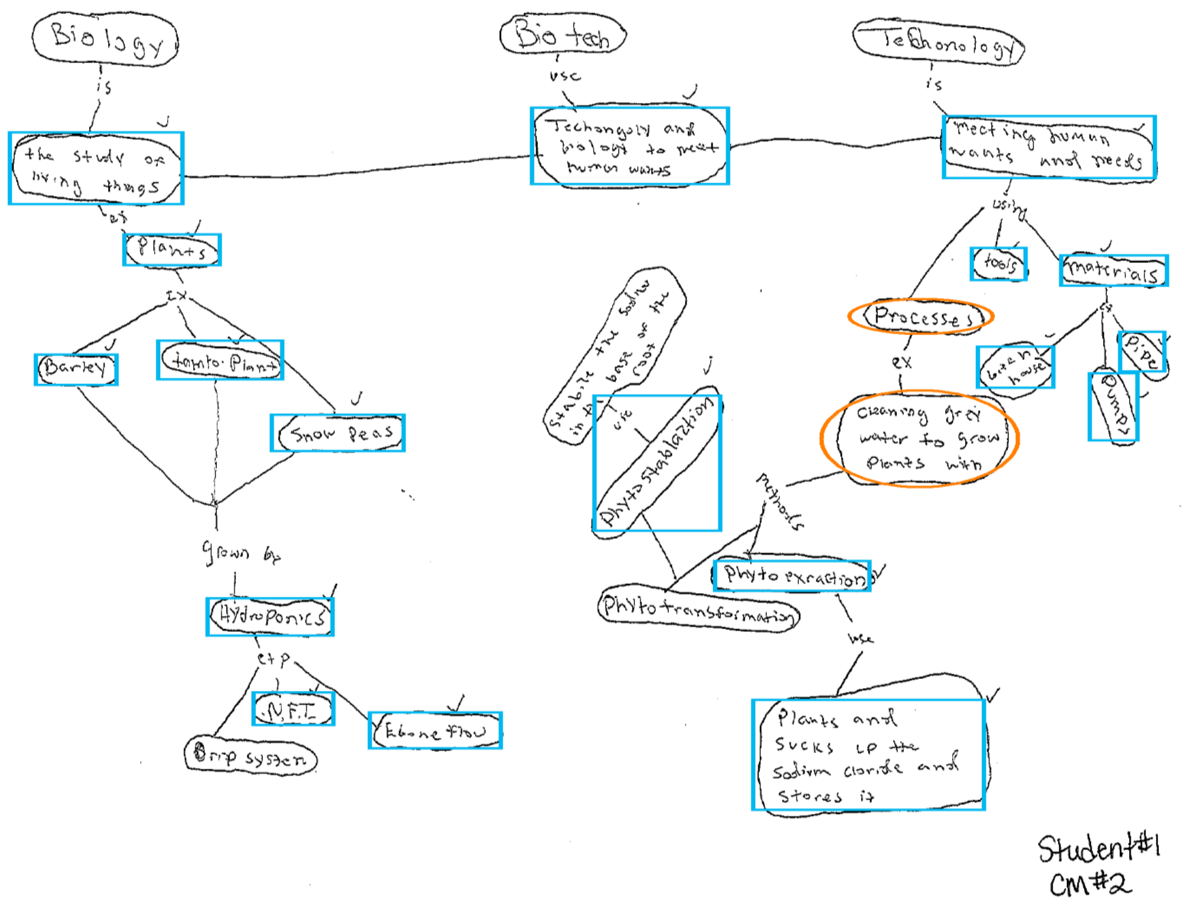
Pathways was the second category uncovered within the qualitative analysis for RQ-2. As described previously, the mid and post concept mapping prompt required the students to "please place a check mark in the concept nodes that you plan to or have already incorporated into your design solution." Raters found that the students' checked concepts exist in pathways throughout the data. Since the checked concepts signify students' informed decisions to design a solution to the Problem Scenario, the pathways provide indications of the students' strategic understanding. Raters examined each participants mid and post-treatment maps separately and in combination to uncover commonalities or inconsistencies between the concepts used strategically within the students' design solutions. Raters used a constant comparative method to evaluate the themes across the data and develop a holistic description of the pathways category. The description will follow in the next section of this chapter. The final qualitative section used the same constant comparative method for analyzing themes to present the description on the meaningful learning category.

Pathways

A commonality found within the participant's concept maps was that the checked concept nodes are evident as pathways throughout the students' maps. Appendix L contains Participant 4's mid and post-treatment concept maps. All of the checked concepts in the map represent the Participant's design solution. The checked concepts were designated with a box around them to provide clarity to the reader. These concept maps demonstrate an example of the pathways (boxed concepts) created by the participants' design solutions.

Raters uncovered several consistencies and inconsistencies regarding the pathways revealed within the participants' concept maps. Almost every hierarchical level within the student maps contained a checked concept. Those concepts in a pathway that did not contain a check appeared to be an error made by the student. This was an understanding agreed upon by the raters based on the analysis. Raters observed that when a concept at the start or middle of a pathway chain lacked a check, but a checked concept followed, it was implied that all of the concepts preceding it in the chain had a check. Because concept maps contain a hierarchy within its structure, raters believed this was a legitimate inference. For instance, Figure 9 includes the mid-treatment concept map generated by Participant 1. All of the concepts checked by Participant 1 for inclusion in the design solution received a box around it to make it visible to the reader. Concepts contained within the pathway, but not checked by Participant 1 received an oval around them. These concepts included, "processes" and "cleaning grey water to grow plants with". Because these two concepts preceded checked concepts (i.e., "phytoextraction", and "uses plants and sucks up the sodium chloride and stores it") in a pathway, and the content of the concepts supported the decision, the raters inferred that these concepts should have been included and this was probably a mistake made by Participant 1.

Figure 9. Participant 1's Mid-Treatment Concept Map



By examining these pathways in all of the participants' mid and post-treatment maps, the raters found additional consistencies across the maps. First, the participants checked a majority of the concepts within their maps, demonstrating that most of information contained within the concept maps was significant to their design solution. Unchecked concepts usually appeared within a portion of the map that diverged into a spoke typology. In these instances, the participants faced options and they usually selected at least one or two of the spokes to include within their design solution. The path or spokes selected by the participant contained more detailed information than the other spokes. The data showed 23 instances within the participants' mid and post-treatment concept maps where the information surrounding the participants' selected pathways was more developed. Any spokes not selected by the participants ended within one or two concepts. This evidence suggests that as the participants' understanding of biology and technology concepts improved, it influenced their design solutions.

Meaningful Learning

By examining each participant's mid and post-treatment maps using a constant comparative qualitative analysis, themes developed demonstrating that the structure and extent of each participant's knowledge grew deeper and more meaningful with each concept map. This was evident by an increase in the amount of information and growth in the richness of the data. Participants' pre-treatment concept maps included minimal content beyond the information contained within the design challenge of the problem scenario. Each of the participants' successive concept maps built off their prior knowledge demonstrated within their pre-treatment map. The structure of the student's prior knowledge remained the same between the pre and mid-treatment concept maps for all participants, but the extent of their biology and technology knowledge grew in complexity and depth. The degree of knowledge growth demonstrated within the data varied greatly for each participant, and subject domain. Overall, the mid-treatment maps demonstrated more subject domain concepts and connections, and incorporated more integrative concepts and links connecting the subject domains. The data from the participants' post-treatment maps demonstrated further knowledge gains in the complexity of their descriptions, and integrative connections. Six of the participants maintained a similar cognitive structure between their mid and post-treatment maps. This data reveals that participants' biology, technology, and integrative concepts and connections grew from their prior knowledge to include a more complex and meaningful understanding of the Problem Scenario and their design solution.

Raters found additional themes within the qualitative analysis, demonstrating that the participants understanding was clear and any misconceptions or omitted information were easily identifiable. Appendix M contains Participant 6's mid and post-treatment concept maps. The largest box in the mid-treatment map indicates a misunderstanding possessed by Participant 6. The data demonstrates that Participant 6 thought all three plants (barley, lettuce, and tomatoes) included in the design solution were hyperaccumulators. Only barley or sugar beets will hyperaccumulate sodium chloride from the grey water. Participant 6's post-treatment map indicated (again by a large box) that he resolved this misunderstanding. The smaller boxes on participant 6's mid-treatment concept map indicate omitted information. When the participants excluded information, it caused the raters to question whether or not the students knew the information or if it was an oversight. Unlabeled linking lines were the most commonly found omitted information across the concept maps. Each participant left at least one or more of the linking lines unlabeled. In the majority of the circumstances, it appeared to be a mistake and not intentional.

Finally, the raters agreed that the information contained within the concept maps was subjective and unique to each student. For a teacher or researcher to gain a thorough understanding of the students' knowledge growth and level of cognitive demands attained, a careful analysis and interpretation of the data was required. A qualitative method of analysis provided the best opportunity to achieve this level of investigation. For example, as some of the students knowledge increased, some of the participants began to leave off the basic information contained in their pre-treatment concept maps, and the additional information contributed to the complexity of the maps. Research Method One showed that Participant 5's concept maps contained the most concepts and connections, but the increased complexity of the maps made them difficult to decipher. This caused the raters to question how clearly the participant actually understood the information. Refer to Figures 10 and 11 or Appendix N to examine the growth in complexity of Participant 5's mid and post-treatment concept maps. In contrast, participant 4 (Appendix L) addressed the most strategic knowledge questions (13) within the qualitative analysis, developed clear concept maps, but only documented an average number of concepts and connections within analysis Methods One and Two. Appendix O contains Participant 1's mid and post-treatment concept maps. The breadth and depth of knowledge increased from the second to third concept map, but the clarity and transparency of the map decreased. The lack of clarity in the third map resulted in a loss according to many of the previous analysis methods. These examples demonstrate that the value of the information contained in the data is more apparent by examining the concept maps qualitatively.

Figure 10. Participant 5's Mid-Treatment Concept Map

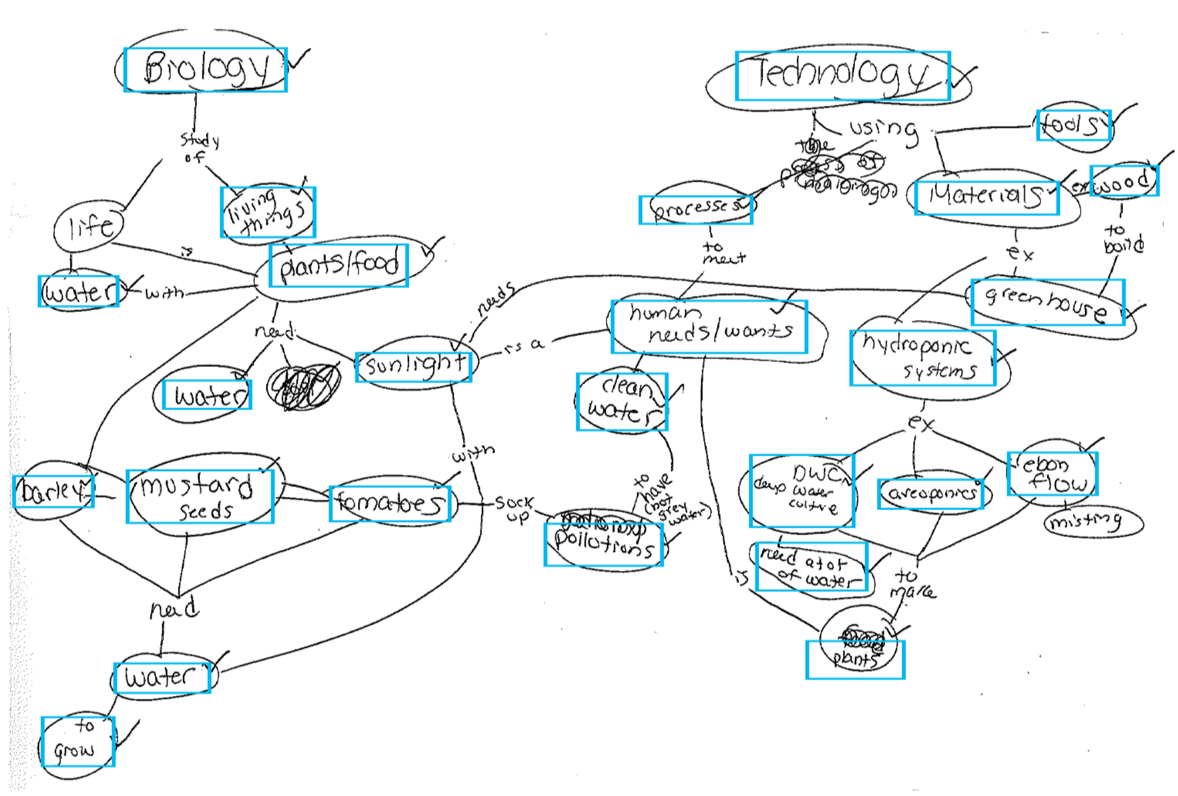
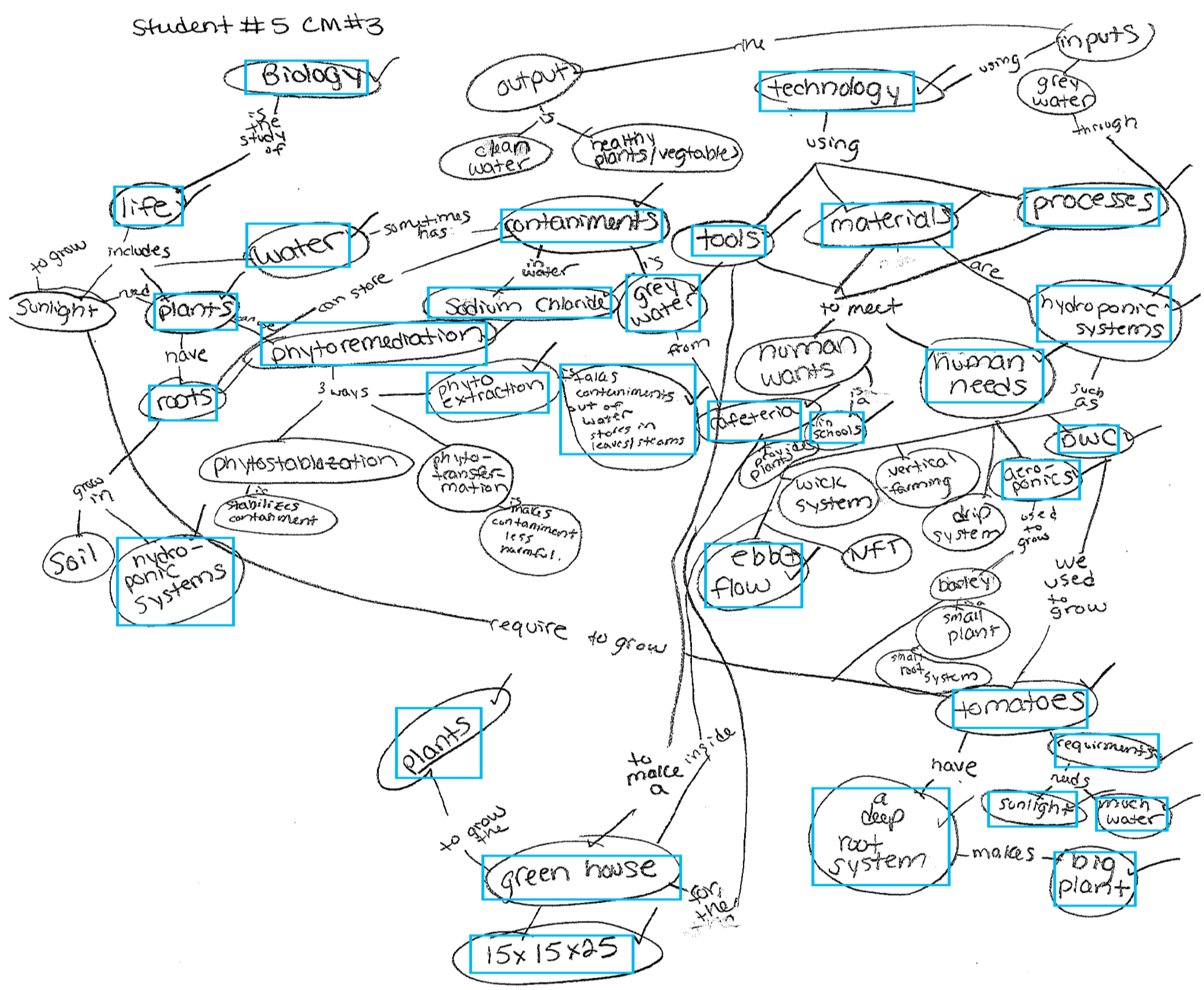


