Design Based Science and Higher Order Thinking

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ABSTRACT

Technological/engineering design based learning (T/E DBL) provides a context in which students may utilize content knowledge and skills to develop prototype solutions to real-world problems. In science education, design based science (DBS) utilizes technological/engineering design based approaches in science education as a means for enhancing the purpose of and relevance for scientific inquiry by contextualizing it within the goal of developing a solution to a real-world problem. This study addressed the need to investigate the ways in which students utilize higher order thinking skills, demonstrated through the use of knowledge associated with declarative, schematic, and strategic cognitive demand when in engaged in DBS activities.

The purpose of this study was to determine what relationships exist between engagement in DBS and changes in students' depth of understanding of the science concepts associated with the development of design solutions. Specifically, the study determined how students' abilities to demonstrate an understanding of the science concepts, required by assessments of different cognitive demand, change as they were engaged in a design-based science unit associated with heat transfer. Utilizing two assessment instruments, a pre/post-1/post-2 test and content analysis of student design portfolios based on Wells (2012) and utilizing Li's (2001) system to code students' responses, the following research question was addressed: What changes in students' science concept knowledge (declarative, schematic, and strategic demand) are evidenced following engagement in design based learning activities?

Although the results are not generalizable to other populations due to the limitations associated with the study, it can be concluded that design based learning activities incorporated in science courses can foster higher order thinking. Results from the study suggests that students' abilities to demonstrate their understanding of certain science concepts through higher order thinking, including utilizing concept knowledge strategically in open-ended problem solving, increased following engagement in design based learn activities. Results have implications in technological/engineering design education, in science education, and in integrative STEM education. Implications include the utility of design portfolios as both an assessment instrument and learning tool to ensure that concept knowledge is explicitly connected to and used in the design activity.

Dedication

I would like to dedicate this dissertation to my family. First and foremost, thank you to my biggest encourager, my husband Don. You have been the most supportive partner in life that anyone could ever hope to have. Thank you for your faith, strength, sacrifice, involvement, encouragement, comic relief, and willingness to do whatever it takes to support me.

To my children, Nathan, David, and Elisabeth, thank you for your support, understanding, and most of all for all of the sacrifices that you have made through this endeavor. It is my joy to see you grow into people who will make the world a better place and into the lives that God intends for you.

Finally, I would like to dedicate this dissertation to my parents, Richard and Sara Gregory. Thank you for your endless support and for believing in me and encouraging me always.

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Table of Contents

List of Tables

List of Figures

CHAPTER ONE: INTRODUCTION

For over three decades there have been calls for improvements in our education system, particularly in science and math and more recently science, technology, engineering, and math or STEM. Calls for reform have been included in publications such as *A Nation at Risk* (National Commission on Excellence in Education, 1983), *Science for All Americans* (Association for the Advancement of Science [AAAS], 1990), *Benchmarks for Science Literacy* (AAAS, 1993), *Technology for All Americans* (ITEA, 1996), *Technically Speaking* (ITEA, 2002), *Standards for Technological Literacy* (ITEA/ITEEA, 2000/2002/2007), *Innovation America* (National Governors Association Center for Best Practices, 2007), *National Action Plan for Addressing the Critical Needs of U.S. Science, Technology, Engineering, and Mathematics Education System* (National Science Board [NSB], 2007), *Rising Above the Gathering Storm* (Committee on Prospering in the Global Economy of the 21st Century, 2007), *Engineering in K-12 Education* (National Association of Engineering [NAE] & National Research Council [NRC], 2009), and *The Case for Being Bold* (U.S. Chamber of Commerce, 2011).

The need to reform STEM education is cited as an imperative for producing an adequate number of people with appropriate skills and talent (Committee on Prospering in the Global Economy of the 21st Century, 2007; NSB, 2007; U.S. Chamber of Commerce, 2011) for the United States to compete in an increasingly technological and globally-competitive, "knowledge-based" economy (NSB, 2007, p. 2). Producing the talent is vital to innovations in STEM fields that contribute to the nation's economy, which based on data from Abromowitz in the U.S. Congress Joint Economic Committee's report *STEM Education: Preparing for the Jobs of the Future* (2012), have contributed to at least 50% of the productivity in the U.S. over the past 50 years (p. 1). Regardless of whether students are interested in pursuing STEM careers, however, STEM education is also crucial for developing productive citizens in the 21st century in that STEM literacy enables higher order thinking skills, including the ability to solve problems and make decisions (AAAS, 1990; ITEA, 1996; ITEA, 2002; ITEA/ITEEA, 2000/2002/2007; ITEA, 2000; NAE & NRC, 2009).

Calls for reformed STEM education emphasize rigor and higher order thinking to address the need to better prepare students for the 21st century (Wells, 2008, 2010). In the early 20th century, Dewey advocated for involving students in learning through engagement in experiences in which the student is an active participant (1902, 1938). Two of the most recent, multi-state education reform efforts, the *Common Core State Standards* (Common Core State Standards Initiative, 2014) and *Next Generation Science Standards* (Next Generation Science Standards [NGSS] Lead States, 2013), are similarly aimed at involving students in authentic practice in science and mathematics to improve students' higher order thinking skills and depth of understanding of content and practices. Higher order thinking according to Krathwohl's (2002) revision of Bloom's taxonomy includes students' creating, which is associated with cognitive processes such as designing, generating, planning, and producing. In another framework for designing mathematics and science curricula developed by Webb (2002), higher order cognitive processes include "extended thinking," which entails students' abilities to design, connect, synthesize, apply concepts, critique, analyze, create, and prove.

Current State of Education Driving Calls for STEM Education Reform

The emphasis on improving student higher order thinking and depth of understanding in the latest calls for education reform are reinforced by international comparisons of U.S. students' performance. Assessments of U.S. students' performance indicate weaknesses in their abilities to apply knowledge in the context of real-world problem solving. U.S. students' performance on the PIRLS (Progress in International Reading Literacy Study) (Loveless, 2013), which assesses reading literacy, and TIMMS (Trends in International Math and Science Study) (Provasnik, Kastberg, Ferraro, Lemanski, Roey, & Jenkins, 2012), which assesses math and science, shows some recent improvement on student performance particularly for grade 4 students. However, on PISA (Programme for International Student Assessment), which is administered by the Organisation for Economic Co-Operation and Development (OECD, 2013) and assesses students' knowledge in math, reading, and science with an emphasis on students' abilities to apply what they know to real-world problems, U.S. students' performance reveals strengths only with lower level, "superficial" tasks that do not consider "context" associated with problem solving. Further, the PISA report suggests that the U.S. system should involve students more in higher order thinking activities while building on the lower level skills that are necessary for understanding higher order activities (p. 74).

One form of context-based problem solving that is implemented in U.S. schools involves technological design. Although the inclusion of technology and engineering in the curriculum is relatively new in the U.S., according to Doppelt et al. (2008) it is prevalent in "the great majority of industrialized nations in the world" (p. 22). Since technological design is implemented in such varying ways in U.S. schools, the National Assessment Governing Board (NAGB, 2014) has developed and administered a pilot in 2014 through the National Assessment of Educational Progress (NAEP) to assess technological and engineering literacy for U.S. students.

The lack of context and real-world application in the U.S. education system was recognized at the beginning of the 20th century by Dewey (1902) who lamented that the unfortunate result of a lack of context for learning would be that information would not be associated with some meaningful experience but rather would be "torn away" from meaning.

Dewey explains that children are not able to relate to facts that are “pigeonholed” according to abstract principles that relate more to how adults characterize the world rather than the way children behave (1902, p. 6). Dewey suggested that learning should not be a process in which the learner is a passive participant. Rather, learning *by doing* can provide the most meaningful way for students to interact with and understand information. Rather than transmitting knowledge in a sterile environment that is dissociated from what students value, Dewey (1902, 1938) wrote that it is the student who is the central determinant as to whether or not information is learned.

In science education, learning by doing is manifested in what Duschl, Schweingruber, and Shouse (2007, p. 251) describe as “teaching science as practice.” Michaels, Shouse, and Schweingruber (2007, pp. 17-21) further describe the characteristics or “strands” involved in student understanding when science is taught as it is practiced: “understanding scientific explanations,” “generating scientific evidence,” “reflecting on scientific knowledge,” and “participating productively in science.” However, there is evidence that science education is not conducted with those principles in mind.

Science inquiry is traditionally utilized in the classroom to involve students in authentic science practice; however, conventional science curriculum in the U.S. often involves prescribed inquiry activities in which the answers are already known and the questions and procedures are provided (Appleton, 1995; Barnett, 2005; Doppelt, Mehalik, Schunn, & Krysinski, 2008; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005). In addition, traditional science curricula often is devoid of meaningful, real-world problem solving, which can contextualize learning and make content recognizably relevant and motivating for leaners (Fortus et al., 2005; Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, and Puntambekar, 2003).

Further, science inquiry activities are often based on the artificial conception of a universal scientific method, which simplifies science investigations in the classroom but unfortunately does not provide students with opportunities to develop rich understandings of content and actual science practice (Roth, 1995; Windschitl, Thompson, & Braaten, 2008). Even when inquiry activities do provide opportunities for students to become involved in directing the development themselves, the questions and investigations often have to do with superficial relationships between variables rather than the actual conceptual mechanisms behind the phenomena being investigated, resulting in little to do with the associated science content (Roth & Garnier, 2007; Seiler, Tobin, & Sokolic, 2001; Windschitl et al., 2008).

Problem solving in science education also suffers from the misconception that “problem solving” entails quantitatively solving a well-defined problem with a teacher-prescribed algorithm in order to arrive at *the* correct answer (Dillon, 1982 as cited in Appleton, 1995, p. 383; Wang, Moore, Roehrig, & Park, 2011). In contrast, open-ended, ill-structured problem solving is described by Seiler, Tobin, and Sokolic (2001) as against the norms of science education, which typically involve note taking, rote learning, and worksheets (p. 762). In fact, Appleton (1995) points out that both teachers and students would rather have curriculum lead to the “correct” answer to a problem since conventional science curricula often follow those norms (p. 388).

Technological/engineering design based learning (T/E DBL) provides a context in which students may utilize content knowledge and skills to develop prototype solutions to real-world problems. Since developing solutions to real-world problems requires an understanding of concepts and adeptness with skills from more than one content area, T/E DBL can provide a means by which integration can occur between STEM and other disciplines (Bybee, 2010;

Hutchinson & Hutchinson, 1991; ITEA/ITEEA, 2000/2002/2007; LaPorte & Sanders, 1993; McCormick, 2004; NAE & NRC, 2009; Pitt, 2000; Raizen, Sellwood, Todd & Vicers, 1995; Satchwell & Loepp, 2002; Savage & Sterry, 1990; Wells, 2010; Wells, 2013). Involvement in integrative, design based learning emphasizes higher order thinking, problem solving, and rich learning of concepts and skills through realistic practices and real-world applications that foster explicit connections between discipline areas (Bybee, 2010; Dugger & Meier, 1994; Loepp, 2004; Wells, 2010). Integrating content across artificially separated subject matter is critically important in that it also provides a context for learning that benefits students by illustrating the relevance of the material to their own lives (Barton, 1998; Doppelt et al., 2008; Drake & Burns, 2004; Huber & Hutchings, 2004; Kaufman, Moss, & Osborne, 2003; Kolodner et al., 2003). Further, making connections between content areas can provide students with the opportunity to see themselves as authentic practitioners, leading to increased awareness about and interest in those fields (NAE & NRC, 2009, pp. 62 and 67).

Design Based Science

Design based science (DBS) utilizes technological/engineering design based approaches in science education as a means for enhancing the purpose of and relevance for scientific inquiry by contextualizing it within the goal of developing a solution to a real-world problem. Design approaches utilized in science education provide students with opportunities to see the relevance of what they are learning. Design based science requires students develop prototype models of a solution that addresses a problem. In the process, students are required to apply their knowledge of science concepts and results from scientific inquiry to develop the solution (Doppelt et al., 2008; Kolodner, 2002).

Rationale for the Study

Problem solving through DBS methodologies has recognized potential for addressing calls for science education reform by providing the opportunity for improved STEM education incorporating relevant contexts, integration between subject areas, real-world representations of content, and higher order thinking and problem solving opportunities, leading to gains in understanding of science concepts. Design based pedagogical approaches can provide a relevant context for learning science concepts and practices by engaging students in problem solving through T/E DBL (Beneson, 2001; Bybee, 2010; Cantrell, Pekcan, Itani, and Velasquez-Bryant, 2006; Doppelt et al., 2008; Linn & Muilenburg, 1996; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Fortus et al., 2005; Lou, Yi, Ru, Tseng, 2011; McCormick, 2004; Wells, 2008; Wells, 2010). Further, such approaches can provide an intentional connection between the content and practices of science inquiry and technological/engineering design, a hallmark of recommendations for reform in science and technology education (AAAS, 1990; AAAS, 1993; ITEA, 1996; ITEA, 2002; ITEA/ITEEA, 2000/2002/2007; ITEA, 2000; NAE & NRC, 2009; NGSS Lead States, 2013; NRC, 2012). DBS pedagogical approaches utilized in science education can also provide a critically important mechanism for engaging and motivating students as they develop design artifacts which serve as concrete representations of science concepts that are constructed while participating in practice that models authentic, ill-structured problem solving (Cajas, 2001; Doppelt et al., 2008; Fortus et al., 2004; Fortus et al., 2005; Kolodner et al., 2003; McCormick, 2004; NAE & NRC, 2014; Roth, 2001).

Given that confirmatory inquiry and problem solving pervades conventional K-12 science education and given the interest in and calls for reform of K-12 education to improve students' higher order thinking and problem solving abilities, DBS has the potential to transform learning in science by infusing relevance, context, more meaningful learning, and knowledge associated with higher cognitive demand through open-ended problem solving. It is well established that DBS activities can result in positive gains in students' science content knowledge (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Barnett, 2005; Chua, Yang, and Leo, 2013; Doppelt et al., 2008; English, Hudson, & Dawes, 2013; Fortus, 2003; Fortus et al., 2004; Fortus et al., 2005; Kolodner et al., 2003; Lachapelle and Cunningham, 2007; Marulcu and Barnett, 2013; Mehalik, Doppelt, & Schunn, 2008; Roth, 2001; Schnittka, 2009; Silk, Schunn, & Cary, 2009). What has not been explored thoroughly is the extent to which DBS approaches encourage higher order thinking as measured through assessments that require multiple levels of cognitive demand.

Few studies have examined DBS from the standpoint of how the approach encourages higher order thinking with the exception of Fortus (2003), Kelley (2008), Schnittka (2009), Schurr (2013), and Wells (2016a). Fortus (2003) examined transfer of content knowledge from a design challenge to a novel but related design task. Kelley (2008) examined, through verbal interviews, the mental processes used by students participating in high school engineering curriculum programs. Schnittka (2009) examined change in students' conceptions of heat transfer concepts while engaged in engineering design activities supported with hands-on demonstrations. Schurr (2013) and Wells (2016a) both examined higher order thinking associated with T/E DBL in the context of biotechnology courses, Schurr with high school students and Wells with graduate students.

Investigating higher order thinking skills utilized by students in DBS in the context of science education will provide additional empirical evidence about the approach and its relationship to higher order thinking at a time when incorporating technological/engineering design into science education has become of great interest nationally. In addition, investigating higher order thinking associated with the use of DBS will meet the need to gather additional empirical evidence concerning how to enhance higher order thinking in K-12 science education, which is traditionally not focused on higher level cognitive tasks and open-ended, real-world problem solving.

Research Problem

Preliminary evidence suggests that DBS practices can engage and motivate students and result in desirable growth of science content knowledge for students. However, few studies have examined DBS in terms of its relationship to students' use of higher order thinking skills. Investigating the extent to which engagement in DBS activities is associated with changes in students' depth of understanding of science concepts will help to inform curriculum and instructional practices associated with DBS, technology education, and integrative curricula toward the goal of transforming curriculum and instructional practices to improve the level of higher order thinking through real-world problem solving. This study addresses the need to investigate the ways in which students utilize higher order thinking skills, demonstrated through the use of knowledge associated with declarative, schematic, and strategic cognitive demand when in engaged in DBS activities.

Purpose of the Study

The purpose of this study is to determine what relationships exist between engagement in DBS and changes in students' depth of understanding of the science concepts associated with the development of design solutions. Specifically, the study will determine how students' abilities to demonstrate an understanding of the science concepts, required by assessments of different cognitive demand, change as they are engaged in a design-based science unit associated with heat transfer.

Research Question

What changes in students' science concept knowledge (declarative, schematic, and strategic demand) are evidenced following engagement in design based learning activities?

Limitations

The limitations and potential threats to the validity of this study include the researcher's functioning as teacher and researcher, the case study design, the convenience sample, and time constraints. The study is a case study conducted in the classroom of the researcher during the implementation of an approximately three-week long curriculum intervention. Although case study research often involves in-depth observation over an extended period of time (Cresswell, 2007), the limited time over which the study will be implemented somewhat limits data collection. Since the researcher also functioned as the teacher, the opportunity to participate in the curriculum intervention was provided to all students enrolled in each course; therefore, the possibility of structuring the study to make comparisons between groups through an experimental or quasi-experimental design, though perceived as preferable (Campbell & Stanley, 1963), was not possible. Since the study utilized convenience sampling, it was not be possible to collect data from a pre-determined demographic of students. Due to these limitations, none of the conclusions generated will infer generalizability of the results.

Operational Definitions

Concept Knowledge

> Understanding a theory or principle such that one can apply his/her understanding to phenomena in new contexts. Developing concept knowledge involves understanding the concept at increasingly sophisticated levels through the process of conceptual change, including "elaborating on a preexisting concept," restructuring a network or concepts,"

and/or "achieving new levels of explanation" (Michaels, Shouse, & Schweingruber, 2007, pp. 42-43).

Declarative Knowledge

"Knowing that" involves students' abilities to "recall, define, represent, use, and relate" science concepts (NAGB, 2014, p. 88).

Design Based Learning (DBL)

A problem-based pedagogical approach in which concepts from various subject areas are taught through design contexts, with an emphasis on students rather than teachers identifying problems, questions, and design criteria and constraints and with learning cycles. DBL learning cycles are structured around "systems design," which involves students analyzing and making design decisions about each subsystem associated with the system associated with the design artifact (Apedoe, Reynolds, Ellefson, and Schunn, 2008; Hmelo, Holton, & Kolodner, 2000; Mehalik, Doppelt, & Schunn, 2008; Gomez Puente, van Eijck, & Jochems, 2013).

Design Based Science (DBS)

A problem-based pedagogical approach employed in science education in which scientific concept knowledge is learned and applied through a design context, which involves students in developing two-dimensional or three-dimensional design artifacts as solutions to real-world problems, which are not necessarily working prototypes (Fortus, 2003). DBS learning cycles are structured around an iterative design process, wherein students use the same design process in cycles, with each cycle focused on different but related science concepts that are associated with the design problem (Fortus, Dershimer, Krajcik, Marx, and Mamlok-Naaman, 2004).

Integrative STEM Education (I-STEM ED)

I-STEM ED is the application of technological/engineering-design-based approaches to *intentionally* teach content and practices of science and mathematics education through the content and practices of technology/engineering education. I-STEM ED is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels (Wells & Ernst, 2012/2015).

Procedural Knowledge

"Knowing how" involves students' abilities to "perform" laboratory techniques and use laboratory tools appropriately (NAGB, 2014, p. 88).

Schematic Knowledge

"Knowing why" involves students' abilities to "explain and predict natural phenomena" and provide evidence-based explanations for scientific conclusions (NAGB, 2014, p. 88).

Strategic Knowledge

"Knowing when and where to apply knowledge" involves students' abilities to apply or transfer the knowledge of a science concept or phenomenon in a different context or to a different problem (National Assessment Governing Board, 2014, p. 88).

Technological/Engineering Design Based Learning (T/E DBL)

T/E DBL is a pedagogical approach in which the student is involved in authentic application of content knowledge through problem solving which leads to the development of a technological solution (student artifact), which is designed to meet a real-world need.

CHAPTER TWO: LITERATURE REVIEW

A review of pertinent literature relating to T/E DBL, DBS, and related higher order thinking was conducted. The review includes foundations for T/E DBL in technology education and Integrative STEM Education, T/E DBL and science inquiry, foundations for DBS approaches in science education, the basis for design based pedagogical approaches in educational learning theory, and research methods for assessing higher order thinking within the context of design based pedagogical approaches.