Figure 11. Participant 5's Post-Treatment Concept Maps



The qualitative analysis of the data within the participants' concept maps revealed themes that fit into three categories. These categories included strategic knowledge questions, pathways, and meaningful learning. The data described within these three categories provides some indication that the Design-Based approach to instruction places higher-order cognitive demands on the students. The compilation of data presented within this section applies directly to RQ-2, which asked in what ways student documentation of cognitive structure demonstrates their use of strategic knowledge.

Interrater Reliability

Interrater reliability is the degree in which raters agree on the findings resulting from the data analysis. To establish interrater reliability for Methods One, Two and Three the researcher calculated a percent agreement to determine the consensus reached by the raters. A percent agreement is a ratio of the number of items the experts agreed upon divided by the total number of criteria, and then multiplied by 100. An overall percent agreement equal to or higher than 80% is preferred, but an acceptable consensus is 70% (Howell, 2007). Therefore, the researcher will accept an interrater reliability above 70%. For Method One, the raters reached an 81.7% agreement on the analysis of participant's knowledge structural change and learning quality. The raters agreed on 93.8% of the concepts, words, and terms the participants used in their post-treatment concept maps for analysis within Method Two. The concept map scores assigned by the raters for Method Three attained a 71.1% agreement. Therefore, the percent agreement for Methods One and Two are considered favorable and reliable, and Method Three is considered acceptable.

Summary of the Findings

The analysis of data for RQ-1a indicated that all participants demonstrated Structural growth and reached a meaningful level of Learning Quality. Method One revealed the average number of correct linking lines, and Biology Concepts for all participants increased. Method Two demonstrated support for the participants' use of key Biology concepts, words, and terms on the instructional list. The combined data from both research methods support participant growth of Biology concepts and connections for all participants.

The data regarding RQ-1b indicated that all participants demonstrated a gain in the number of technology concepts used in their concept maps as established by analysis Method

One. Overall, the participants demonstrated larger gains in Technology concepts than Biology concepts. The data from Method Two, suggests that the Technology concepts, words, and terms used by the participants were important to the Problem Scenario based on their inclusion in the instructional list.

The data analysis for RQ-1c indicated an increase in the average of integrative concepts and connections across the participants' concept maps as demonstrated in Method One. A majority of the integrative concepts used by the participants in their post-treatment concept maps were on the instructional list of relevant terms established within Method Two. The participants included a higher percentage of integrative concepts, words, and terms from the instructional list than biology or technology.

The data analysis for Method Three showed that all of the participants demonstrated positive total gain scores across all concept maps, pre to post. Most of the participants demonstrated growth in their scores between each concept map and construct but to a varying degree. The largest gain scores across all participants occurred in the construct of Conceptual Richness, and the lowest gain scores were in Linkage Quality. The data from Method Three indicates that the quality of student's growth varied depending on the construct, concept map, and participant.

The qualitative analysis focused on the evidence related to the students' strategic knowledge. The data analysis for RQ-2 revealed ten "when," "where," and "how" questions from the students concept maps. The participants' concept mapping data indicated an increase in the number of strategic knowledge questions addressed from the mid to the post-treatment maps. Participants' checked concept nodes of their design solution revealed pathways throughout the concept maps. As the participants' prior knowledge grew to include more biology, technology, and integrative concepts and connections, the data indicated a more complex and meaningful understanding of the Problem Scenario and their design solution. Raters' ability to gain a thorough understanding of student knowledge when using a qualitative approach to analyze the data indicated the value for using this method.

Data analysis across all four methods indicated that all participants experienced some degree of growth in biology, technology, and integrative concepts and connections. In addition, all of the participants reached a meaningful level of learning quality. The data indicated a varying degree of growth for each participant's concepts, between subject domains, and analysis methods. Findings across all data analysis methods indicated that the technological design-based approach to instruction challenged students to make design decisions. This provides some indication that the Design-Based Biotechnology Literacy Problem Scenario presents students with cognitive demands at the strategic knowledge level.

CHAPTER FIVE: DISCUSSION, IMPLICATIONS, AND RECOMMENDATIONS

Chapter Five includes a discussion of the findings, the implications of the study, and recommendations for further research.

Discussion

The purpose of this study was to demonstrate that the technological design-based approach to teaching biotechnology literacy develops students' cognitive connections of science and technology concepts. As established within the literature review, cognitive structure is a person's mental organization of information, and it is idiosyncratic. There is a structure and extent to an individual's knowledge within a subject domain. The extent of a person's knowledge relates to the depth and complexity of their understanding. When an individual's cognitive structure grows to include more concepts and connections, it reflects a growth in their understanding. The extent of an individual's learning (i.e., depth and complexity) of new knowledge exists on a continuum from rote to meaningful (low to high). Meaningful learning is well connected and anchored in concrete ways to existing concepts within the cognitive structure (Ausubel, 1968). Meaningful knowledge is relevant to the learner and more easily retainable. Schematic and strategic knowledge demands encourage meaningful learning and active construction in memory. Increases in the extent of an individual's knowledge can be demonstrated by examining changes revealed in concept maps. As such, these changes can be used to explain the meaning of data and justify the participant's use of schematic and strategic knowledge to achieve the goal of this study.

When an individual's cognitive structure grows to include more concepts and connections, it reflects a growth in their understanding. As indicated throughout many of the different methods of analysis used within the study, the number of technology, biology, and integrative concepts and connections used by the participants' increased between each successive concept map. This indicates that as the students' knowledge structure grew to include more concepts and connections, it reflected a growth in the extent of their understanding. Each concept map represents a 'snap shot' in time of the students' representations of meaning (Shavelson et al, 2005). Since, each concept map was collected at three key intervals throughout the technological design based approach to instruction; the concept maps combined demonstrate changes in students' cognitive structure due to instruction.

The extent or depth and complexity of a person's understanding exist on a continuum from rote to meaningful learning. Ausubel's theory on cognitive learning articulates the importance of building upon students' prior knowledge (1968). It is the connections between old and new knowledge that promotes meaningful learning and the development of cognitive structure. As demonstrated within Method One and the qualitative analysis of the study each student reached a meaningful level of learning quality. This indicates that their newly acquired knowledge was anchored in concrete ways to their prior (retained) knowledge. The increase in the extent of students' biology and technology domain knowledge demonstrates some degree of growth beyond the minimal structure expected of a novice.

The degree of knowledge growth demonstrated within the data varied greatly for each participant, construct, and subject domain. Since, cognitive structure is humans' inherent and idiosyncratic mental organizations of information (Ruiz-Primo & Shavelson, 1996), a varying degree of knowledge growth across participants' was expected. For this reason, mean scores were used across the analysis methods to describe the average growth and gains across participants' concept maps. As evidenced throughout the findings students' data demonstrated growth within each cognitive domain, and method of analysis. One disadvantage of using average gain scores with a small sample size is that any outliers tend to skew the data. One example where this occurred was within data analysis Method Three. Participant 1 demonstrated a loss of five points in the Linkage Quality construct between his mid and post-treatment map, which affected the mean score. By examining the same data within the qualitative analysis, it is evident that the clarity and transparency of Participant 1's maps decreased between the mid and post-treatment map. This was largely due to a lack of labeled linking lines in Participant 1's post-treatment map, and explained the loss in Linkage Quality.

All of the sub-questions within RQ-1 asked about changes in students' cognitive structure specific to the concepts and connections within the cognitive domains. The intent of these questions was to demonstrate a growth of student schema in the cognitive domains of science and technology. As indicated repeatedly throughout the data, each student demonstrated a growth in their cognitive structure as represented by their technology, biology, and integrative concepts and connections. The findings within this study support the notion that the design based approach to instruction does indeed increase a student's schematic understanding within and between the subject domains of biology and technology. This indicated that participants gained a more complex, integrative, and meaningful understanding of the Problem Scenario, which informed their design solution.

The focus of RQ-2 was on students' strategic knowledge. The data showed that pathways within the participants' concept maps revealed their design decisions. The number of strategic knowledge questions addressed by the participants increased from the mid to post-treatment concept maps. This indicated that the participants' knowledge growth positively influenced the number of design decisions made by the participants. Providing some indication, that students' increased schematic understanding encouraged them to make strategic decisions while engaged within a design-based approach to instruction. As suggested by the literature and indicated by the data within this study, schematic and strategic knowledge encouraged meaningful learning and active construction of students' new knowledge within their memory. Collectively this study supports the notion that the technological design-based approach to instruction does indeed (1) encourage meaningful learning, and (2) increase students' use of higher order thinking indicated by their abilities to demonstrate their use of schematic and strategic knowledge within their concept maps.

Implications

The results of this study have direct implications within the areas of Technology Education, Science Education, classroom practice, and concept mapping. One of the primary motivations behind this research was the increasing need for our nation's educational system to provide STEM literate individuals with the knowledge and skills required to compete in a technological society and workforce. Many national publications have provided recommendations for the inclusion of STEM curricula in K-12 education (Bybee, 2010; Friedman, 2005; Keller & Pearson, 2012; NAE & NRC, 2009; NAS, NAE, & IoM, 2006; NSB, 2006a, 2006b, 2007; NRC, 2011; NSB, 2007). The *Framework for K-12 Science Education, Next Generation Science Standards,* 2009 Science National Assessment of Educational Progress (NAEP), and the 2014 Technology and Engineering NAEP encourage student participation in the technological/engineering design process as an integrative practice (National Research Council, 2011; NAGB, 2014; NAGB, 2009).

The technological design process offers an integrative approach to teach content from multiple subject domains to prepare students to solve real-world problems. The cyclical and iterative nature of the design process enables students to refine their understanding to improve their solution (Kolodner, 2002; Puntambekar & Kolodner, 2005). The process of refining and constructing understanding solicits a series of cognitive monitoring strategies, which include questioning, predicting, clarifying, and summarizing (Brown, 1992). These cognitive monitoring devices encourage students' active construction and meaning making within their schema (Barlex & Trebell, 2008). The findings demonstrated that as students constructed their conceptual knowledge and connections within their schema, it increased the number of strategic design decisions within their solutions. Therefore, this provides some indication that throughout the technological design process students were confronted with the higher order cognitive demands of schematic and strategic knowledge.

Key researchers have pointed out that there is a lack of empirical evidence to support the technological design-based approach on students' cognitive development (Zuga, 1994, 1997; Petrina, 1998; Lewis, 1999). These researchers have established the need for technology education to demonstrate its benefits to student learning and have demanded evidence to validate its practice. This investigation implies that the technological design-based approach to teaching biotechnology literacy provides a valid methodology that requires students to use higher order cognitive demands of schematic and strategic knowledge. In addition, it prepares students for future careers by teaching them to solve real-world integrative problems indicative of the 21st century.

This study has further implications within Science Education. The *Next Generation Science Standards* support the integration of science and engineering ideas (Achieve Inc., 2013). Two key engineering and technology ideas within the *Next Generation Science Standards* include "Engineering Design," and "Links among Engineering, Technology, Science, and Society" (Achieve Inc., 2013). The rationale behind the inclusion of engineering and technology practices within the science discipline was for all students to learn how their increased science knowledge can be used to solve problems. This study provided evidence to support the use of and demonstrate how the technological design-based approach to instruction can be used as a valid method for increasing students' biology and technology domain knowledge to solve a real-world problem.

Concept mapping was used within this study as an assessment tool to monitor students' schematic and strategic knowledge growth at three key intervals throughout the technological design process. Concept mapping provided an authentic method for assessing multiple cognitive domains (biology and technology) and the integrative connections between them. This is only one of the many ways concept mapping can be adapted for classroom practice. One of the biggest advantages in concept mapping is that it provides alternative evidence of students' understanding and misconceptions. This provides the teacher with the additional information they need to make informed decisions and direct their instruction. One of the biggest challenges to implementing concept mapping in the classroom is the time required to teach the process and analyze the concept maps. This implies that concept mapping is a valid method for assessing student learning when using a design-based approach to instruction, or when using multiple and integrative cognitive domains.