Foundation for T/E DBL

Technological/engineering design based learning (T/E DBL) is the characteristic pedagogical methodology of technology and engineering education and involves students in problem solving for the purpose of developing technological literacy (ITEA, 1996). The International Technology Education Association (2000/2002/2007) has described a technologically literate person as one who understands technology in terms of how it is developed by human society and how it, in turn, influences society (p. 9).

The T/E DBL process builds on the early framework for Industrial Arts education from Bonser and Mossman (1930), which describes the value of the field as providing students with the opportunity to learn through application of knowledge by emphasizing “something to be done” that actively engages students, furthers their interests, and provides meaningful applications of concepts to facilitate new learning. The process also builds on the “Technological Method” described in Savage and Sterry (1990, p. 12) as the method by which technology is done. Savage and Sterry’s (1990) Technological Method model was introduced as the field of technology education evolved in the latter part of the 21st century from Industrial Arts, shop-oriented classes, with an emphasis on the use of tools toward an emphasis on the use of content knowledge for the purpose of problem solving grounded in real-world contexts (Foster, 1994; McCormick, 2004; Sanders, 2001). The Technological Method was the basis for a curricular structure and a model for problem solving associated with students identifying and proposing technological solutions to problems based on human and/or societal needs (Savage & Sterry, 1990, p. 13). However, problem solving practices have been employed in the field of Industrial Arts Education for nearly a century for the purpose of providing practical application of content knowledge in other subject areas and appealing to students' natural curiosities through both general education and vocational training (Bonser & Mossman, 1930, p. 59). McCormick (2004) describes problem solving as "the most important procedural knowledge" in technology education and any other human endeavor (p. 25).

The Technological Method has further evolved into T/E DBL by incorporating engineering design into Savage and Sterry's model. The incorporation of engineering design was formally signified in 2010 by the changing of the name of the technology education professional organization from the *International Technology Educators Association* (ITEA) to the *International Technology and Engineering Educators Association* (ITEEA).

The T/E DBL process of problem solving leads to the development of a technological solution, the student artifact, which is designed to meet a real-world need. In the *Standards for Technological Literacy* (ITEA/ITEEA, 2000/2002/2007) the process of technological design is described as "the core problem-solving process of technological development" with the following characteristics: "it is purposeful; it is based on certain requirements; it is systematic; it is iterative; it is creative; and there are many possible solutions" (pp. 90-91).

Technological/engineering design is distinguished from design in other fields such as the arts in that the end products are actual built devices or innovative processes that perform a function to meet certain criteria within certain limitations or constraints (ITEA/ITEEA, 2000/2002/2007). Hmelo, Holton, and Kolodner (2000) describe the processes of design and modeling as going hand-in-hand. As students design a solution to a problem, their 3-D model is built as a representation and testable device for the design process. Engineering design, specifically, is described in *Engineering in K-12 Education* (2009) as “the approach engineers use to solve engineering problems – generally, to determine the best way to make a device or process that serves a particular purpose” (NAE & NRC, p. 38). The potential benefit of engineering design education for students is described in five areas: “improved learning and achievement in science and mathematics,” “increased awareness of engineering and the work of engineers,” “understanding of and the ability to engage in engineering design,” “interest in pursuing engineering as a career,” and “increased technological literacy” (NAE & NRC, 2009, pp. 49-50).

Incorporating engineering design into technology education can impact learning by increasing “rigor” (Wicklein, Smith, & Kim, 2009). However, there are important differences between design as it is commonly employed in technology education compared with design as it is employed in engineering fields. In technology education, design involves (1) a “narrative explanation” of the technological problem, (2) a “graphical representation” of the proposed solution to the problem, and (3) a “physical artifact” that can be “manipulated or tested” (Wicklein & Thompson, 2008, p. 69). Engineering design employed in engineering fields, however, employs more mathematical analyses to make predictions about the proposed solution before it is put into production (Kelley, 2008; Wicklein & Thompson, 2008).

As T/E DBL is focused on authentic problem solving, it is assessed through the use of authentic assessment mechanisms. For example, learning assessments may include student portfolios (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008), self-evaluations (English, Hudson, and Dawes, 2013), and/or design diaries (Puntambekar & Kolodner, 2005), which can be used for student assessment as well as student self-assessment and scaffolding for ensuring that student learning is connected to learning objectives. Such assessments have value not only in student evaluations; they also can be employed to make explicit connections between student understanding of related content knowledge associated with the design process and design products that are made (Puntambekar & Kolodner, 2005; Wicklein & Thompson, 2008).

The problem solving task in T/E DBL is often introduced through an engineering design challenge. The terms used to describe such challenges vary. LaPorte and Sanders (1993) refer to the challenges associated with an integrated, design-based technology, science, and math program as “design briefs.” Wells (2011) refers to biotechnology-related design challenges as “Problem Scenarios” or “ProbScens.” Regardless of the term used, the general purpose of the challenge is to frame the curriculum unit and learning objectives, provide real-world context, and serve as the prompt to introduce the problem and design criteria to set the stage for designing the solution that students will develop through the T/E DBL process.

Fundamental Learning Theory and T/E DBL

The theoretical basis for educational reform efforts advocating for the incorporation of T/E DBL in the curriculum is based on the premise that developing technological literacy for all students must involve engaging students as active participants in the experiences of technology. Actively participating in technology involves instruction that is designed to provide context-rich opportunities for students to learn by experience, as advocated by Dewey in the early 20th century. Learning through participation in practice is based on principles from the educational theories of constructivism in which the student actively constructs and makes meaning of new information as it is associated with prior knowledge (Bruner, 1997; Duffy & Cunningham, 1996; Liu & Chen, 2010; Savery & Duffy, 1995; Schunk, 2012; Splitter, 2008) and situated cognition in which learning is embedded in authentic practice and contexts (Brown, Collins, & Duguid, 1989; Herrington & Oliver, 1995; Herrington & Oliver, 2000; Oyserman, Sorensen, Reber, & Chen, 2009; Semin & Smith, 2013).

Constructivism and T/E DBL

In constructivism, learners actively shape and make meaning of knowledge in the process of reconciling new experiences which are socially and culturally based. Duffy and Cunningham (1996) describe constructivism as being based on two principles, "(1) learning is an active process of constructing rather than acquiring knowledge, and (2) instruction is a process of supporting that construction rather than communicating knowledge" (p. 2). In constructivist settings, the learner does not passively receive information from the instructor; rather, the learner is actively engaged in learning and making meaning of information (Liu & Chen, 2010; Schunk, 2012; Splitter, 2008).

The constructivist learning theory is based in part on principles of cognition described by John Dewey, Jean Piaget, Lev Vygotsky, and Jerome Bruner in the early to middle part of the 20th century (Duffy & Cunningham, 1996; Liu & Chen, 2010; Schunk, 2012). John Dewey has been a seminal figure of educational reform, beginning in the early 20th century with publications advocating for student-centered methodologies. Dewey suggested that without engaging the student in experiences that are relevant, the facts that are being relayed become nothing more than "abstractions" that have little meaning to the learner. However, when education is based on the premise that the learner must experience information in order to learn, then the learner has an opportunity to "psychologize" the information by applying the information, interacting with it, and using it to inform future experiences (Dewey, 1902, p. 23). The application of knowledge through experience is critical in that by witnessing the "consequences" of knowledge principles through application, those principles can become "concrete" (Dewey, 1938, p. 22). By learning through doing, experiences have long term impacts, enabling students to draw on and apply information in future situations (Dewey, 1902, p. 21).

A summary of Piaget's propositions is that previous experiences can build cognitive schemas, which serve as frameworks within which new experiences are constructed. Through a process Piaget called "disequilibration," which is associated with various mental stages of development through childhood, new experiences are "internalized" and learned within the framework of the cognitive schemas present (Bruner, 1997, p. 66). Schunk (2012) explains that the disequilibrium described by Piaget involves "incongruity" to build on existing schemas resulting in the learning of new knowledge (p. 240). Through the process of encountering incongruous information through active experiences, the child's mind makes meaning of information based on the child's own experiences, which serves as the mechanism for learning (Savery & Duffy, 1995; Schunk, 2012). Bruner (1997) states, "For Piaget, knowledge of the world is made, not found" (p. 66).

In the mid-20th century, Vygotsky also theorized that it is the learner who provides meaning for experiences and knowledge. Bruner (1997) notes that Vygotsky described the mind as the "process for endowing experience with meaning (p. 68)." Bruner also notes the importance of language and social interactions in Vygotsky's theory as the mechanisms by which knowledge becomes "internalized" (p. 68). For Vygotsky, in order for learners to process, internalize, and make meaning of knowledge, they must be provided with opportunities to grow within the Zone of Proximal Development (ZPD). Duffy and Cunningham (1996) describe the

ZPD as “the distance between the actual developmental level of a child as determined by independent problem solving and the level of potential development as determined through problem solving under guidance or in collaboration with more capable peers.” Learning occurs as the leaner becomes more independent and brings knowledge into his or her own cognitive control (Duffy & Cunningham, 1996, p. 14). Further, Vygotsky’s theory also relates the outcome of learning to the social and peer context within which new experiences are embedded, since it is through social experiences that students learn from one another and model “self - efficacy” (Schunk, 2012, pp. 235-246).

Similar to Vygotsky’s concept of ZPD, Bruner suggests that knowledge is constructed by the learner through the process of “active struggling” with the content in a new experience in which the learner is actively engaged (as cited in Duffy and Cunningham, 1996, p. 5). Bruner promoted the idea that learning through “discovery” and “disciplined inquiry” can motivate students to take responsibility for their own learning (as cited in Takaya, 2008, pp. 7-8). The discovery of new information should be appropriately supported based on the child’s developmental stage with “scaffolds” that guide construction of knowledge (Education Portal, n.d.). Bruner emphasizes scaffolding students’ understanding such that learning is a process of having the learner understand what he or she already knows and then being able to expand upon what is known (Liu & Chen, 2010).

In constructivism, context and active learning are crucial factors for enabling learners to make meaning of new information. Context provides relevance and can motivate student learning. As Savery and Duffy (1995) explain, “Understanding is in our interactions with the environment” (p. 1). A learning theory built on the fundamental principles of constructivism and the importance of context is problem-based learning (PBL). PBL was first introduced in medical training as a way to teach future practitioners to learn through practice (Duffy & Cunningham, 1996; Savery & Duffy, 1995).

In PBL, the student interacts with the environment and constructs meaning of new information through explorations of real-world problems relating to the concepts being learned. PBL is a constructivist model in that it involves relevant problems, challenges students' thinking, and promotes seeking out and making meaning out of new information (Schank, 1995). Rather than the subject matter driving the learning experience, open-ended, authentic problems drive the curriculum and learning (Duffy & Cunningham, 1996, p. 23). The teacher's role in PBL is to ensure that students are enabled to solve those problems by providing them with experiences and "exposing" the knowledge and skills they need in order to address those problems (Schank, 1995, The Role of the Teacher section, para. 3). PBL's emphasis on open-ended problem solving serves as the vehicle for the disequilibration process which involves students proposing answers to problems that may actually turn out to be incorrect, causing the need for the student to learn more and, therefore, serving as an inducement for learning (Savery & Duffy, 1995; Schunk, 2010, p. 240). The selection of the problem is one of the crucial factors for PBL. The problems that drive PBL must be complex and rich enough to engage students in thinking and authentic problem solving, which Strobel and van Barneveld (2009) note may lead to "long-term retention and performance" when compared to traditional instruction. However, if the problem is not authentic, Splitter (2008) notes the student "will, at best, play the familiar game of telling the teacher what she wants to hear" (p. 142).

Situated Cognition and T/E DBL

A second fundamental learning theory that serves as the basis for educational reform efforts to incorporate T/E DBL is situated cognition. The situated cognition learning theory has evolved in part from principles associated with the work of Dewey relating to the importance of providing children with opportunities to learn through experiences in which they are actively involved and on the work of Vygotsky relating to the importance of social groups in learning (Herrington & Oliver, 1995; Herrington & Oliver, 2000). Situated cognition emphasizes the context within which information is learned and advocates involving students in learning through real-world experiences. As Brown, Collins, and Duguid (1989) describe, learning is a function of the context within which new information is learned (p. 32). Social anthropologist and proponent of situated cognition learning theory, Jean Lave, described the principle that humans as social beings are "defined by" the activities in which they participate and the groups with whom they interact (as cited in Herrington & Oliver, 1995, 2000; Wilson & Myers, 1999). Those social experiences can promote learning by encouraging dynamic mental representations of the information learned (Brown, Collins, & Duguid, 1989; Semin & Smith, 2013).

An important concept associated with situated cognition is that of "cognitive apprenticeship." Through cognitive apprenticeship, the learning context and environment enable involvement in authentic practices as vital components for understanding and developing representations of new information based on schemas that relate to the field of practice (Brown, Collins, & Duguid, 1989; Herrington & Oliver, 2000; Oyserman, Sorensen, Reber, & Chen, 2009; Semin & Smith, 2013).

The context of learning can be enhanced by the social nature of the experiences, which can result in a heightened awareness of contextual information and the use of a more diverse set of such information in decision making (Fonseca & Garcia-Marques, 2013). McCormick (2004) relates these principles to Technology Education in which tasks are structured within an authentic context rather than in abstractions such that there is an "intimate connection between knowing and doing" (pp. 22-23).

Pedagogical Implications of Constructivism and Situated Cognition

There are many implications for curriculum development and instructional methods built on constructivism, problem-based learning, and situated cognition principles. In fact, there are many shared pedagogical implications of the theories, which are manifest in changing roles for the teacher and student, changes in the learning environment favoring authentic learning experiences, an emphasis on authentic contexts as the organizing structure for the curriculum, an emphasis on students developing artifacts as tools for understanding, and changes in assessment methods. T/E DBL incorporates the pedagogical implications associated with constructivism and situated cognition and serves as a mechanism for teaching content and practices of STEM and other disciplines.

Role of the Teacher and Meaningful Learning. In constructivist and situated learning environments, the premise that students must use their own cognitive abilities and the learning environment to construct meaning of new knowledge implies a change in the structure of the roles for the teacher and student. The teacher's part becomes one of guide or facilitator whose primary role is to develop learning activities in which students have the opportunity to actively experience new information that challenges their preconceptions, promotes curiosity, enables discovery of information, and results in meaningful learning (Dewey, 1902, 1938; Duffy & Cunningham, 1996; Liu & Chen, 2010; Schank, 1995; Schunk, 2012; Splitter, 2008). Teaching by creating experiences for students to actively acquire understanding transforms the teaching role into one of facilitation rather than knowledge transmitter. In problem-based learning, the role of the teacher is also to support students by modeling processes and asking open ended questions that encourage higher order thinking (Duffy & Cunningham, 1996; Savery & Duffy, 1995).

Relevant Contexts for Learning. In constructivist and situated learning, experiences are built within authentic communities of practice that provide students with the real-world contextual applications in which concrete representations of concepts may be acquired. Learning experiences also provide students with the opportunity to interact in social groups and utilize skill sets that allow them to act as practitioners in the domain and develop a sense of themselves (Splitter, 2008; Strobel, Wang, Weber, & Dyehouse, 2013; Wilson & Myers, 1999).

The structure of an authentic curriculum is driven by designing opportunities for students to experience the applications of knowledge that makes the knowledge most useful and meaningful for future applications rather than through the abstract concepts associated with the subject matter (Dewey, 1902/1938). Rather than using the textbook as the primary structure for curriculum, learning experiences are built around and within big ideas that are chosen based on what is relevant and meaningful to the student (Bransford, Brown, & Cocking, Eds., 2000; Dewey, 1902, 1938; Duffy& Cunningham, 1996; Herrington & Oliver, 2000; Schank, 1995; Schunk, 2012; Splitter, 2008). The student acquires knowledge as it connects to the series of tasks that are necessary for actively doing and as it relates to an end goal that requires application of the knowledge that the teacher wants the student to learn (Schank, 1995).

Student Artifacts as Conceptual Representations. An important component of curriculum and instruction associated with constructivist and situated cognition principles is the use of student artifacts. Artifacts can support students' developing representations of new information by becoming the mechanism by which students construct knowledge. Student artifacts support Dewey's and Vygotsky's notion that the learner provides meaning to knowledge in that they serve to facilitate cognitive processes necessary for the students to form their own understanding (Liu & Chen, 2010). In developing artifacts, students also become involved in the society and culture in which the artifacts are developed, furthering the students' understanding and creation of cognitive schema (Wilson & Myers, 1999).

Assessment Opportunities. Involving students in constructivist and situated learning experiences requires assessment of a culminating application of knowledge rather than traditional tests of rote knowledge. In learning experiences involving application of knowledge, students must do rather than just repeat, which requires assessment of learning as it relates to how well the students have demonstrated their understanding (Liu & Chen, 2010). In PBL, for example, assessment methods may include self-assessments, peer-assessments, teacher observations, or assessment of student portfolios and evaluate student knowledge, skills, and abilities to work in a group relating to the learning experience (Duffy & Cunningham, 1996; Savery & Duffy, 1995; Schunk, 2012).

Content Integration. Because of their emphasis on involving students in realistic situations and problems encountered in everyday life, constructivist methodologies have also been promoted as learning practices that can provide the opportunity for integration between disciplines (Albanese, 2010; Barrows & Tamblyn, 1980; Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palencsar, 1991; Hmelo-Silver, 2004; Krajcik, Blumenfeld, Marx, & Soloway, 1994). Schunk (2012) describes one application of constructivist learning theories such as PBL as "holistic teaching," which he relates to interdisciplinary teaching, carried out through integrative themes that have applications in multiple subject areas and provide opportunities for students to, for example, experience historical events, authentically communicate, and practice in authentic science (p. 262). In his description about the importance of learning by doing, Schank

(1995) also notes that a curriculum designed to teach students skills that allow them to accomplish goals should not be done along traditional subject areas (How to Do It: Skills as Microscripts, para. 21). From the standpoint of situated learning, organizing a holistic, integrated curriculum supports learning by supplying information from any subject area when it is needed by students for application in practice (Brown & Duguid, 1993 as cited in Wilson & Myers, 1999).

Integrating content and practices from STEM subject areas through engineering design learning experiences can lead to what Nathan, Atwood, Prevost, Phelps, & Tran (2013) describe as shaping of “affordances” for students. As integration between subjects is made, students develop an understanding of the “cohesion” between curriculum content and practices through representations associated with the design. That understanding can shape the conceptual representation students have about the content which, in turn, can shape how they prepare a response to future experiences.

T/E DBL and Integrative STEM Education

At the beginning of the 20th century, Dewey (1902) recognized that artificially separating subject matter and rearranging it with reference to some “general principle” can result in learning experiences that are devoid of relevance to students’ lives and lack of motivation for students to learn (p. 6). Further, Dewey (1938) also recognized that without the benefit of learning material in connection to relevant experiences, the knowledge that was supposed to have been learned would only be available to the learner under “exactly the same conditions recurred as those under which it was acquired” (pp. 19-20).

Content integration serves to makes the most of the natural connections between subject areas by structuring curriculum around cohesive curriculum units (Bybee, 2010; Kaufman, Moss,

& Osborn, 2003). While Drew (2011) suggests that the value of curriculum is minor compared to the value of good teaching, he quotes Parker Palmer in stating that "good teachers have the capacity for connectedness" (p. 90). Therefore, curriculum integration also has the potential to facilitate good teaching. Nathan et al. (2013) suggest several mechanisms by which "cohesion" can be incorporated into instruction in STEM education, which can improve students' perceptions about and understanding of the design process and design objects. Those mechanisms are "identification" of the underlying meaning of representations utilized across content areas, "coordination" of clear connections between representations utilized across content areas, and "forward and backward projection" to provide students with a review of past activities and preview of future activities and how they fit in with the bigger picture to ensure connections "between new and prior knowledge" (p. 110). With sufficient scaffolding to emphasize underlying concepts, T/E DBL can provide a means by which integration can occur between STEM and other disciplines (Bybee, 2010; Dunham, Wells, & White, 2002; Hutchinson & Hutchinson, 1991; ITEA/ITEEA, 2000/2002/2007; LaPorte & Sanders, 1993; McAlister, Hacker, & Tiala, 2008; McCormick, 2004; NAE & NRC, 2009; Pitt, 2000; Raizen et al., 1995; Satchwell & Loepp, 2002; Savage & Sterry, 1990; Wells, 2010).

There are many models describing different methods by which integrative curriculum can be developed. Table 1 below compares the models from Fogarty (1991); Hurley (2001); Kaufman, Moss, and Osborne (2003); and Drake and Burns (2004) from least integrated to most integrated. Although attempts were made to compare equivalencies across the models, they are very approximate equivalencies since the authors' purposes and the perspectives from which they approached the topic differed.