The analysis methods for this study were derived from Hay et al's (2008) three-method analysis for measuring the quality of students' knowledge change as a consequence of an e-learning instruction approach. The content taught within Hay et al's study included the principles of magnetic resonance imaging (MRI). This research examined students' cognitive growth throughout the technological design-based approach to instruction in the cognitive domains of biology and technology. Even though the content and instructional approaches within Hay et al's research and this study were very different, the methods for concept mapping analysis were applicable within both investigations. Therefore, the concept mapping implementation and analysis methods from this study have potential for use within other content areas or instructional approaches.

Due to the potential for the use of concept mapping as an assessment tool within any content area, this study has implications across general education to demonstrate student knowledge growth. Increasing demands within New York State (and nationally from Race to the Top funding) have placed pressure on school districts to demonstrate teacher effectiveness based on student performance and growth through Annual Professional Performance Reviews (APPR) (NYSED, 2012). The APPR process now requires teachers to provide pre and post course assessments to at least 50% of all of their students to determine student growth, and teacher effectiveness within four categories ("highly effective," "effective," "developing," or "ineffective") (NYSED, 2012). For a majority of K-12 classroom teachers their assessments are predetermined based on statewide testing, but for non-core disciplines there is an opportunity to use concept mapping as an authentic assessment of student understanding. Since, standardized testing rarely challenge students beyond the cognitive demand of declarative knowledge, concept mapping provides an opportunity for teachers to establish evidence of students' understanding within any content area and at the schematic and strategic knowledge levels.

Recommendations for Further Research

As indicated by the limitations, this study implemented a case study research design with a purposive convenience sample, which yields a poor rationale and low credibility (Patton, 1990). Therefore, the findings from this study do not apply directly to other courses, subjects, or geographical locations. Due to these factors, the researcher will not generalize or suggest any transferability. Instead, the researcher will recommend two directions for further research. The discussion and implications suggest the need to expand the research conducted within this study, and to improve methods for concept mapping analysis so they are more practical for classroom use.

The need for further empirical research within the field of technology education has been well-documented (Zuga, 1994, 1997; Petrina, 1998; Lewis, 1999). This study generated preliminary data to support the benefits of the technological design-based approach to instruction on the growth of student's cognitive structure. The implementation of a replication study within a different context (classroom, subject area, or location) would help support the evidence found within this research that the technological design-based approach to instruction supports the growth of students' schema. Two suggested adaptations on this research direction include conducting student interviews to support the concept mapping data, and using the students' concept maps as a cognitive monitoring device throughout instruction and as an assessment for knowledge retention.

The first suggested adaptation on the current research design was to interview the students after each concept map was complete. Interviewing the students would help clarify for the raters any of the missing information within the concept maps. As indicated within the study, each student omitted labels on their linking lines. An interview after each concept map was completed or a think-a-loud protocol while the students completed their concept maps would allow the researcher to capture the students' thought process and clarify any omitted information. This methodology could produce further data to demonstrate evidence of the reasoning for students' design decisions, and use of their strategic knowledge.

The second suggested adaptation on the current research study is to use the students' concept maps as a cognitive monitoring device throughout instruction and as an assessment for knowledge retention. Instead of assessing students' concept maps at three key intervals throughout instruction, students' would develop their concept map continuously throughout the technological design process. This would serve as a learning tool to encourage students' cognitive monitoring throughout instruction. At the completion of the design challenge, the researcher would collect the students' concept maps, and continue on to the next Problem Scenario. After a given time period, the researcher would assess the students' knowledge retention using the concept mapping prompts. This approach would help the students' monitor their own learning, and provide data on the extent of students' knowledge retained after instruction. Since the ultimate goal of education is for student to retain learned information, it seems logical to assess students' knowledge retained over time after instruction.

The last recommendation is to refine the methods of concept mapping analysis. The current methods are insufficient for a classroom teacher, as they are too labor intensive and require too much time. The qualitative examination within this study was the strongest method of analysis because it offered a comprehensive examination of the structure and extent of the students' schematic and strategic knowledge. In addition, Method Three (the rater scored Likert-scaled instrument) paired with the analysis rubric, has potential for classroom implementation. Classroom teachers are accustomed to using rubrics for analysis, so the training required to implement the use of a rubric would be minimal. In addition, rubrics provide the opportunity to assess the quality of information within the concept maps without the time commitment that a qualitative analysis requires. However, the instrument and rubric used within this study would require further refinement as it attained a 71.1% interrater reliability.

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APPENDICES

Appendix A

Institutional Review Board Approval Letter

VirginiaTech

Office of Research Compliance
Institutional Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, Virginia 24060
540/231-4606 Fax 540/231-0959
e-mail irb@vt.edu
Website: www.irb.vt.edu

MEMORANDUM

DATE: November 16, 2011

TO: John Wells, Kelly Schurr

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)

PROTOCOL TITLE: Cognitive Structural Change and the Technological Design Process

IRB NUMBER: 11-759

Effective November 16, 2011, the Virginia Tech IRB Chair, Dr. David M. Moore, approved the new protocol for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at http://www.irb.vt.edu/pages/responsibilities.htm (please review before the commencement of your research).

PROTOCOL INFORMATION:
Approved as: **Expedited, under 45 CFR 46.110 category(ies) 5, 7**
Protocol Approval Date: **11/16/2011**
Protocol Expiration Date: **11/15/2012**
Continuing Review Due Date*: **11/1/2012**
*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:
Per federally regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals / work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

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Appendix B

IRB Continuation Request Approval Letter

VirginiaTech

Office of Research Compliance
Institutational Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, VA 24060
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE:	October 18, 2012
TO:	Kelly Laural Schurr, John Wells
FROM:	Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)
PROTOCOL TITLE:	Cognitive Structural Change and the Technological Design Process
IRB NUMBER:	**11-759**

Effective October 17, 2012, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the Continuing Review request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	**Expedited, under 45 CFR 46.110 category(ies) 5,7**
Protocol Approval Date:	**November 16, 2012**
Protocol Expiration Date:	**November 15, 2013**
Continuing Review Due Date*:	**November 1, 2013**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

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Appendix C

Audit Log

Date	Classroom Activities	Technological Design Process Steps	Metacognitive Skills	NYS Standards
11/8/2012	The class received the design challenge and reviewed the key aspects of the project by Framing the Problem. To Frame the Problem the students were required to complete a chart. The chart included the following topics: state the problem, explain why the problem was important, describe the context of the problem, state the requirements and constraints of the challenge, and list the available resources. The teacher offered moderate guidance as the students completed the chart. Then, the students developed a second chart that included information about what they already knew and what they believed they needed to know to solve the design challenge. Once both of these tasks were completed, the students developed their first concept map. This concept map served as baseline data for the study and represented student's prior knowledge of the topic. The teacher collected all of the students' concept maps.	**Frame the Problem** **Reflect and Communicate**	Questioning Clarifying Summarizing	**1.1.C**. 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
11/9/2012	Students reviewed the new project challenge on phytoremediation and hydroponics. Then the teacher provided the students with a short handout outlining the big ideas related to the challenge along with websites that would help the students with their research. The class went to the computer lab to begin researching the following topics: Phytoremediation (phytoextraction, phystostabilization & Phytotransformation), Hydroponics (systems & vertical farming), Plant (growth requirements & nutrients), grey water recycling, plant tolerances, and green houses. The teacher worked with a few students individually that were having a few technical problems with concept mapping.	**Frame the Problem** **Reflect and Communicate**	Questioning Clarifying Summarizing	**1.1.C**. 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
11/12/2012	Veteran's Day – No School			
11/13/2012	The class reviewed the design challenge, the requirements for the challenge, and the key topics of research. Then, the class went to the computer lab to continue their research	Frame the Problem **Conduct Research** Reflect and Communicate	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C**

	on the Phytoremediation & Hydroponics project. They focused on the following concepts: bioremediation, phytoremediation, the three types of phytoremediation (phytostabilization, phytoextraction, and phytotransformation), and the seven types of hydroponics (ebb & flow, wick, water culture, aeroponics, drip, flood, and vertical farming). The students took notes on the information they found.			5.3.C. 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
11/14/2012	The class went to the computer lab to continue their research on the Phytoremediation & Hydroponics project. They focused on the following concepts: bioremediation, phytoremediation, the three types of phytoremediation (phytostabilization, phytoextraction, and phytotransformation), and the seven types of hydroponics (ebb & flow, wick, water culture, aeroponics, drip, flood, and vertical farming). The students took notes on the information they found. The teacher circulated to each team to determine where they were in their research and guide them towards needed information.	Frame the Problem **Conduct Research** Reflect and Communicate	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
11/15/2012	The teacher used guiding question to lead a whole-class review of the information the students had researched so far. Then, the class went back to the computer lab to continue their research. They focused on the following concepts: bioremediation, phytoremediation, the three types of phytoremediation (phytostabilization, phytoextraction, and phytotransformation), and the seven types of hydroponics (ebb & flow, wick, water culture, aeroponics, drip, flood, and vertical farming). The students took notes on the information they found.	Frame the Problem **Conduct Research** **Reflect and Communicate**	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
11/16/2012	The class went over to the computer lab to continue researching the following topics: bioremediation, phytoremediation, the three types of phytoremediation (phytostabilization, phytoextraction, and phytotransformation), the seven types of hydroponics (ebb & flow, wick,	Frame the Problem **Conduct Research** Reflect and Communicate	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. 5.4.C. 5.6.C.

	water culture, aeroponics, drip, flood, and vertical farming), greywater, and plant tolerances for sodium chloride. The teacher circulated to each team ensure they were making progress in their research and to guide the students to required information.			6.1.C. 7.1.C. 7.2.C.
11/19/2012	The class went over to the computer lab to continue researching the following topics: bioremediation, phytoremediation, the three types of phytoremediation (phytostabilization, phytoextraction, and phytotransformation), the seven types of hydroponics (ebb & flow, wick, water culture, aeroponics, drip, flood, and vertical farming), greywater, and plant tolerances for salt. The teacher gave the students their brainstorming sketches to begin developing possible solutions to the design challenge once their research was complete. She asked the students to come up with two possible floor plan layouts for the green house, and three possible hydroponics designs on one side of the brainstorming sketches. On the back of the brainstorming sketches, the students were required to select two of their hydroponics designs and redraw them with dimensions and details. The teacher circulated to each team to ensure they were making progress in their research, to guide the students to required information, and answer any questions.	Frame the Problem **Conduct Research** Reflect and Communicate **Develop Possible Solutions**	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
11/20/2012	The teacher used guiding question to lead a whole-class discussion on the information researched so far. The students were able to answer all of the teacher's questions, with the exception of which types of plants work best in which types of hydroponics systems. The class returned to the computer lab to research this question, and to continue working on their brainstorming sketches.	Frame the Problem **Conduct Research** **Reflect and Communicate** **Develop Possible Solutions**	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** **4.LE.6.C.** **4.LE.7.C.** **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. **7.1.C.** **7.2.C.**
11/21/2012	Students worked individually to develop their second concept maps as a snapshot of what they know now that their research and sketches (develop possible solutions) are complete. All students turned in their mid-assessment	**Reflect and Communicate** Frame the Problem Develop Possible Solutions **Select a Solution**	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C.

	concept maps. The students spent the remainder of class finishing the details on their sketches, and working in pairs to select their design solutions.			5.4.C. 5.6.C. 6.1.C. **7.1.C.** **7.2.C.**
11/22/2012	Thanksgiving Recess – No School			
11/23/2012	Thanksgiving Recess – No School			
11/26/2012	The teacher used guiding questions to lead a whole-class discussion on the context and information related to the design challenge. Students worked in pairs to develop their design for the working hydroponics system. Once the teacher approved their final idea, the students began constructing their working prototype. For the remainder of the class the students planned their construction, generated a list of required materials, and began constructing their design.	Frame the Problem **Reflect and Communicate** Develop Possible Solutions **Select a Solution** Construct the Solution	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** **4.LE.6.C.** **4.LE.7.C.** **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. **7.1.C.** **7.2.C.**
11/27/2012	The students continued constructing their working prototypes. As students came across design and construction issues, they had to redesign to develop different possible solutions.	**Construct the Solution** Test the Solution **Redesign for Improvements** Develop Possible Solutions Select a Solution Reflect and Communicate	Questioning Clarifying Summarizing Predicting	**1.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** **5.2.C.** **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** 7.1.C. 7.2.C.
11/28/2012	The students continued constructing their working prototypes. As students came across design and construction issues, they had to redesign to develop different possible solutions.	**Construct the Solution** **Test the Solution** **Redesign for Improvements** Develop Possible Solutions Select a Solution Reflect and Communicate	Questioning Clarifying Summarizing Predicting	**1.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** **5.2.C.** **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** 7.1.C. 7.2.C.
11/29/2012	The teacher used guiding questions to lead a whole-class discussion on the context and information related to the design challenge. Then, the students continued constructing their working prototypes. As students came across design and construction issues, they had to redesign to develop different possible solutions. Some of the groups tested	**Construct the Solution** **Test the Solution** **Redesign for Improvements** Develop Possible Solutions Select a Solution Reflect and	Questioning Clarifying Summarizing Predicting	**1.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** **5.2.C.** **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.**

	their designs to ensure they had enough room to house the water pumps and the pumps for the air stones.	Communicate		7.1.C. 7.2.C.
11/30/2012	Parent/Teacher Conferences – No School			
12/3/2012	The teacher used guiding questions to lead a whole-class discussion on the context and information related to the design challenge. The students finished constructing their working prototypes. As students came across design and construction issues, they had to redesign to develop different possible solutions. Once their hydroponics system was complete, each team began drawing their final floor plan layout of their green house.	**Construct the Solution** **Test the Solution** **Redesign for Improvements** Develop Possible Solutions Select a Solution Reflect and Communicate	Questioning Clarifying Summarizing Predicting	**1.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** **5.2.C.** **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** 7.1.C. 7.2.C.

12/4/2012	The class was in the computer lab drawing their green house layout, and developing their PowerPoint presentation to answer all of the questions below.
	• Describe the context of the challenge.
	• Describe each part of your system (i.e., input, processes, output & feedback)
	• Describe your design and explain how it will scrub the greywater, while providing produce for the school lunches.
	• Describe the different types of Phytoremediation.
	    o State which Phytoremediation method you selected to use in your design, and explain why you chose this method.
	• What specifically are you trying to remediate from the greywater?
	• What hydroponics methods did you choose?
	    o Why did you select these methods?
	• What is the living organism (i.e., the biology component) of your system?
	• What type of plants are you using? Why are you using these plants?
	    o What is the purpose of each of the plants within your system?
	• What are the growth requirements
		Reflect and Communicate
		Frame the Problem
		Conduct Research
		Develop Possible Solutions
		Select a Solution
			Questioning
			Clarifying
			Summarizing
			Predicting
				1.1.C.
				2.1.C.
				4.LE.6.C.
				4.LE.7.C.
				5.1.C
				5.2.C.
				5.3.C.
				5.4.C.
				5.6.C.
				6.1.C.
				7.1.C.
				7.2.C.

	for your plants? o How did the growth requirements for your plants affect your design? • Explain how you will know if your system is working successfully. • What methods will you use to monitor your system?			
12/5/2012	I was out sick, the students watched a video on Engineering an Empire.	**Reflect and Communicate**	Questioning Clarifying Summarizing	5.2.C. 5.4.C. **5.5.C.** **5.6.C.** 7.1.C.
12/6/2012	The class was in the computer lab drawing their green house layout, and developing their PowerPoint presentation to answer all of the required questions from 12/4/2012.	**Reflect and Communicate** **Frame the Problem** **Conduct Research** Develop Possible Solutions Select a Solution	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** **5.2.C.** 5.3.C. **5.4.C.** 5.6.C. 6.1.C. **7.1.C.** **7.2.C.**
12/7/2012	The class was in the computer lab to finish drawing their green house layouts, and to develop their PowerPoint presentation to answer all of the required questions from 12/4/2012.	**Reflect and Communicate** **Frame the Problem** **Conduct Research** Develop Possible Solutions Select a Solution	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** **5.2.C.** 5.3.C. **5.4.C.** 5.6.C. 6.1.C. **7.1.C.** **7.2.C.**
12/10/2012	The teacher reviewed the expectations and procedures for presenting with the class. Then, two groups presented their PowerPoint presentations to the class, described their green house drawings, and demonstrated their working prototypes. The students and teacher asked each group questions to clarify any missing or unclear information.	**Reflect and Communicate** Frame the Problem	Questioning Clarifying Summarizing	**1.1.C**. 2.1.C. 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** **7.1.C.** **7.2.C.**
12/11/2012	Two groups presented their PowerPoint presentations to the class, described their green house drawings, and	**Reflect and Communicate** Frame the Problem	Questioning Clarifying Summarizing	**1.1.C**. 2.1.C. 4.LE.6.C.

	demonstrated their working prototypes. The students and teacher asked each group questions to clarify any missing or unclear information. A third group, gave their presentation, but did not have time to demonstrate their working prototype or greenhouse drawing. This group was the first group to present the following day.			4.LE.7.C. **5.1.C** 5.3.C. **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** **7.1.C.** **7.2.C.**
12/12/2012	The group that had to finish their presentation the day before, began the class by demonstrating their working prototype and greenhouse drawing layout. Then, two more groups presented their PowerPoint presentations to the class, described their green house drawings, and demonstrated their working prototypes. The students and teacher asked each group questions to clarify any missing or unclear information.	**Reflect and Communicate** Frame the Problem	Questioning Clarifying Summarizing	**1.1.C**. 2.1.C. 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** **7.1.C.** **7.2.C.**
12/13/2012	The last two groups presented their PowerPoint presentations to the class, described their green house drawings, and demonstrated their working prototypes. The students and teacher asked each group questions to clarify any missing or unclear information.	**Reflect and Communicate** Frame the Problem	Questioning Clarifying Summarizing	**1.1.C**. 2.1.C. 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** **7.1.C.** **7.2.C.**
12/14/2012	The students completed their third concept map in response to the third prompt. When each student finished, the teacher collected the concept map and gave each student the conclusion questions to work on. Once all students finished and turned in their concept maps, the teacher led a class discussion on the quality of the projects, information learned, and any remaining misconceptions uncovered within the presentations.	**Reflect and Communicate** Frame the Problem	Questioning Clarifying Summarizing	**1.1.C**. 2.1.C. 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** **7.1.C.** **7.2.C.**

Appendix D

Pilot Study Audit Log

Date	Classroom Activities	Technological Design Process Steps	Metacognitive Skills	NYS Standards
4/25/2012	Students received the design challenge and were required to Frame the Problem by filling in a chart. The teacher offered moderate guidance as the students completed the chart. The chart required the students to state the problem, explain why the problem was important, describe the context of the problem, state the requirements and constraints of the challenge, and list the available resources. They developed a second chart that included information about what they already knew and what they believed they needed to know to solve the design challenge.	**Frame the Problem** Reflect and Communicate	Questioning Clarifying Summarizing	**1.1.C**. 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
4/26/2012	Students finished presenting the previous project on bioremediation and turned in all of their overdue materials. Students reviewed the new project challenge on phytoremediation and hydroponics then completed their concept maps based on their prior knowledge of the topic. The teacher collected all of the students' concept maps. Then the teacher provided the students with a short handout outlining the big ideas related to the challenge along with websites that would help the students with their research.	Frame the Problem Reflect and Communicate **Pre-treatment Concept Map**	Questioning Clarifying Summarizing	**1.1.C**. 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
4/27/2012	The teacher returned the concept maps to the students. The class went to the computer lab to begin researching the following topics: Phytoremediation (phytoextraction, phystostabilization & Phytotransformation), Hydroponics (systems & vertical farming), Plant (growth	Frame the Problem **Conduct Research** Reflect and Communicate	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.

	requirements & nutrients), grey water recycling, plant tolerances, and green houses. The students continued developing their concept maps throughout the class.			
4/30/2012	One student was absent from school at the end of the last project, so he and his partner presented their bioremediation project to the class. The class went to the computer lab to continue their research on the Phytoremediation & Hydroponics project. They focused on the following concepts: bioremediation, phytoremediation, the three types of phytoremediation (phytostabilization, phytoextraction, and phytotransformation), and the seven types of hydroponics (ebb & flow, wick, water culture, aeroponics, drip, flood, and vertical farming). The students continued developing their concept maps throughout the class.	Frame the Problem **Conduct Research** Reflect and Communicate	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
5/1/2012	The teacher used guiding question to lead a whole-class review of the information the students had researched so far. Then, the class went back to the computer lab to continue their research. They focused on the following concepts: bioremediation, phytoremediation, the three types of phytoremediation (phytostabilization, phytoextraction, and phytotransformation), and the seven types of hydroponics (ebb & flow, wick, water culture, aeroponics, drip, flood, and vertical farming). The students continued developing their concept maps throughout the class.	Frame the Problem **Conduct Research** Reflect and Communicate	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
5/2/2012	The class went over to the	Frame the Problem	Questioning	**1.1.C.**

	computer lab to continue researching the following topics: bioremediation, phytoremediation, the three types of phytoremediation (phytostabilization, phytoextraction, and phytotransformation), the seven types of hydroponics (ebb & flow, wick, water culture, aeroponics, drip, flood, and vertical farming), greywater, and plant tolerances for salt.	**Conduct Research** Reflect and Communicate	Clarifying Summarizing	**2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. 7.1.C. 7.2.C.
5/3/2012	The teacher used guiding question to lead a whole-class discussion on the information researched so far. The students were able to answer all of the teacher's questions, with the exception of which types of plants work best in which types of hydroponics systems. The teacher assigned this question to the students to look up for homework. The students continued developing their concept maps throughout the class, and were given their brainstorming sketches to begin developing possible solutions.	Frame the Problem **Conduct Research** Reflect and Communicate Develop Possible Solutions	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** **4.LE.6.C.** **4.LE.7.C.** **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. **7.1.C.** **7.2.C.**
5/4/12	The teacher used guiding questions to lead a whole-class discussion on the homework question from yesterday (on which types of plants work best in which types of hydroponics systems). The students continued developing their concept maps and their brainstorming sketches.	Frame the Problem Conduct Research Reflect and Communicate **Develop Possible Solutions**	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** **4.LE.6.C.** **4.LE.7.C.** **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. **7.1.C.** **7.2.C.**
5/7/12	The class was in the computer lab for the duration of the class researching which hydroponics systems work best with their selected plants. By the end of the class each pair of students reported which three plants and two hydroponics systems they are going to use for their design.	Frame the Problem Conduct Research Reflect and Communicate Develop Possible Solutions **Select a Solution**	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** **4.LE.6.C.** **4.LE.7.C.** **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. **7.1.C.**

				7.2.C.
5/8/2012	Students worked individually to develop their concept maps as a snapshot of what they know now that their research and sketches (develop possible solutions) are completed. All students turned in their mid-assessment maps, while only some of the students turned in their continuous concept map. The students spent the remainder of class updating their continuous concept maps and finishing the details on their sketches.	Reflect and Communicate Frame the Problem Develop Possible Solutions Select a Solution **Mid-treatment Concept Map**	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. 5.4.C. 5.6.C. 6.1.C. **7.1.C.** **7.2.C.**
5/9/2012	Students worked in pairs to develop their design for the working hydroponics system. Once the teacher approved their final idea, the students began constructing their working prototype. For the remainder of the class the students planned their construction and began building.	Develop Possible Solutions **Select a Solution** Reflect and Communicate **Construct the Solution**	Questioning Clarifying Summarizing Predicting	**1.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** **5.2.C.** **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** 7.1.C. 7.2.C.
5/10/2012	The students continued constructing their working prototypes. As students came across design and construction issues, they had to redesign to develop different possible solutions.	**Construct the Solution** **Test the Solution** Redesign for Improvements Develop Possible Solutions Select a Solution Reflect and Communicate	Questioning Clarifying Summarizing Predicting	**1.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** **5.2.C.** **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** 7.1.C. 7.2.C.
5/11/2012	The students continued constructing their working prototypes. As students came across design and construction issues, they had to redesign to develop different possible solutions. During the middle of the class there was a fire drill and a safety concern arose which had to be addressed,	**Construct the Solution** **Test the Solution** **Redesign for Improvements** Develop Possible Solutions Select a Solution Reflect and Communicate	Questioning Clarifying Summarizing Predicting	**1.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** **5.2.C.** **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** 7.1.C.

	causing a loss in productivity.			7.2.C.
5/14/2012	The students finished constructing their working prototypes. As students came across design and construction issues, they had to redesign to develop different possible solutions.	**Construct the Solution** **Test the Solution** **Redesign for Improvements** Develop Possible Solutions Select a Solution Reflect and Communicate	Questioning Clarifying Summarizing Predicting	**1.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** **5.2.C.** **5.4.C.** 5.6.C. **6.1.C.** **6.2.C.** 7.1.C. 7.2.C.

5/15/2012	The class was in the computer lab continuing their concept maps, drawing their green house layout, and developing their PowerPoint presentation to answer all of the questions below.
	• Describe the context of the challenge.
	• Describe each part of your system (i.e., input, processes, output & feedback)
	• Describe your design and explain how it will scrub the greywater, while providing produce for the school lunches.
	• Describe the different types of Phytoremediation.
	    ○ State which Phytoremediation method you selected to use in your design, and explain why you chose this method.
	• What specifically are you trying to remediate from the greywater?
	• What hydroponics methods did you choose?
	    ○ Why did you select these methods?
	• What is the living organism (i.e., the biology component) of your system?
		Reflect and Communicate
		Frame the Problem
		Conduct Research
		Develop Possible Solutions
		Select a Solution
			Questioning
			Clarifying
			Summarizing
			Predicting
				1.1.C.
				2.1.C.
				4.LE.6.C.
				4.LE.7.C.
				5.1.C
				5.3.C.
				5.4.C.
				5.6.C.
				6.1.C.
				6.2.C.
				7.1.C.
				7.2.C.

	• What type of plants are you using? Why are you using these plants? o What is the purpose of each of the plants within your system? • What are the growth requirements for your plants? o How did the growth requirements for your plants affect your design? • Explain how you will know if your system is working successfully. • What methods will you use to monitor your system?			
5/16/2012	The class was in the computer lab continuing their concept maps, drawing their green house layout, and developing their PowerPoint presentation to answer all of the required questions from 5/15/2012.	**Reflect and Communicate** Frame the Problem Conduct Research Develop Possible Solutions Select a Solution	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. **5.4.C.** 5.6.C. 6.1.C. 6.2.C. **7.1.C.** **7.2.C.**
5/17/2012	The class was in the computer lab finishing their concept maps, drawing their green house layout, and developing their PowerPoint presentation to answer all of the required questions from 5/15/2012.	**Reflect and Communicate** Frame the Problem Conduct Research Develop Possible Solutions Select a Solution	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. **5.4.C.** 5.6.C. 6.1.C. 6.2.C. **7.1.C.** **7.2.C.**
5/18/2012	The prom is this evening. All juniors and seniors attending the prom were allowed to leave school at 11:30a. Since there were only two students in class today, they put a few final additions on their	Construct the Solution **Redesign for Improvements** **Reflect and Communicate**	Questioning Clarifying Summarizing Predicting	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. **5.4.C.**

	models/presentation, and/or completed overdue work.			5.6.C. 6.1.C. 6.2.C. **7.1.C.** 7.2.C.
5/21/2012	Four groups presented their PowerPoints to the class, described their green house drawings, and demonstrated their working prototypes.	**Reflect and Communicate** Frame the Problem	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.2.C. 5.3.C. **5.4.C.** 5.6.C. 6.1.C. 6.2.C. **7.1.C.** 7.2.C.
5/22/2012	One student from each of the groups needing to present was absent from class due to a school leadership training program. The rest of the class had a short class discussion on the project presented the day before. They completed their third concept map assessment, when finished they began completing their conclusion questions.	Reflect and Communicate Frame the Problem **Post-treatment Concept Map**	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. **5.4.C.** 5.6.C. 6.1.C. **7.1.C.**
5/23/2012	The last four groups presented their PowerPoints to the class, described their green house drawings, and demonstrated their working prototypes.	**Reflect and Communicate** Frame the Problem	Questioning Clarifying Summarizing	**1.1.C.** **2.1.C.** 4.LE.6.C. 4.LE.7.C. **5.1.C** 5.3.C. **5.4.C.** 5.6.C. 6.1.C. 6.2.C. **7.1.C.** 7.2.C.

Appendix E

Phytoremediation and Hydroponics Presentation Questions

Phytoremediation & Hydroponics
Presentation Questions

Directions: Develop an in-class presentation that answers all of the questions and statements below.