Table 1

Comparison of Models for Curriculum Integration

Fogarty (1991)[a] (Not specific to subject area)	Hurley (2001) (Science and math)	Kaufman, Moss, and Osborne (2003) (Not specific to subject area)	Drake and Burns (2004) (Not specific to subject area)
Fragmented – traditional subject areas	Enhanced – concepts from the other discipline enhance the major discipline	Cross-disciplinary – viewing one subject from the perspective of the other	
Connected – connections within a subject area	Partial – separate disciplines taught by teacher in the same class		
Nested – multiple skills within a subject area	Sequenced – sequential planning and teaching in different subjects	Multi-disciplinary – several subjects involved; no attempt to integrate ideas	Multidisciplinary – disciplines remain intact but organized around a theme
Sequenced – topics or units aligned in different subject areas			
Shared – planning and teaching of overlapping concepts in separate subject areas	Parallel – related concepts planned and taught simultaneously	Interdisciplinary – same as above but with focus on integrating ideas	Interdisciplinary – focus on emergent interdisciplinary knowledge and practices
Webbed – theme across curriculum			
Threaded – skills, technology, and multiple intelligences across curriculum			
Integrated – team teaching of overlapping concepts across curriculum	Total – intentionally taught together	Transdisciplinary – driven by a problem such that distinctions of subjects become blurred	Transdisciplinary – disciplines less prominent and connected through real-world contexts, project-based learning, or student-driven questions

[a]*Note:* Two additional models focus on the learner rather than the curriculum: "immersed" and "networked"

Integrating content across subject matter is critically important for student learning in that it provides a context for learning that benefits students by illustrating the relevance of the material to their own lives (Doppelt et al., 2008; Kaufman et al., 2003; Kolodner et al., 2003). Drake and Burns (2004) suggest that integrative curriculum also provides the opportunity to embed and purposefully assess the "complex performance skills" that may not explicitly be taught and often are merely assumed to be part of learning in the individual disciplines (p. 47). Performance skills become essential for learning experiences involving active, authentic experiences (Drake & Burns, 2004). In science education, a technological/engineering design approach can provide a relevant context for the curriculum by involving learning activities that are driven by open-ended problem solving (Doppelt, et al. 2008; Linn & Muilenburg, 1996; Fortus et al, 2004, 2005; Lou et al., 2011; McCormick, 2004). Further, a technological/engineering design approach in science education can provide an intentional connection between process and content, which is a hallmark of recommendations for reform in science education (see AAAS, 1990; AAAS, 1993; Michaels et al, 2008; NRC, 2012).

Involving students in creative, open-ended problem solving, in which they synthesize knowledge from multiple content areas to design and create a solution brought about through their own imaginations, can also be an important means to engage a variety of student populations (Barnett, 2005; Barton, 1998; Doppelt et al., 2008; Han, Capraro, & Capraro, 2014; Mehalik, Doppelt, & Schunn, 2008; Scarborough & White, 1994; Seiler et al., 2001). Further, Ritz and Moye (2011) suggest that technological design practices associated with real-world problem solving can be particularly engaging for students who have grown up in a digital age and "want information presented quickly and then want to be able to do something with the new knowledge that they can see will make a difference to them, their families, or the greater society"

(p. 139). However, in order to “avoid the trap of superficiality” in which integrative projects become nothing more than engaging but frivolous activities, Drake and Burns (2004) suggest that the integrative projects must be the fundamental basis for the development of curriculum and “contextualize all curricular activities” (p. 21).

Integrative STEM Education can be utilized to develop curriculum that is contextualized and capitalizes on the relatedness of the content standards and practices employed in the individual disciplines of science, math, and technology education (Childress, 1996; Loepp, 2004); math and technology education (Merrill & Comerford, 2004); science and language arts (Their & Daviss, 2002); and science and technology education (Wells, 2010). The recommendations in the most recent standards for STEM fields show many overlaps in the desired characteristics for core practices in the fields. Table 2 below compares the core practices associated with the most recent national standards efforts in each of the STEM fields.

Table 2

Recommended Core Practices in Technology, Math and Science Education Standards

Standards for Technological Literacy (ITEA/ITEEA, 2000/2002/2007)	*Common Core Mathematics Standards* (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010)	*A framework for K-12 science education: Practices, crosscutting concepts, and core ideas* (NRC, 2012,)
Technology Education	Mathematics Education	Science Education
Understanding of The Nature of Technology	Make sense of problems and persevere in solving them.	Asking questions (for science) and defining problems (for engineering)
Understanding of Technology and Society	Reason abstractly and quantitatively	Developing and using models
Understanding of Design	Construct viable arguments and critique the reasoning of others	Planning and carrying out investigations
Abilities for a Technological World	Model with mathematics	Analyzing and interpreting data
Understanding of The Designed World	Use appropriate tools strategically	Using mathematics and computational thinking
	Attend to precision	Constructing explanations (for science) and designing solutions (for engineering)
	Look for and make use of structure	Engaging in argument from evidence
	Look for and express regularity in repeated reasoning	Obtaining, evaluating, and communicating information

The T/E DBL process can be interpreted and utilized in the classroom for different purposes depending on the content knowledge and skills it is designed to elicit. Berland (2013) suggests that design challenges can be thought of as fitting into three categories based on the learning goals associated with the challenge and the content focus. Those three categories are (1) “problem-based challenges” in which the learning goals are focused on the use of science and math but not design; (2) “engineering design-based challenges” in which the learning goals are focused on engineering design but only incidentally also involving the application of science and math; and (3) “STEM-based challenges” in which the learning goals “can only be completed when relevant math and science concepts are applied” (pp. 25-26). Since knowledge from multiple subject areas and domains is required to understand and propose solutions to real-world problems in T/E DBL, it is often promoted in terms of Berland’s (2013) “STEM-based challenge,” in that it functions as a means by which integration can occur between STEM disciplines (Dunham, Wells, & White, 2002; Hutchinson & Hutchinson, 1991; ITEA/ITEEA, 2000/2002/2007; LaPorte & Sanders, 1993; McAlister, Hacker, & Tiala, 2008; NAE & NRC, 2009; Pitt, 2000; Raizen, Sellwood, Todd, & Vicers, 1995; McCormick, 2004; Pitt, 2000; Savage & Sterry, 1990; Wells, 2010).

Such an approach is employed in Integrative STEM Education (I-STEM ED), defined by Wells and Ernst (2012/2015):

> Integrative STEM Education is the application of technological/engineering-design-based approaches to *intentionally* teach content and practices of science and mathematics education through the 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.

T/E DBL is the primary pedagogical approach of I-STEM ED, which is intended to be “mutually inclusive” to concepts in STEM and other subject areas (Wells, 2013, p. 29). Therefore, I-STEM ED, driven by T/E DBL fits into Drake and Burns’ (2004) “transdisciplinary” model of integration (p. 21) in which there is an emphasis the “KNOW/BE/DO” bridge of curriculum development (p. 35), focusing not only on what is learned but also on what students can do with that knowledge. A transdisciplinary approach involves students in learning subject matter as it pertains to solving a problem, and in I-STEM ED the T/E DBL problem drives the curriculum such that subject matter is learned outside of the typical subject area silo in which it otherwise would reside. Figure 1 below is a depiction of the T/E DBL pedagogical model utilized in I-STEM ED from Wells (2016), which can be utilized to integrate content and practices from multiple disciplines through design challenges through "phases of engagement encountered by the designer when attempting to resolve an engineering challenge" (p. 4).

Figure 1. "PIRPOSAL Model" for I-STEM ED

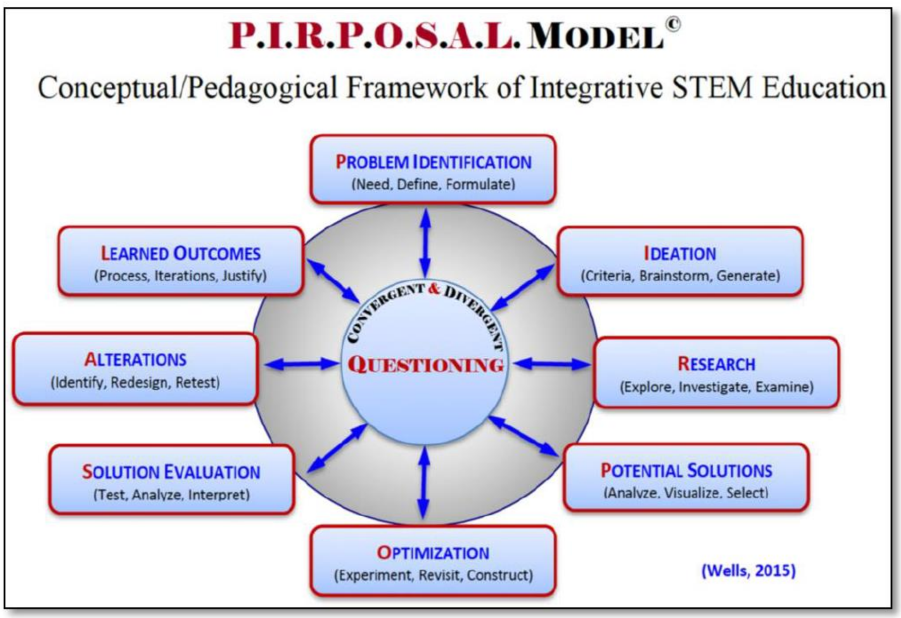

Figure 1. "PIRPOSAL Model" for I-STEM ED through T/E DBL (Wells, 2016b).

The promise of utilizing T/E DBL in Integrative STEM Education aligns with recommendations for incorporating instructional practices relating to both science inquiry and engineering design in science education reform efforts in the NRC's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (2012), which served as the guiding document for the development of the *Next Generation Science Standards* (Next Generation Science Standards Lead States, 2013). The interest in "integrated STEM education" has also prompted the publication of *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research* (NAE & NRC, 2014), which calls for additional research in this promising area of education reform.

I-STEM ED is built on constructivist, situated, problem-based learning principles in which students are engaged in problem solving and constructing knowledge by actively creating. The approach capitalizes on the relatedness and interconnectedness between the content standards and practices employed in the individual STEM disciplines, making connections between content and practices. Further, I-STEM ED provides a means for meeting the calls for educational reform by emphasizing higher order thinking, problem solving, and rich learning of concepts and skills through immersive practice and real-world applications that foster connections between discipline areas (Bybee, 2010; Dugger & Meier, 1994; Loepp, 2004; Wells, 2010, 2016a, 2016b).

Science Inquiry and T/E DBL

Science inquiry is the characteristic pedagogical methodology of science education, emphasizing 'science as a process' (NRC, 1996, p. 105). It is defined in The *National Science Education Standards* (NSES) (NRC, 1996) as "a multifaceted activity that involves making observations; posing questions; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results" (p. 23). However, the implementation of inquiry in the classroom yields varying levels of student autonomy and cognitive demands. Banchi and Bell (2008) describe four levels of inquiry, "confirmation," "structured," "guided," and "open" (p. 27). "Open inquiry" is the methodology that most closely matches the description of inquiry in the NSES, but inquiry as practiced in the classroom often resembles confirmation level inquiry in which students are verifying a relationship between variables that is already known (Appleton, 1995; Barnett, 2005; Doppelt et al., 2008; Fortus et al., 2005) and in which there is a lack of opportunity for students to critically examine and critique evidence-based explanations associated with the results of scientific findings (Next Generation Science Standards Lead States, 2013, p. 44).

Acknowledging the similarity in the goals and methods of both technological/engineering design and science inquiry, national science education publications and standards have for years included the "technological design" pedagogical methodology as a valuable tool to link to and provide applications for inquiry practices in science education (AAAS, 1990, 1993; NRC, 1996; NRC, 2013; NGSS Lead States, 2013). In fact, Cajas (2001) notes that connections between methodologies is essential since the goal of developing scientifically literate students also requires developing students who are technologically literate. The promise of utilizing design based learning in the context of science instruction is reflected in the *National Science Education Standards* (NRC, 1996). In the *Framework for K-12 Science Education* (NRC, 2012), the use of engineering design activities in science provide opportunities for students to learn through experiences that relay an understanding of authentic practice of science, particularly with respect to critique of explanations, which is often lacking in K-12 science education (p. 44). In the subsequent *Next Generation Science Standards* (Next Generation Science Standards Lead States, 2013), science inquiry and engineering design practices are treated as equally important in that they provide applications across all science content areas.

Proponents of using design as the means for integration between science and technology/engineering education suggest that connections between the fields are natural since the practices and purposes associated with the fields are so complementary (Barak, 2013; Bybee, 2010; Cajas, 2001; ITEA/ITEEA, 2000/2002/2007; Hmelo, Holton, & Kolodner, 2000; Lewis, 2006; McAlister, Hacker, & Tiala, 2008; McCormick, 2004; NAE & NRC, 2009; Pitt, 2000; Roth, 2001; Raizen et al., 1995; Roy, 1990; Sidawi, 2009; Wells, 2010; Zubrowski, 2002). Lewis (2006) describes inquiry and design as "navigational devices that serve the purpose of bridging the gap between problem and solution." Both processes, however, also require practitioners to draw upon content knowledge (p. 271).

In *A Framework for K-12 Science Education*, the NRC (2012) developed a comparison of the characteristics of "scientific and engineering practices," which shows more commonalities than differences. The distinguishing characteristics in their comparison are the beginning purposes and ending goals associated with the processes. Scientific practice starts with "asking questions," whereas engineering practices begin with "defining problems." The culminating purpose for data analysis and interpretation in science is "constructing explanations," whereas in engineering design the purpose for data analysis and interpretation is for "designing solutions" (p. 3). Inquiry also differs from design in that design is conducted in the context of "constraints," "trade-offs," "failure," and "practicality" associated with the design (Lewis, 2006).

Design Based Science

Design Based Science (DBS) is a pedagogical approach associated with integrative curriculum, science inquiry, and T/E DBL utilized in science education. Based on Berland's (2013) design challenge framework, whereas T/E DBL in Integrative STEM Education may be thought of in terms of "STEM-based challenges" with an emphasis on engineering solutions in which the learning goals "can only be completed when relevant math and science concepts are applied," DBS may be thought of in terms of "problem-based challenges" in which the learning goals are focused on the use of science concepts but not explicitly on design (pp. 25-26). DBS activities are built upon open-ended problem solving challenges that require students to draw from science content and procedural knowledge to conceptualize and design a solution to a real world problem. In conceptualizing a solution, students develop "artifacts" of science concepts, which may be working prototypes but may also be two-dimensional or three-dimensional models (Fortus, 2004, p. 46).

DBS provides a design context in which scientific principles are learned and applied. In DBS, the process of design is not the primary learning goal, rather it is the mechanism by which science learning takes place and science content is applied. DBS involves iterative design processes, wherein students use the same design process in cycles, with each cycle focused on different but related science concepts that are associated with the design problem (Fortus, 2003; Fortus et al., 2004; Fortus et al., 2005). The process of building artifacts that provide solutions to open-ended, real-world problems enables students to develop their own understanding of science conceptual knowledge in concrete ways. Figure 2 below is a representation of the Design Based Science learning cycle as described in Fortus (2003, p. 41).

Figure 2. The DBS Learning Cycle

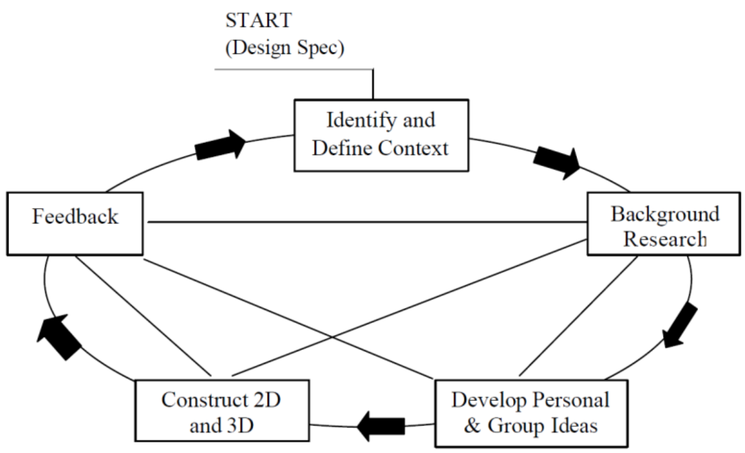

Figure 2. The DBS Learning Cycle (Fortus, 2003, p. 41)

Utilizing DBS in science education capitalizes on the complementary relationship between science inquiry and engineering design (AAAS, 1990; ITEA, 1996; ITEA, 2002; ITEA/ITEEA, 2000/2002/2007; ITEA, 2000; NAE & NRC, 2009). Coupling inquiry and design in the process of DBS also provides students with the benefit of the opportunity to construct multiple representations of knowledge through different contexts while developing an evidence-based explanation in science and a solution to a problem in engineering.

Science concepts, especially those on the micro scale can be abstract, but when they are applied in a design context for the purpose of real-world utility, they may become more thoroughly understood as they are represented in concrete artifacts (McCormick, 2004; Pitt, 2000; Roth, 2001). Further, an understanding of the science underlying the design also provides the means for developing improved technological devices (Raizen et al., 1995). Since the practices of science inquiry and T/E DBL involve “uncertainty” as both a starting point and a framework within which to operate, with sufficient scaffolding and careful planning, the approach necessitates that students draw upon content knowledge and use that knowledge to solve problems (Lewis, 2006, p. 271).

Importance of Scaffolding

In any design based learning strategy, ensuring that students make connections between the concepts associated with the learning objectives and the design project is crucial. Design projects can be an engaging way for students to learn science concepts; however, they can often focus on aspects of building and accomplishing the design challenge with little emphasis on the underlying science concepts, particularly if the social culture of the school and peer group is at odds with the culture of science that the activity is designed to promote (Seiler, Tobin, Sokolic, 2001). Involving students in design does not in and of itself support learning of science concepts without associated learning activities and supports that are developed to support student learning (Penner, Lehrer, & Schauble, 1998; Puntambekar & Kolodner, 2005) and address alternative conceptions (Schnittka, 2009).

Scaffolding is also crucial in supporting the integration of content between subject areas. With sufficient emphasis on learning activities that support students' understanding and assessment of underlying concepts, design projects can require students to make connections between content knowledge that is traditionally handled as unrelated topics in school curricula and draw on that knowledge to make decisions about their design (Humphreys, 2005; Satchwell & Loepp, 2002).

Related Pedagogical Models

Several pedagogical and curriculum development models have been developed that integrate technological/engineering design in science education. In addition to DBS, design-based learning (DBL) is a pedagogical model that utilizes engineering design and Learning by

Design™ (LBD) is a curriculum development approach that utilizes the development of models as a means for content integration. Each of the models involves similar learning processes but slightly different learning goals and learning sequences.

Although DBL is very similar to DBS, DBL is associated with learning experiences that focus on slightly different learning goals. DBL utilizes cyclical learning cycles, each focused on related but different science concepts (Hmelo, Holton, & Kolodner, 2000; Mehalik, Doppelt, & Schunn, 2008; Gomez Puente, van Eijck, & Jochems, 2013). For example, Mehalik, Doppelt, and Schunn (2008) used a "systems design" process in their DBL model which involved students in designing an alarm system. The design challenge started with students identifying the design and the description of the design criteria. The authors explain that the approach differed from traditional design challenges in that the students provide questions for investigating and the design criteria, rather than the teacher-supplied design challenge (pp. 1085-1086). Apedoe et al. (2008) note that the "systems design" approach also involves analysis and design decisions focused on "subsystems" of the design, each of which is associated with a particular science concept or "big idea" (p. 456).

Learning by Design™ (LBD), developed by Kolodner et al. (2003), is a curriculum development model based on the premise that involving students in designing solutions to problems can be engaging and motivating and can improve understanding of science concepts and attendant skills. LBD is based on theories of developing transfer of knowledge and conceptual change. The LBD process is designed to be cyclical, with each cycle focusing on increasingly complex understandings of the same science concepts. In LBD a key component for making connections between technological design and science understanding is the extensive use of design "rules-of-thumb" as scaffolds which are designed to have students articulate relationships between design variables as the bridge between abstract science concepts and practical design considerations (Crismond, 2011).

Evidence Technological Design Approaches Promote Higher Order Thinking

Empirical evidence associated with T/E DBL is preliminary and few controlled experiments have been conducted on design-based learning approaches (Barron & Darling-Hammond, 2008). In fact, research evidence for "integrated" STEM education in general, without regard to specific pedagogical approach, is limited so much so that the publication of *STEM Integration in K-12 Education* (NAE & NRC, 2014), although not specifically focused on T/E DBL, describes the effects of integrative curriculum as "variable." It also describes research in the field as "not extensive, and concerns related to both the design of the studies and the reporting of results hamper the ability to make strong claims about the effectiveness of integrated approaches" (pp. 51-52).