Challenge:
Develop a proposal/presentation to share with school officials. Your proposal should include a floor plan of the green house (including a minimum of three different plant types and two different hydroponics systems), a phytoremediation system for scrubbing the grey water, and a working model of one of your hydroponics systems.

- Describe the context of the challenge.
- Describe each part of your system (i.e., input, processes, output & feedback)
- Describe your design and explain how it will scrub the greywater, while providing produce for the school lunches.
- Describe the different types of Phytoremediation.
  - State which Phytoremediation method you selected to use in your design, and explain why you chose this method.
- What specifically are you trying to remediate from the greywater?
- What hydroponics methods did you choose?
  - Why did you select these methods?
- What is the living organism (i.e., the biology component) of your system?
- What type of plants are you using? Why are you using these plants?
  - What is the purpose of each of the plants within your system?
- What are the growth requirements for your plants?
  - How did the growth requirements for your plants affect your design?
- Explain how you will know if your system is working successfully.
- What methods will you use to monitor your system?

Appendix F

Instructional List of Terms

Method Two: List of terms

This list contains the relevant concepts, words, and terms as determined by the teacher and used throughout the instructional materials within the "Biorestoration" unit of study. The raters compared the student-generated post-treatment concept maps against this list to generate a frequency count of the concepts used by each student.

1. Biotechnology
2. Tools
3. Materials
4. Process(es)
5. Human Needs
6. Human Wants
7. System
8. Input
9. Output
10. Feedback (monitoring)
11. Living Organisms (living things)
12. Solve Problems
13. Design
14. Design Process
15. Phytoremediation
16. Clean the Environment (water)
17. Plants
18. Phytostabilization
19. Confine Contaminants (Immobilize)
20. Phytoextraction
21. Absorbs & Stores Contaminants
22. Leaves, stems, pedals (above ground tissue)
23. Phytotransformation
24. Converts/Transforms Contaminants (Metabolically)
25. Hydroponics
26. Growing Plants without Soil
27. Vertical Farming
28. Drip System
29. Ebb & Flow
30. Flood & Drain
31. Deep Water Culture (DWC or water culture)
32. Floatation System (Raft)
33. Aeroponics

34. Misting Roots
35. Nutrient Film Technique (NFT)
36. Roots Suspended in Nutrients (thin film, little water)
37. Gravity
38. Polyvinyl Chloride (PVC)
39. Wick System
40. Wick Transfers Nutrients to Roots
41. Water pumps
42. Wood/plastic bin (materials)
43. Reservoirs
44. Air stones
45. Oxygen
46. Growth Requirements (Grow)
47. pH
48. Temperature
49. Water (H_2O)
50. Nutrients
51. Sunlight
52. Root system
53. Green House
54. Hyperaccumulators
55. Contaminants (Toxins)
56. Salt (Sodium Chloride)
57. Grey Water
58. Black Water
59. Barley
60. Sugar Beets
61. Beet Root
62. Vegetables (specific varieties)
63. Herbs (specific varieties)
64. Fruits (specific varieties)
65. Food (for cafeteria or school)

Appendix G

Method Three: Rater Scored Instrument

Appendix G: Method three - Rater scored instrument

Rater Number:

Participant Number:

	Pre-Treatment					
	SA	A	U	D	SD	#
Constructs:						
Conceptual Richness						
1. The map uses all of the concepts that are important to the topic	SA	A	U	D	SD	
2. The map fails to include most of the important concepts	SA	A	U	D	SD	
3. All of the concepts used in the map are appropriate to the topic	SA	A	U	D	SD	
4. Most of the concepts used are actually irrelevant to the topic	SA	A	U	D	SD	
Sub-total						
Link Quality						
5. All of the possible links are identified & explained	SA	A	U	D	SD	
6. Most of the important links between the concepts are neglected	SA	A	U	D	SD	
7. All of the links in the map are relevant and correctly labelled	SA	A	U	D	SD	
8. Most of the links are irrelevant or inadequately explained	SA	A	U	D	SD	
Sub-total						
Evidence of Understanding						
9. All of the propositions in the map show evidence of understanding	SA	A	U	D	SD	
10. Most of the propositions in the map are actually misconceptions	SA	A	U	D	SD	
11. The map is a clear definition of the topic	SA	A	U	D	SD	
12. The map fails to provide a clear definition for the topic	SA	A	U	D	SD	
Sub-total						
Hierarchy and Structure						
13. The map shows justifiable hierarchy	SA	A	U	D	SD	
14. There is no justifiable hierarchy to the map	SA	A	U	D	SD	
15. The over-arching structure of the map is a complex network	SA	A	U	D	SD	
16. The map is simple (it is a spoke or a chain but not a network)	SA	A	U	D	SD	
Sub-total						
Total						
Gain score						

*SA = Strongly Agree, A = Agree, U = Undecided, D = Disagree, SD = Strongly Disagree

Rater Number:						
Participant Number:	Mid-Treatment					
	SA	A	U	D	SD	#
Constructs:						
Conceptual Richness						
1. The map uses all of the concepts that are important to the topic	SA	A	U	D	SD	
2. The map fails to include most of the important concepts	SA	A	U	D	SD	
3. All of the concepts used in the map are appropriate to the topic	SA	A	U	D	SD	
4. Most of the concepts used are actually irrelevant to the topic	SA	A	U	D	SD	
Sub-total						
Link Quality						
5. All of the possible links are identified & explained	SA	A	U	D	SD	
6. Most of the important links between the concepts are neglected	SA	A	U	D	SD	
7. All of the links in the map are relevant and correctly labelled	SA	A	U	D	SD	
8. Most of the links are irrelevant or inadequately explained	SA	A	U	D	SD	
Sub-total						
Evidence of Understanding						
9. All of the propositions in the map show evidence of understanding	SA	A	U	D	SD	
10. Most of the propositions in the map are actually misconceptions	SA	A	U	D	SD	
11. The map is a clear definition of the topic	SA	A	U	D	SD	
12. The map fails to provide a clear definition for the topic	SA	A	U	D	SD	
Sub-total						
Hierarchy and Structure						
13. The map shows justifiable hierarchy	SA	A	U	D	SD	
14. There is no justifiable hierarchy to the map	SA	A	U	D	SD	
15. The over-arching structure of the map is a complex network	SA	A	U	D	SD	
16. The map is simple (it is a spoke or a chain but not a network)	SA	A	U	D	SD	
Sub-total						
Total						
Gain score						

*SA = Strongly Agree, A = Agree, U = Undecided, D = Disagree, SD = Strongly Disagree

Rater Number:

Participant Number:

Constructs:	Post-Treatment					
	SA	A	U	D	SD	#
Conceptual Richness						
1. The map uses all of the concepts that are important to the topic	SA	A	U	D	SD	
2. The map fails to include most of the important concepts	SA	A	U	D	SD	
3. All of the concepts used in the map are appropriate to the topic	SA	A	U	D	SD	
4. Most of the concepts used are actually irrelevant to the topic	SA	A	U	D	SD	
Sub-total						
Link Quality						
5. All of the possible links are identified & explained	SA	A	U	D	SD	
6. Most of the important links between the concepts are neglected	SA	A	U	D	SD	
7. All of the links in the map are relevant and correctly labelled	SA	A	U	D	SD	
8. Most of the links are irrelevant or inadequately explained	SA	A	U	D	SD	
Sub-total						
Evidence of Understanding						
9. All of the propositions in the map show evidence of understanding	SA	A	U	D	SD	
10. Most of the propositions in the map are actually misconceptions	SA	A	U	D	SD	
11. The map is a clear definition of the topic	SA	A	U	D	SD	
12. The map fails to provide a clear definition for the topic	SA	A	U	D	SD	
Sub-total						
Hierarchy and Structure						
13. The map shows justifiable hierarchy	SA	A	U	D	SD	
14. There is no justifiable hierarchy to the map	SA	A	U	D	SD	
15. The over-arching structure of the map is a complex network	SA	A	U	D	SD	
16. The map is simple (it is a spoke or a chain but not a network)	SA	A	U	D	SD	
Sub-total						
Total						
Gain score						

*SA = Strongly Agree, A = Agree, U = Undecided, D = Disagree, SD = Strongly Disagree

Appendix H

Method Three: Rater Scored Instrument – Likert Scale Criteria

Method 3: Rater Scored Instrument – Likert Scale Criteria					
Conceptual Richness					
Note: The concepts that are important to the topic include: Biotechnology, living organisms (living things), phytoremediation, plants, phytostabilization, phytoextraction, phytotransformation, hydroponics, drip system, ebb & flow, deep water culture (dwc), aeroponics, nutrient film technique (NFT), wick system, vertical farming, barley (sugar beets or beet root), water, contaminants (toxins), salt, greenhouse, and grey water					
Constructs:	**SA**	**A**	**U**	**D**	**SD**
1	The concept map includes almost all (20) of the important concepts listed above.	The concept map includes at least 15 of the important concepts listed above.	The concept map includes at least 10 of the important concepts listed above.	The concept map includes at least 5 of the important concepts listed above.	The concept map includes less than 5 of the important concepts listed above.
2	The concept map includes less than 5 of the important concepts listed above.	The concept map includes at least 5 of the important concepts listed above.	The concept map includes at least 10 of the important concepts listed above.	The concept map includes at least 15 of the important concepts listed above.	The concept map includes almost all (20) of the important concepts listed above.
3	All of the concepts used in the map are appropriate *for the topic.*	There is 1 inappropriate concept *for the topic* in the map.	There are 2 inappropriate concepts *for the topic* in the map.	There are 3 inappropriate concepts *for the topic* in the map.	There are 4 or more inappropriate concepts f*or the topic* in the map.
4	Half of the concepts used are irrelevant *to the topic.*	A quarter of the concepts used are irrelevant *to the topic.*	A few of the concepts used are irrelevant *to the topic.*	Less than 2 of the concepts used are irrelevant *to the topic*.	All of the concepts used are relevant *to the topic*.
Link Quality					
Constructs:	**SA**	**A**	**U**	**D**	**SD**
5	Almost all (98%) of the possible links *for the topic* are identified & explained.	At least 75% of the possible links *for the topic* are identified and explained.	At least 50% of the possible links *for the topic* are identified and explained.	At least 25% of the possible links *for the topic* are identified and explained.	Less than 25% of the possible links *for the topic* are identified and explained.
6	At least 50% of the important links between concepts in the map are neglected.	Less than 40% of the important links between concepts in the map are neglected.	Less than 30% of the important links between concepts in the map are neglected.	Less than 20% of the important links between concepts in the map are neglected.	Less than 10% of the important links between concepts in the map are neglected.
7	Almost all (98%) of the links in the map are relevant and correctly labeled.	At least 75% of the links in the map are relevant and correctly labeled.	At least 50% of the links in the map are relevant and correctly labeled.	At least 25% of the links in the map are relevant and correctly labeled.	Less than 25% of the links in the map are relevant and correctly labeled.
8	At least 50% of the links in the map are irrelevant or inadequately explained.	Less than 40% of the links in the map are irrelevant or inadequately explained.	Less than 30% of the links in the map are irrelevant or inadequately explained.	Less than 20% of the links in the map are irrelevant or inadequately explained.	Less than 10% of the links in the map are irrelevant or inadequately explained.

Evidence of Understanding					
Note: A proposition is two concepts connected by a linking line, and make up the most basic unit of meaning. An example is rain is liquid precipitation. This construct focuses on the accuracy of meaning (or student understanding) within the concept map.					
Constructs:	**SA**	**A**	**U**	**D**	**SD**
9	Almost all (98%) of the propositions in the map show evidence of understanding.	75% of the propositions in the map show evidence of understanding.	50% of the propositions in the map show evidence of understanding.	25% of the propositions in the map show evidence of understanding.	Less than 25% of the propositions in the map show evidence of understanding.
10	At least 50% of the propositions in the map are misconceptions	Less than 40% of the propositions in the map are misconceptions	Less than 30% of the propositions in the map are misconceptions	Less than 20% of the propositions in the map are misconceptions	Less than 10% of the propositions in the map are misconceptions
11	The map is a clear definition *of the topic.* It includes almost all of the relevant information.	The map is mostly clear. It includes a lot of information *on the topic*, and a little of the information may be inaccurate.	The map is moderately clear. It includes a good amount of information *on the topic*, but some of it might be inaccurate.	The map is mostly unclear. It includes little information *on the topic*, or a lot of the information is inaccurate.	The map fails to provide a clear definition for the topic. It includes almost no information *on the topic* or it is almost entirely inaccurate.
12	The map fails to provide a clear definition for the topic. It includes almost no information *on the topic* or it is almost entirely inaccurate.	The map is mostly unclear. It includes little information *on the topic*, or a lot of the information is inaccurate.	The map is moderately clear. It includes a good amount of information *on the topic*, but some of it might be inaccurate.	The map is mostly clear. It includes a lot of information *on the topic*, and a little of the information may be inaccurate.	The map is a clear definition of the topic. It includes almost all of the relevant information *on the topic*.

Hierarchy and Structure					
Note: Integrative connections refer to: (1) any correct connection (linking line) to an integrative concept or, (2) any connection between a Biology and a Technology concept.					
Constructs:	**SA**	**A**	**U**	**D**	**SD**
13	The map shows many levels of understandable and *clear* hierarchy.	The map shows many levels of understandable, but *slightly unclear* hierarchy.	The map shows a few levels of hierarchy, or the map shows many *unclear* levels of hierarchy.	The map shows one or two levels of hierarchy.	There is no hierarchy to the map.
14	There is no hierarchy to the map.	The map shows one or two levels of hierarchy.	The map shows a few levels of hierarchy, or the map shows many *unclear* levels of hierarchy.	The map shows many levels of understandable, but *slightly unclear* hierarchy.	The map shows many levels of understandable and *clear* hierarchy.

15	The structure of the map is a *complex* network with few incorrect connections.	The structure of the map is a network with some incorrect connections.	The structure of the map is series of complex chains and spokes, or a simple network.	The structure of the map is a combination of spokes and chains	The structure of the map is a single spoke or chain.
16	The map is simple (it is a spoke or a chain, but not a network).	The map is moderately developed using a combination of spokes and chains.	The map is a simple network and contains at least 2 integrative connections.	The map is a moderately developed network and contains at least 4 integrative connections.	The map is a complex network and contains at least 6 integrative connections.