However, preliminary evidence does suggest that design based approaches can lead to student learning through several cognitive mechanisms. Evidence exists that the approaches can serve as the basis for cognitive conflicts, which can lead to the activation of prior knowledge. By providing a real-world context, the learning approaches can also lead to transfer of knowledge by making connections with concepts in multiple contexts and through multiple representations. Additional evidence exists that the approaches can lead to improved student motivation, increased use of multiple domains of knowledge, improved metacognitive abilities, and improved understanding and use of content knowledge and skills from science and technology. Shulman (2004) points out from Edgerton's essay (1997) that methods including PBL can be thought of as "pedagogies of engagement," which have the benefit of not only engaging students but also improving their understanding (p. 55). Therefore, the evidence described below is associated with a variety of technological design approaches.

Disequilibrium

When presented with a real-world problem, students are faced with complex situations that they must actively think about and consider on the basis of what they have learned and experienced. Appleton (1995) describes these situations as "discrepant events." Discrepancies that challenge students' preconceived notions may happen during the design process through the collection of anomalous data (Chinn & Brewer, 1993; De Grave, Boshuizen, &Schmidt, 1996). In the process of technological/engineering design, students' may be confronted with prototypes that do not function as intended, challenging students to improve the device and providing the motivation for more deeply understanding the science underlying the design (Cajas, 2010; Raizen et al., 1995). Such discrepancies that confront prior knowledge also necessitate higher order thinking and problem solving that motivate students to understand underlying science concepts associated with design prototypes on a deeper level (Cajas, 2010, p. 722).

Discrepant events also serve to activate relevant prior knowledge, which is essential for learning as information is internalized and processed (Appleton, 1995; De Grave, Boshuizen, & Schmidt, 1996; Schmidt, 1993). With the activation of prior knowledge, new information is then anchored to the learner's existing cognitive structures. The result of this process is what Ausubel terms "subsumption," which can result in long-term, meaningful learning when the student connects the new information with existing cognitive schema that serve to anchor the new information in the student's mind (as cited in Ivie, 1998). Cognitive conflicts are prominent features of inquiry and design as both processes start from the basis of open-endedness (Lewis, 2006). In design based learning open-endedness of the challenge is a central feature of problem solving. Hmelo et al. (2000) explain that designing, building, and testing a technological artifact requires students to “grapple with one’s conceptions” as an essential component of the process (p. 287).

Transfer

T/E DBL and learning models like it also have been advanced on the basis that they promote transfer of knowledge, enabling students to use and apply information from a variety of content areas in new contexts. Perkins (1986) suggests that “all information potentially is design” (p. 4). Further, the author describes knowledge applied through design as active rather than “inert” (p. 19). Transfer through actively applying knowledge in new contexts is the key to learning. As explained by Perkins and Salomon (1992), “To say that learning has occurred means that the person can display that meaning later.” Design based learning can promote transfer by providing students with the opportunity to learn concepts in multiple contexts such that they are able to use that information when presented with novel, related contexts (Fortus et al., 2005, p. 860). Schank (1995) describes the process of making knowledge available for later use as “indexing.” Indexing involves labeling an experience and internalizing the experience. Schank emphasizes that the process of indexing with all the associated details of an experience can only be gained through having opportunities for learning through active experiences (para. 13-14).

Metacognition

Learning by doing through T/E DBL and similar pedagogical approaches also enhances students’ metacognition, providing an understanding about their own thinking, which has an important role in the transfer of knowledge. Improving the learners’ metacognitive abilities allows the learner to become cognizant of the purpose of knowledge and, through application in the design process, illustrates to students measures of their abilities to demonstrate their understanding in the design product (Barron et al., 1998; Fortus et al., 2005). In short, students are involved in experiences that provide the opportunity for them to answer the question of why they are learning the content (Mehalik, Doppelt, & Schunn, 2008).

Motivation

Motivation associated with design based learning is another of the factors cited by many researchers as promoting transfer (Fortus et al. 2004, 2005; Kolodner et al., 2003; Hmelo-Silver, 2004). One way to think about T/E DBL is that it combines PjBL and PBL, which incentivizes students in that they actually are involved in a project that has real world utility and could provide benefit to their community (Barron et al., 1998). The use of design in science is motivating to students in that in the process of developing their own design solution to an authentic problem, students take ownership of the product of their own minds, creativity, and effort (Apedoe et al., 2008; Cantrell et al., 2006; Fortus et al., 2004, 2005; Roth, 2001; Seiler et al., 2001). Ritz and Moye (2011) suggest that engineering and technological problems are motivating because they allow students to overcome failures and in the process of producing a tangible accomplishment develop perseverance and "self-efficacy" (pp. 133-134).

Design-based learning can motivate students through striving to achieve goals in what Schank (1995) describes as "goal-based scenarios." Through goal-based scenarios, students try, occasionally unsuccessfully, but are engaged in such a way that they want to try again (The Role of the Teacher, para. 2**).** Students can become "personally invested" in their own learning (Huber and Hutchings, 2004, p. 6) as they develop a "fixed, tangible reality" produced directly from their own minds (Barton, 1998, p. 139).

Multiple Domains of Knowledge

As described earlier, T/E DBL pedagogical approaches lend themselves to integrative curriculum. In addition, design based learning also requires students to draw on and utilize knowledge from a variety of domains (Beneson, 2001). Marulcu and Barnett (2013) describe that design-based learning involves Sternberg's (2001) "triarchic intelligence principles," which involve students in "analytical, creative, and practical skills" (p. 1829). McLaren (2012) describes "learning through making" as involving the "domains of heart (affective), hand (psychomotor), and head (cognitive)" (p. 251). By requiring knowledge from multiple domains, the learning experience can be transformed into one that is much more rich and meaningful to students.

Multiple Representations of Concepts and Cognitive Flexibility

Design based learning can promote the development of abilities in dealing with problem solving in creative ways rather than based on some static algorithm. Roth (1995) explains that design activities in science can lead students to develop "interpretive flexibility" as they use concepts and skills associated with authentic practices, which allows them to approach future problems more skillfully (p. 378). Sherman, Sanders, Kwon, and Pembridge (2009) conclude based on their literature review that teaching students an ideal heuristic for problem solving may prompt students to only think of the situation in terms of a textbook model. Rather, they suggest, students should learn to "follow their noses" in order to develop thinking skills that are needed in open-ended problem solving and higher order thinking (p. 63).

Spiro, Coulson, Feltovich, and Anderson (1988) developed the theory of cognitive flexibility in which the aim of learning is not just coverage of content but rich understanding of content in terms of multiple contexts. In order for advanced knowledge acquisition to occur, the learner must understand information in terms of multiple representations and be able to use the information selectively. Such flexibility is accomplished through encountering information in complex situations involving multiple cases and appropriate and adequate support that illustrates the interrelatedness of applications (Spiro et al., 1988). In T/E DBL, if structured appropriately, students have the opportunity to construct advanced knowledge by encountering multiple representations of information in multiple contexts and learning how the information must be used to solve problems.

Crismond (2001) described the differences in the ways in which “naïve, novice, and expert designers” utilize science knowledge in a T/E DBL activity associated with simple machines. More expert designers understand how science concepts are connected with the design problem and how to utilize the science concepts in the context of developing the design solution. Thus, those who are more adept at design also understand how and when to draw on concept knowledge for use in problem solving.

To emphasize higher order thinking, improve depth of understanding in science education, and improve students’ abilities to apply their understanding in real-life contexts the *Framework for K-12 Science Education* (NRC, 2012) and the subsequent *Next Generation Science Standards* (NGSS Lead States, 2013) include engineering design and science inquiry as practices that are both worthy of inclusion in science education. The rationale for including engineering design is on the basis that an emphasis only on science would “tend to shortchange the importance of applications” and that engineering and technology provide a context for science that improves both understanding of science concepts as well as engagement in the practices of science and engineering (NGSS Lead States, p. 12).

Assessing Higher Order Thinking

The National Assessment of Educational Progress (NAEP) (NAGB, 2014) has developed a framework for assessments of science knowledge based on cognitive demand associated with the processes of both scientific inquiry and technological design. The levels of cognitive demand associated with knowledge of science and science inquiry include “declarative (knowing that) knowledge,” “procedural (knowing how) knowledge”, and “schematic (knowing why) knowledge.” However, the levels of cognitive demand associated with knowledge of technological design include all of those above as well as the highest cognitive demand, “strategic (knowing when and where to apply) knowledge” (pp. 63-73). The NAEP framework will be utilized to evaluate higher order thinking in the current dissertation study.

Studies examining higher order thinking have utilized a variety of assessment methods and research designs. Researchers have assessed students’ higher order thinking through content analysis of responses to open-ended questions developed to assess varying levels of cognitive demand, pre/posttests, interviews to assess mental processes when presented with a novel design challenge, development of concept maps, and student pre/post questionnaire surveys.

Li (2001) developed a system to code test questions from the NAEP assessment according to the cognitive demand imposed on the student from the test items’ format, knowledge required to answer the test items, and the openness of the test item. The NAEP science assessment utilizes Li’s coding system as a framework for developing assessments of knowledge in a variety of formats relative to the imposed cognitive demand (declarative, procedural, schematic, and strategic) for each assessment item.

Fortus (2003) (and associated publications, Fortus et al., 2004; Fortus et al., 2005) utilized a combination of pre/posttests, artifact analysis, classroom observations, and observations of students' verbalizations during a novel problem solving design task to assess knowledge transfer and transfer of problem solving or "designerly" skills (p. 55). The multiple choice and open-ended questions on the pre/posttests for each DBS curriculum intervention appeared to be associated with declarative and schematic cognitive demand based on the format and knowledge required to answer the questions. Results from the assessment showed evidence for transfer of knowledge developed during DBS activities to the novel tasks. Fortus found that the design models developed in DBS provided students with a representation of underlying science concepts that served as a mechanism to enhance meaningful learning and transfer of knowledge. In addition, a strong correlation was found between scores of transfer tasks and post-test results, suggesting that the new knowledge constructed during the transfer task supported and transferred to the novel design task.