Appendix I

Method One: Measures of Student Learning

		Participant #			
Concept map typologies	**Categorization**	1	2	3	4
Concept map 1 (Prior-knowledge)	(Spoke/Chain/Net)	Chain	Chain	Chain	Chain
Concept map 2 (Mid-treatment)	(Spoke/Chain/Net)	Chain	Net	Chain	Net
Concept map 3 (Post-treatment)	(Spoke/Chain/Net)	Chain	Net	Net	Net
Typology change	(Yes/No)	No	Yes	Yes	Yes
Structural growth	(Yes/No)	Yes	Yes	Yes	Yes
Concept comparisons (mid/post)					
Biology concepts					
Frequency of retained concepts	*(f / f)*	(6 / 4)	(4 / 8)	(4 / 11)	(2 / 12)
Frequency of new concepts	*(f / f)*	(5 / 8)	(8 / 4)	(13 / 15)	(10 / 2)
Technology concepts					
Frequency of retained concepts	*(f / f)*	(8 / 13)	(8 / 18)	(8 / 13)	(9 / 21)
Frequency of new concepts	*(f / f)*	(7 / 15)	(10 / 8)	(5 / 11)	(14 / 8)
Total concepts					
Frequency of retained concepts	*(f / f)*	(12 / 15)	(11 / 22)	(11 / 21)	(11 / 28)
Frequency of new concepts	*(f / f)*	(12 / 15)	(14 / 8)	(18 / 21)	(17 / 8)
Meaning making (pre/mid/post)					
Frequency of correct linking lines	*(f / f / f)*	(11 / 13 / 12)	(7 / 12 / 16)	(10 / 19 / 20)	(8 / 17 / 18)
Categorization of learning quality					
Learning quality	(Non/Rote/Meaningful)	Meaningful	Meaningful	Meaningful	Meaningful
Integrative connections (pre/mid/post)					
Frequency of correct linking lines between biology and technology concepts	*(f / f / f)*	(3 / 6 / 6)	(0 / 3 / 6)	(5 / 5 / 9)	(1 / 9 / 8)

Note. This measurement of student learning quality is Method One of the Hay et al.'s (2008) three-method analysis approach for recording participant's concept mapping data.

		Participant #			
Concept map typologies	**Categorization**	**5**	**6**	**7**	**Totals**
Concept map 1 (Prior-knowledge)	(Spoke/Chain/Net)	Net	Net	Chain	(5) Chain (2) Net
Concept map 2 (Mid-treatment)	(Spoke/Chain/Net)	Net	Net	Net	(2)Chain (5) Net
Concept map 3 (Post-treatment)	(Spoke/Chain/Net)	Net	Net	Net	(1)Chain (6) Net
Typology change	(Yes/No)	No	No	Yes	(3) No (4) Yes
Structural growth	(Yes/No)	Yes	Yes	Yes	(7) Yes
Concept comparisons	(mid/post)				**Mean scores**
Biology concepts					
Frequency of retained concepts	*(f / f)*	(8 / 8)	(5 / 12)	(12 / 14)	(6 / 10)
Frequency of new concepts	*(f / f)*	(4 / 11)	(7 / 10)	(12 / 12)	(8 / 9)
Technology concepts					
Frequency of retained concepts	*(f / f)*	(5 / 18)	(11 / 19)	(5 / 8)	(8 / 16)
Frequency of new concepts	*(f / f)*	(11 / 21)	(12 / 11)	(10 / 19)	(10 / 13)
Total concepts					
Frequency of retained concepts	*(f / f)*	(11 / 25)	(13 / 26)	(15 / 17)	(12 / 22)
Frequency of new concepts	*(f / f)*	(13 / 23)	(14 / 12)	(15 / 26)	(15 / 16)
Meaning making	(pre/mid/post)				**Mean scores**
Frequency of correct linking lines	*(f / f / f)*	(19 / 16 / 29)	(6 / 14 / 22)	(11 / 16 / 22)	(10 / 15 / 20)
Integrative meaning making (pre/mid/post)	(pre/mid/post)				**Mean scores**
Frequency of correct linking lines between biology and technology concepts	*(f / f / f)*	(6 / 6 / 15)	(2 / 8 / 17)	(0 / 6 / 13)	(2 / 6 / 11)

Note. This measurement of student learning quality is Method One of the Hay et al.'s (2008) three-method analysis approach for recording participant's concept mapping data.

Appendix J

Method Two: Participant Usage of Concepts, Words and Terms

	Participant #		
	1	2	3
Frequency of concepts, words and terms The instructional materials consisted of 65 concepts, words and terms. Examining the student's post-treatment concept maps, the following concepts, words, and terms were used:	1) Tools 2) Materials 3) Process(es) 4) Living Organisms 5) Phytoremediation 6) Clean the Environment 7) Plants 8) Hydroponics 9) Growing Plants without Soil 10) Vertical Farming 11) Drip System 12) Ebb & Flow 13) Deep Water Culture 14) Aeroponics 15) Nutrient Film Technique 16) Polyvinyl Chloride 17) Wick System 18) Water Pumps 19) Air stones 20) Oxygen 21) Growth Requirements 22) Water 23) Root System 24) Contaminants 25) Salt 26) Grey Water 27) Barley	1) Biotechnology 2) Tools 3) Materials 4) Process(es) 5) Human Needs 6) Human Wants 7) Output 8) Living Organisms 9) Phytoremediation 10) Plants 11) Phytostabilization 12) Phytoextraction 13) Adsorbs & stores toxins 14) Phytotransformation 15) Converts contaminants 16) Hydroponics 17) Vertical Farming 18) Drip System 19) Ebb & Flow 20) Deep Water Culture 21) Aeroponics 22) Nutrient Film Technique 23) Wick System 24) Water 25) Green House 26) Contaminants 27) Salt 28) Vegetables 29) Herbs 30) Food	1) Biotechnology 2) Tools 3) Materials 4) Process(es) 5) Human Needs 6) Human Wants 7) Living Organisms 8) Phytoremediation 9) Clean the Environment 10) Plants 11) Phytostabilization 12) Confine Contaminants 13) Phytoextraction 14) Adsorbs & stores toxins 15) Leaves, stems, pedals 16) Phytotransformation 17) Converts contaminants 18) Hydroponics 19) Growing Plants without Soil 20) Vertical Farming 21) Drip System 22) Ebb & Flow 23) Deep Water Culture 24) Aeroponics 25) Nutrient Film Technique 26) Wick System 27) Growth Requirements 28) Temperature 29) Water 30) Sunlight 31) Root System 32) Contaminants 33) Barley 34) Vegetables 35) Food
Biology concepts, words & terms	6 / 14	6 / 14	9 / 14
Technology concepts, words & terms	18 / 37	17 / 37	15 / 37
Integrative concepts, words & terms	3 / 14	7 / 14	11 / 14
Total concepts, words & terms	27 / 65	30 / 65	35 / 65

Note. This measurement is Method Two of Hay et al.'s (2008) three-method analysis approach for recording the rater's documentation of the frequency of participants' use of key concepts, words, and terms used in their post-treatment concept maps.

	Participant #			
	4	5	6	7
Frequency of concepts, words, and terms The instructional materials consisted of 65 concepts, words and terms. Examining the student's post-treatment concept maps, the following concepts, words, and terms were used:	1) Biotechnology	1) Tools	1) Biotechnology	1) Biotechnology
	2) Tools	2) Materials	2) Tools	2) Tools
	3) Materials	3) Process(es)	3) Materials	3) Materials
	4) Process(es)	4) Human Needs	4) Process(es)	4) Process(es)
	5) Human Needs	5) Human Wants	5) Human Needs	5) Human Needs
	6) Human Wants	6) System	6) Human Wants	6) Human Wants
	7) Living Organisms	7) Input	7) Living Organisms	7) System
	8) Phytoremediation	8) Output	8) Phytoremediation	8) Input
	9) Clean the Environment	9) Living Organism	9) Clean the Environment	9) Output
	10) Phytostabilization	10) Phytoremediation	10) Plants	10) Feedback
	11) Confine Contaminants	11) Plants	11) Phytostabilization	11) Living Organisms
	12) Phytoextraction	12) Phytostabilization	12) Confine Contaminants	12) Phytoremediation
	13) Adsorbs & stores toxins	13) Confine Contaminants	13) Phytoextraction	13) Clean the Environment
	14) Phytransformation	14) Phytoextraction	14) Absorbs & stores toxins	14) Plants
	15) Converts contaminants	15) Adsorbs & stores toxins	15) Phytotransformation	15) Phytostabilization
	16) Hydroponics	16) Leaves, stems & pedals	16) Converts contaminants	16) Confine contaminants
	17) Vertical Farming	17) Phytotransformation	17) Hydroponics	17) Phytoextraction
	18) Drip System	18) Converts contaminants	18) Vertical Farming	18) Absorbs & stores toxins
	19) Ebb & Flow	19) Hydroponics	19) Drip System	19) Leaves, stems, pedals
	20) Deep Water Culture	20) Vertical Farming	20) Ebb & Flow	20) Phytotransformation
	21) Aeroponics	21) Drip System	21) Deep Water Culture	21) Converts contaminants
	22) Misting Roots	22) Ebb & Flow	22) Aeroponics	22) Hydroponics
	23) Nutrient Film Technique	23) Deep Water Culture	23) Nutrient Film Technique	23) Vertical Farming
	24) Roots Suspended…	24) Aeroponics	24) Plyvinyl Chloride	24) Drip System
	25) Wick System	25) Nutrient Film Technique	25) Wick System	25) Ebb & Flow
	26) Wick Transfers Nutrients	26) Wick System	26) Water pumps	26) Deep Water Culture
	27) Water	27) Growth Requirements	27) Wood/plastic bin	27) Aeroponics
	28) Root System	28) Water	28) Water	28) Nutrient Film Technique
	29) Green House	29) Sunlight	29) Nutrients	29) Polyvinyl Chloride
	30) Contaminants	30) Root System	30) Sunlight	30) Wick System
	31) Salt	31) Green House	31) Hyperaccumulators	31) Growth Requirements
	32) Barley	32) Contaminants	32) Contaminants	32) Water
	33) Sugar Beets	33) Salt	33) Salt	33) Sunlight
	34) Vegetables	34) Grey Water	34) Grey Water	34) Contaminants
	35) Food	35) Barley	35) Barley	35) Salt
		36) Vegetables	36) Sugar Beets	36) Grey Water
			37) Vegetables	37) Sugar Beets
				38) Vegetables
Biology concepts, words & terms	4 / 14	7 / 14	6 / 14	5 / 14
Technology concepts, words & terms	20 / 37	20 / 37	19 / 37	21 / 37
Integrative concepts, words & terms	11 / 14	9 / 14	12 / 14	12 / 14
Total concepts, words & terms	35 / 65	36 / 65	37 / 65	37 / 65

Note. This measurement is Method Two of Hay et al.'s (2008) three-method analysis approach for recording the rater's documentation of the frequency of participants' use of key concepts, words, and terms used in their post-treatment concept maps.

Appendix K

Method Three: Rater Scores of Participant Concept Maps

	Concept Map Scores	Participant #			
Constructs	pre/mid/post (gain score)	1	2	3	4
Concept richness	0-20 / 0-20 / 0-20 (+0-20)	10 / 16 / 16 (+6)	7 / 16 / 18 (+11)	14 / 16 / 18 (+4)	10 / 16 / 18 (+8)
Linkage quality	0-20 / 0-20 / 0-20 (+0-20)	16 / 17 / 11 (-5)	13 / 16 / 16 (+3)	13 / 15 / 16 (+3)	13 / 17 / 16 (+3)
Evidence of understanding	0-20 / 0-20 / 0-20 (+0-20)	11 / 15 / 13 (+2)	12 / 16 / 16 (+4)	12 / 14 / 17 (+5)	12 / 16 / 16 (+4)
Hierarchy and structure	0-20 / 0-20 / 0-20 (+0-20)	10 / 14 / 16 (+6)	10 / 14 / 18 (+8)	12 / 12 / 19 (+7)	10 / 16 / 16 (+6)
Total	0-80 / 0-80 / 0-80 (+0-80)	47 / 62 / 56 (+9)	42 / 62 / 68 (+26)	51 / 57 / 70 (+19)	45 / 65 / 66 (+21)

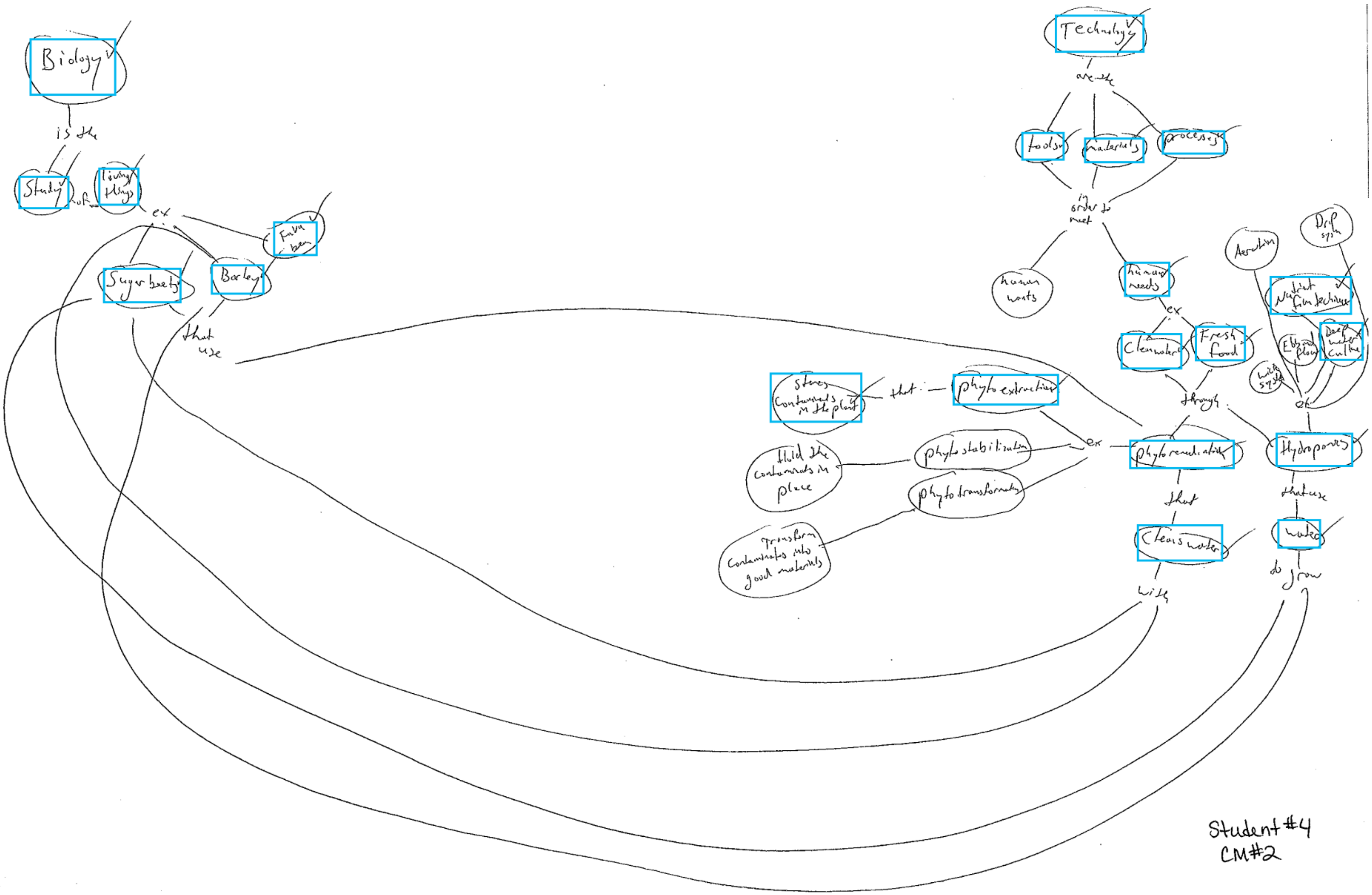
Note . This measurement is Method Three of the Hay et al.'s (2008) three-method analysis approach for recording rater scores for participant's pre, mid, and post concept maps based on a 16 item, five-point likert scale instrument.

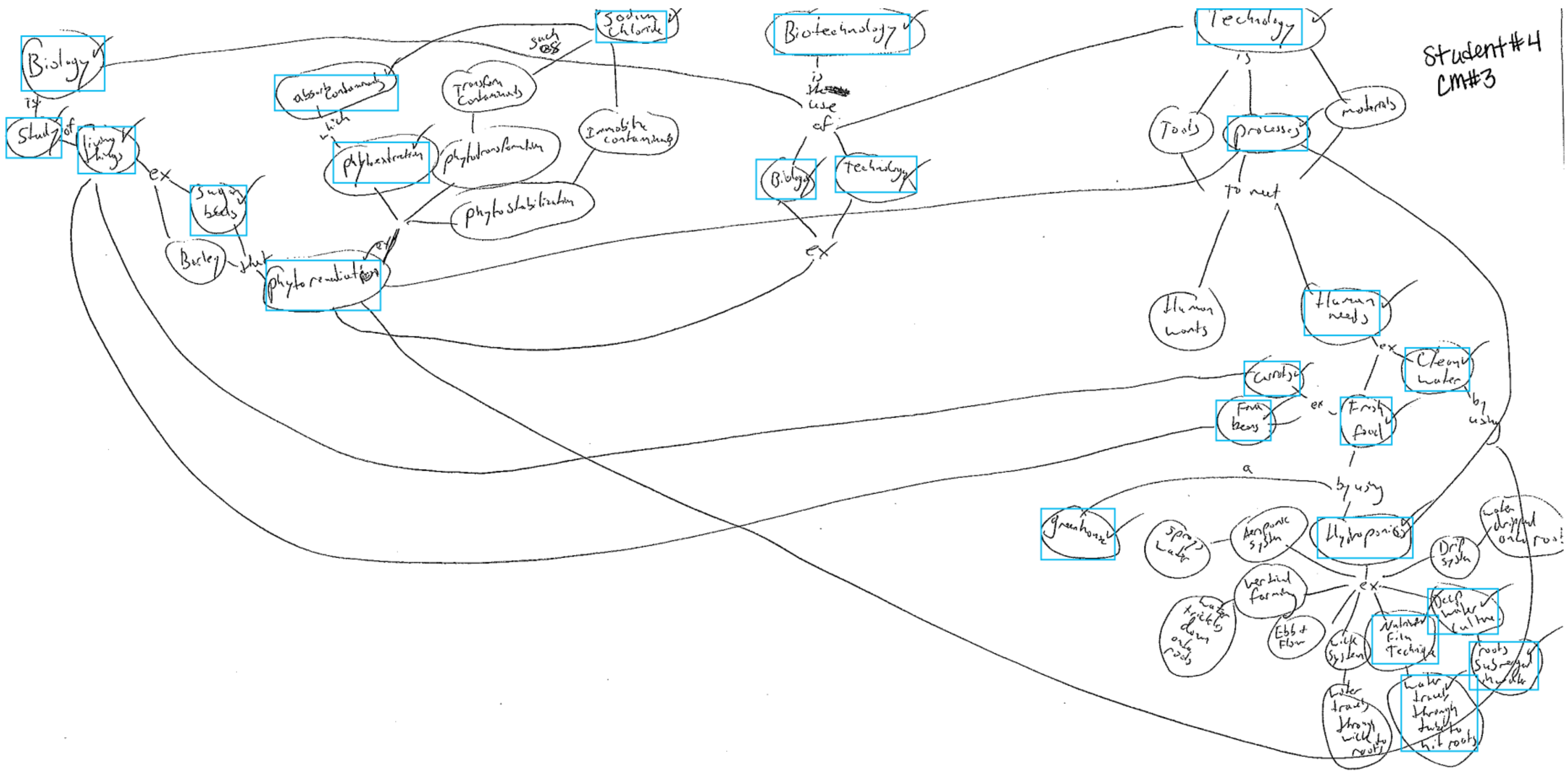
	Concept Map Scores	Participant #			Mean Scores
Constructs	pre/mid/post (gain score)	5	6	7	All
Concept richness	0-20 / 0-20 / 0-20 (+0-20)	10 / 13 / 20 (+10)	12 / 18 / 20 (+8)	10 / 12 / 20 (+10)	10 / 15 / 19 (+8)
Linkage quality	0-20 / 0-20 / 0-20 (+0-20)	8 / 12 / 16 (+8)	6 / 12 / 15 (+9)	13 / 12 / 13 (+0)	12 / 14 / 15 (+3)
Evidence of understanding	0-20 / 0-20 / 0-20 (+0-20)	10 / 14 / 16 (+6)	10 / 14 / 17 (+7)	12 / 11 / 17 (+5)	11 / 14 / 16 (+5)
Hierarchy and structure	0-20 / 0-20 / 0-20 (+0-20)	14 / 16 / 18 (+4)	8 / 16 / 16 (+8)	10 / 14 / 16 (+6)	11 / 15 / 17 (+6)
Total	0-80 / 0-80 / 0-80 (+0-80)	42 / 55 / 70 (+28)	36 / 60 / 68 (+32)	45/ 49 / 66 (+21)	44/ 59 / 66 (+22)

Note . This measurement is Method Three of the Hay et al.'s (2008) three-method analysis approach for recording rater scores for participant's pre, mid, and post concept maps based on a 16 item, five-point likert scale instrument.

Appendix L

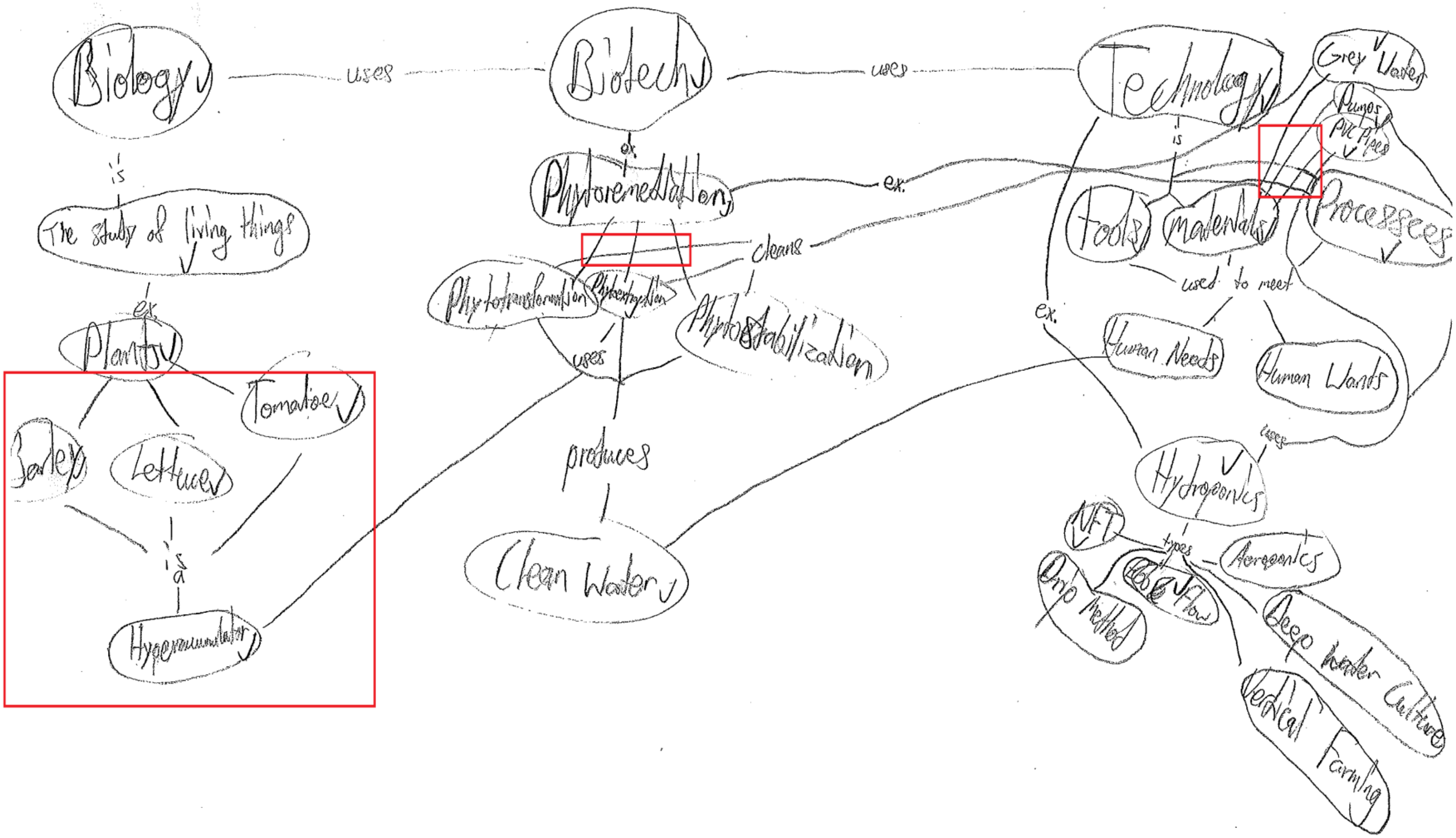
Pathways: Participant 4's Mid and Post-Treatment Concept Maps


Biology
is the
Study
of
living things
ex
Sugar beets
Barley
Fava bean
that use
Technology
tools
materials
processes
in order to meet
human wants
human needs
ex
Clean water
Fresh food
through
phytoremediation
Hydroponics
Aeration
Drip system
Nutrient film technique
Deep water culture
Ebb and flow
wick system
that use
water
to grow
that
Clean water
with
ex
phytoextraction
phytostabilization
phytotransformation
that
Stores contaminants in the plant
Hold the contaminants in place
transform contaminants into good materials
Student #4
CM#2

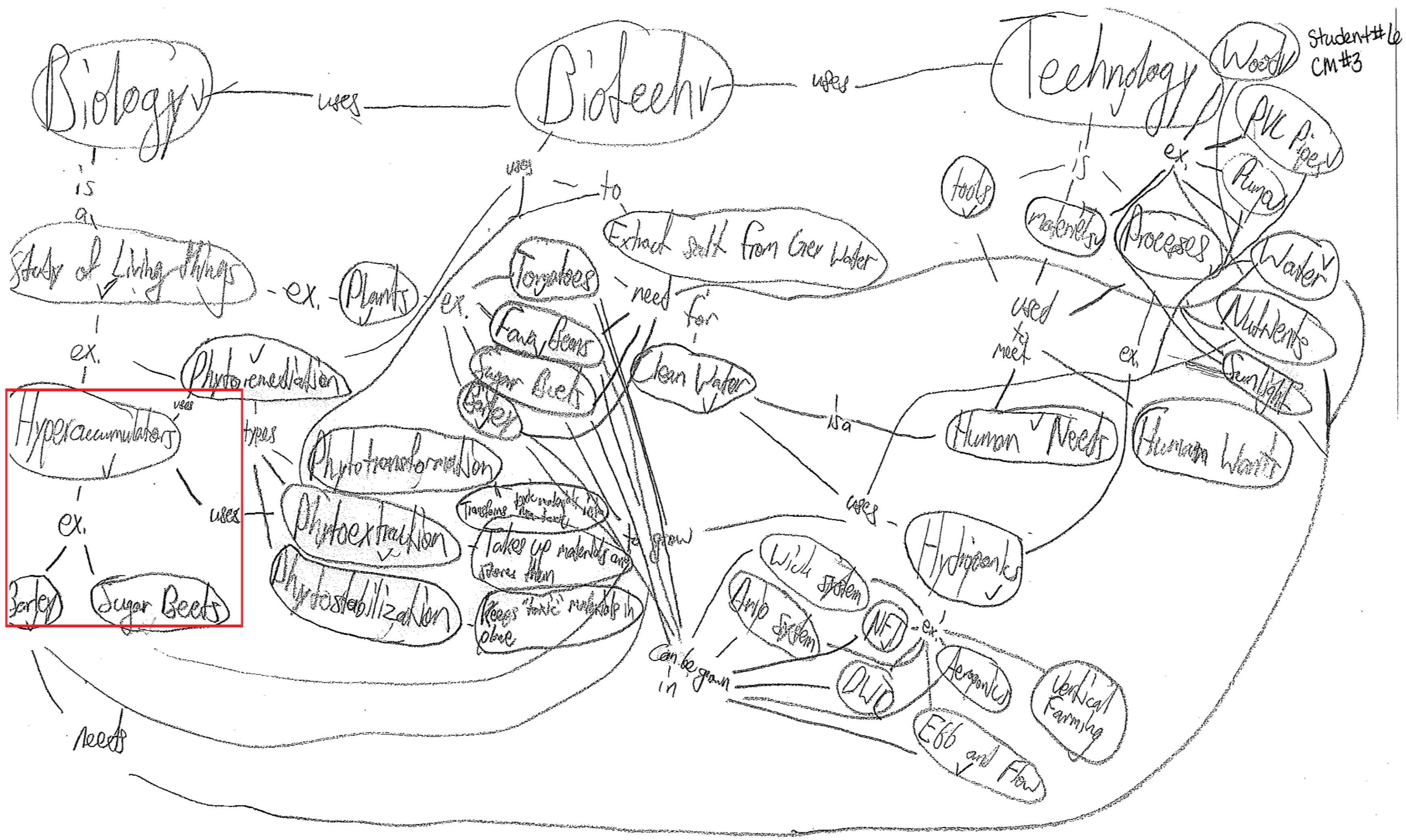

Student #4
CM#3
Biology
Study of
living things
Sugar beets
Barley
Phytoremediation
absorb contaminants
Transform contaminants
Sodium Chloride
Immobilize contaminants
phytoextraction
phytotransformation
phytostabilization
Biotechnology
is the use of
Biology
Technology
ex
Technology
is
Tools
processes
materials
to meet
Human wants
Human needs
Clean water
Fresh food
by using
Greenhouse
Spray water
Aeroponic system
Hydroponics
Drip system
Vertical farming
Ebb + Flow
Wick System
Nutrient Film Technique
Deep water culture
roots submerged in water

Appendix M

Meaningful Learning: Participant 6's Mid and Post-Treatment Concept Maps

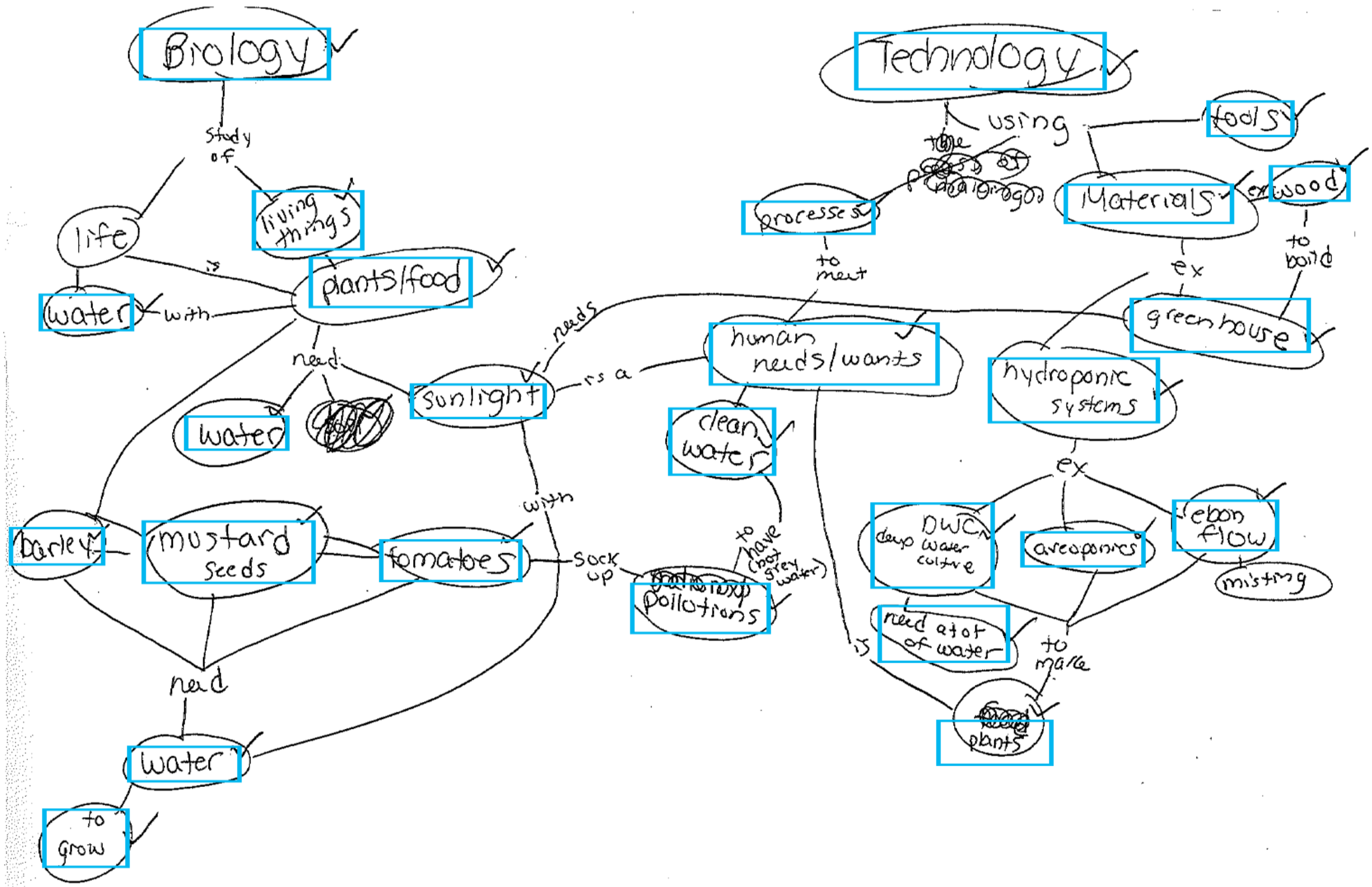


Student #6
CM#2


Student #6
CM #3
Biology
uses
Biotech
uses
Technology
Wood
PVC Pipes
Pumps
is
a
Study of Living things
ex.
Plants
Phytoremediation
Hyperaccumulators
uses
types
Phytotransformation
Phytoextraction
Phytostabilization
ex.
Barley
Sugar Beets
needs
to
Extract salt from Grey Water
ex.
Tomatoes
Fava Beans
Sugar Beets
Barley
need
for
Clean Water
is a
Human Needs
Human Wants
tools
materials
Processes
used to meet
Water
Nutrients
Sunlight
Takes up materials and stores them
Keeps "toxic" materials in place
to grow
uses
Hydroponics
Wick system
Ebb system
NFT
ex.
DWC
Aeroponics
Vertical Farming
Ebb and Flow
Can be grown in

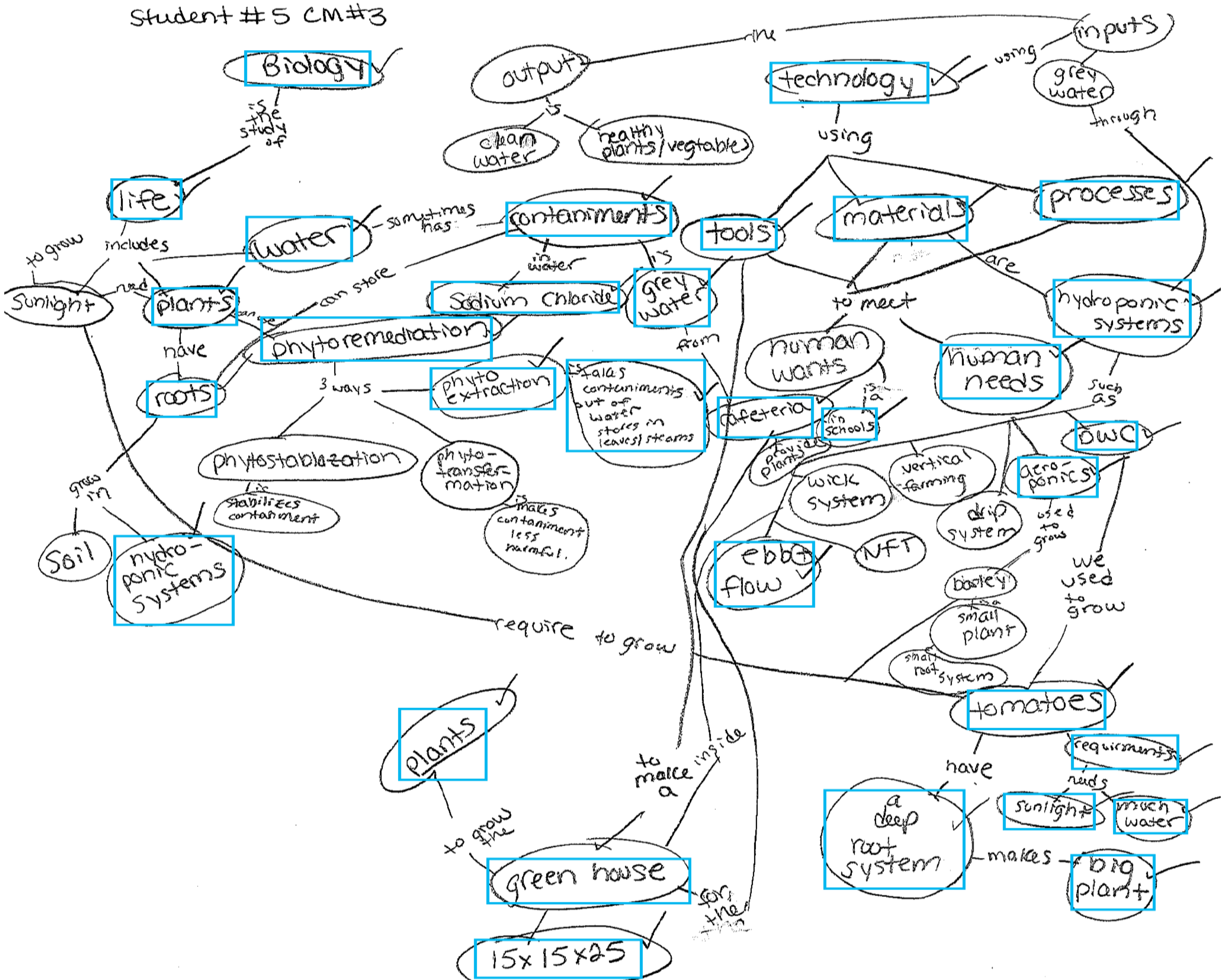
Appendix N

Meaningful Learning: Participant 5's Mid and Post-Treatment Concept Maps



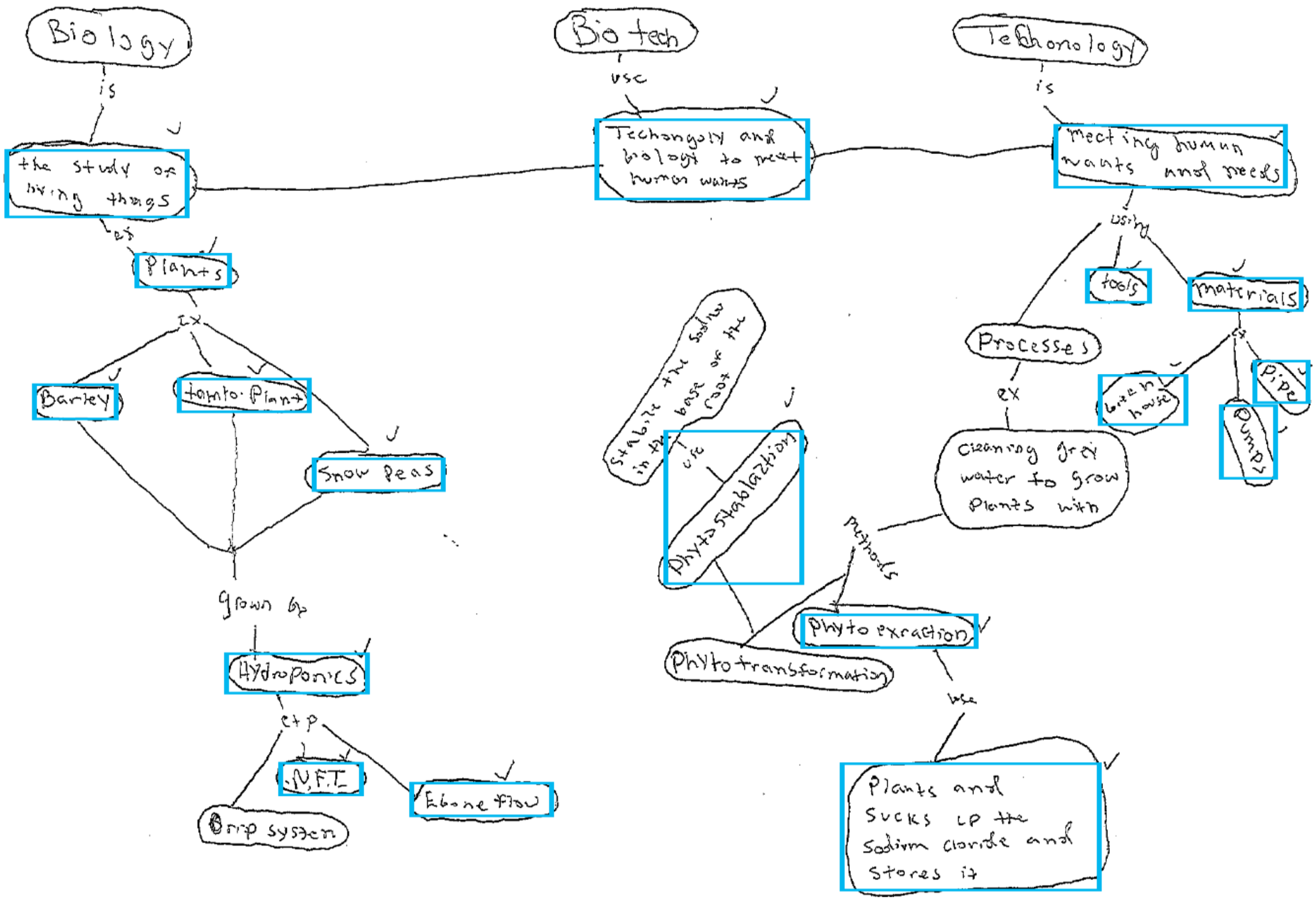
Student #5
CM#2

Student #5 CM#3



Appendix O

Meaningful Learning: Participant 1's Mid and Post-Treatment Concept Maps



Student#1
CM#2

Student#1
CM#3