Kelley (2008) examined the cognitive processes used by individual students involved in National Center for Engineering and Technology Education and Project Lead the Way pre-engineering design curriculum programs. The author presented a novel technological design problem to students in both groups and assessed, through verbal descriptions, the time spent on the use of seventeen cognitive processes associated with Halfin's (1973) study when verbally describing the problem solving process they would undertake (as cited in Kelley, 2008). The author used an updated version of the Observation Procedure for Technology Education Mental Processes (OPTEMP) developed by Hill (1997) to code and assess time spent on various mental processes (as cited in Kelley, 2008). Kelley found that ten of the seventeen mental processes from Halfin (1973) were utilized by students in the study. Kelley noted that the time available for the verbal descriptions (30 minutes) probably limited the students to the processes associated with the beginning stages of problem solving, and the seven cognitive processes that were not displayed most likely had to do with the limited amount of time provided for the design verbalization and the lack of an actual model building process.

Through a combination of classroom observations, interviews, and pre/post content knowledge tests, Schnittka (2009) assessed conceptual change of heat transfer concepts in middle school students engaged in an engineering design-based learning experience. Schnittka found statistically significant gains in students' conceptual understanding of heat transfer, particularly when the intervention was designed to address student alternative conceptions with five different hands-on demonstrations during the course of the engineering design challenge.

Schurr (2013) found through concept mapping that students involved in technological design based biotechnology learning experiences were able to demonstrate schematic and strategic knowledge. Schurr's dissertation involved high school students enrolled in an elective biotechnology course whose cognitive structures were assessed via concept maps constructed at three selected times throughout the course. Schurr evaluated the concept maps for students' representation of connections between and among biology and technology education based on scoring methods developed by Hay, Kehoe, Miquel, Hatzipanagos, Kinchin, Keevil, and Lygo-Baker (2008) (as cited in Schurr, 2013). To demonstrate students' strategic knowledge, Schurr conducted a qualitative case study analysis of concept maps.

Wells (2016a) demonstrated through pre/post "content knowledge and practice questionnaires" that graduate students involved in a graduate level biotechnology course demonstrated gains in declarative and procedural knowledge as well as schematic and strategic knowledge, which represent higher order thinking. Questions were developed to ascertain understanding of knowledge from each of the cognitive knowledge areas. The graduate students came from a variety of subject area teaching assignments and teaching experiences. Students participating in the course were able to demonstrate gains in declarative, procedural, schematic, and strategic knowledge relating to two, design-based biotechnology design challenges (p. 10).

In the present study, a pre/posttest was developed, in part, by incorporating and adapting questions from instruments developed by Fortus (2003) and Schnittka (2009). The questions were coded according to their imposed cognitive demand associated with Li's (2001) framework such that there is an approximately equal number of declarative, schematic, and strategic cognitive demand questions. To replicate a novel design task approach utilized by Fortus (2003) and Kelley (2008), several questions associated with strategic cognitive demand were developed by the researcher or adapted from another source to constitute novel, open-ended tasks. In the curriculum intervention itself, several of the activities developed by Schnittka (2009) to address alternative conceptions related to heat transfer were incorporated into the "conventional instruction" phase in the present study. Finally, Li's (2001) coding system was adapted for the purpose of qualitative content analysis of students' design portfolio responses.

CHAPTER THREE: RESEARCH METHOD

This chapter describes the research method for the study including research design, participant characteristics, sampling procedures, assessment instruments, data collection, and data analysis. The following research question guided this dissertation:

> What changes in students' science concept knowledge (declarative, schematic, and strategic demand) are evidenced following engagement in design based learning activities?

The purpose of the study was to determine the changes in students' depth of understanding of science concepts demonstrated by students as they were engaged in two phases of instruction associated with heat transfer: conventional instruction/guided inquiry and design based science (DBS). Specifically, the study determined how students' abilities to demonstrate an understanding of science concept knowledge changed, as required by assessments of different cognitive demand, as they were engaged in a curriculum unit on heat transfer. The study involved examining students' demonstrations of conceptual knowledge during each phase of instruction, culminating in the engagement in a design challenge to develop a prototype that prevents heat transfer.

Mixed methods were utilized to examine changes in students' depth of understanding of science concepts assessed through two primary data sources, a pre/post-1/post-2 test and students' written responses to open-ended prompts in design portfolios. The open-ended prompts were utilized during the DBS phase of instruction and accompanied design challenge portfolio components according to the structure developed by Wells (2012). (See Appendix A for the student design challenge document.)

The independent variable associated with the study was the DBS phase of instruction during the curriculum unit on heat transfer. The dependent variable was students' depth of understanding as characterized by demonstrations of declarative, schematic, and strategic knowledge of science concepts evidenced through data collected from pre/post-1/post-2 test administered during three occasions during the intervention. In addition, qualitative written responses to design portfolio prompts utilized during the DBS phase of instruction were analyzed to corroborate findings from the pre/post-1/post-2 test. Table 3 below describes the data sources and data analysis procedures relating to the research question during each phase of instruction.

Table 3

Alignment of Data Sources and Analysis Procedures

Phase of Instruction	Data Source	Data Analysis
Conventional/Guided Inquiry	Quantitative: Pre/post-1 Test	*t*-test analysis comparison of means
DBS	Quantitative: Post-2 Test	*t*-test analysis comparison of means (pre vs. post-2 test, post-1 vs post-2)
	Qualitative: Design Challenge Portfolios	Content analysis of demonstrations of declarative, procedural, schematic, and strategic knowledge

Research Design

This study followed a mixed methods design conducted through a case study implemented in an 8th grade Physical Science classroom. Based on the mixed methods typologies described in Teddlie and Tashakkori (2006), the research involved both quantitative and qualitative methods of assessment conducted through a monostrand (one strand of research involving conceptual, experiential (methodological/analytical), and inferential phases). The study was implemented as a mixed methods monostrand conversion design in that the quantitative data collected will be utilized to make qualitative inferences and the qualitative data will be converted to quantitative codes and utilized to make qualitative inferences.

Cresswell (2007) describes case study research as a study involving "an issue explored through one or more cases within a bounded system" involving "in-depth data collection" and "multiple sources of information" that result in "a case description and case-based themes" (p. 73). This research will be a case study conducted in the classroom of the researcher during the implementation of an approximately three-week long curriculum intervention. Although case study research often involves in-depth observation over an extended period of time (Cresswell, 2007), the limited time over which the study will be implemented somewhat limits data collection. Since the researcher also functioned as the teacher, the opportunity to participate in the curriculum intervention was provided to all students enrolled in each course; therefore, the possibility of structuring the study to make comparisons between groups through an experimental or quasi-experimental design, though perceived as preferable (Campbell & Stanley, 1963), was not possible. Since the study utilized convenience sampling, it was not possible to collect data from a pre-determined demographic of students. Due to these limitations, none of the conclusions generated will infer generalizability of the results.

Participant Characteristics

The subject pool consisted of approximately 130 male and female students aged 13-14 years enrolled in the Physical Science class of the researcher in the 8th grade at a school district in southwestern Pennsylvania. Based on data published from the Pennsylvania Department of Education (2015), the district is a small, suburban school. For the 2014-15 school year, there were 1,522 students enrolled in grades K-12 with approximately equal proportions of males and females in the elementary, middle, and high schools. Approximately 91.7% of the students enrolled are white, 3.2% are multi-racial, 1.8% are Asian, 1.8% are Hispanic, and 1.5% are black or African American. Free and reduced lunch rates for 2014 indicate that approximately 31% of the students at the middle school are eligible for free or reduced lunches. All students enrolled in 8^{th} grade and Physical Science were eligible for inclusion in the study. Students enrolled in the course who were eligible to participate in the study included those with Individualized Education Plans (IEPs) for giftedness or learning support as well as 504 plans for a physical or mental disability.

Sample Size

The participants in the study consisted of a convenience sample comprised of students enrolled in the researcher's classroom. Only the data from those who voluntarily agreed to participate and who submitted an assent letter and parent consent letter were included in the study. The sample size for the study was determined by the number of students who volunteered to participate.

Curriculum Intervention

Prior to implementation of the curriculum unit, students in the course were introduced to inquiry and the technological/engineering design process through a previous unit on the nature of science and technology. The unit, which involved instruction on a straw rocket design challenge, included lessons on developing testable questions, testable hypotheses, identifying variables, developing a controlled experiment, developing line graphs, identifying criteria and constraints, and technological design and redesign from data collected through scientific inquiry. In addition to introducing students to essential concept knowledge, the unit also introduced students to the design portfolio format by utilizing the same format as that which will be used in this dissertation study. Students in the course were also introduced to fundamental concepts in chemistry, including the structure of atoms, molecules, and compounds, and physical and chemical properties of matter. Therefore, students were expected to possess prerequisite knowledge about the nature of science and science inquiry, the nature of technology and technological design, independent and dependent variables, constants, controls, graphing, matter (atoms, molecules, and compounds), energy, and density.

The curriculum unit was developed utilizing a DBS pedagogical approach with design portfolio elements interwoven throughout the unit, utilizing Wells' (2012) *Technological and Engineering Design Folio Elements* as a scaffolding tool. The entire unit, lessons, and corresponding state and national academic standards are provided in Appendix B. The learning activities and assessments of student learning were implemented during two phases of instruction, including activities associated with science inquiry and T/E DBL: phase 1 included a combination of conventional direct instruction/guided inquiry and phase 2 included the design challenge itself. The unit was designed to be approximately 3 weeks in duration. The researcher was the classroom teacher and, therefore, was the instructor for all components of the study.

The structure of the curriculum intervention was modeled after the Biological Sciences Curriculum Study's (BSCS) 5E Instructional Model (Bybee et al., 2006). The first phase, consisting of conventional direct instruction/guided inquiry activities, functioned as the first three phases of the 5 E instructional model, "engagement, exploration, and explanation." The second phase, consisting of the design challenge, functioned as the "elaboration" phase of the 5E instructional model (Bybee et al., 2006, p. 2). Students' demonstration of understanding of science concepts was assessed prior to the start of instruction, after phase 1 (conventional direct instruction/guided inquiry phase), and after phase 2 (design challenge) and comparisons made to answer the research question.

The heat transfer curriculum unit was designed to meet the following learning objectives:

1. Identify and describe the term heat; what temperature measures; and the processes of heat transfer through conduction, convection, and radiation.
2. Describe the direction of heat transfer (implied from 1st Law of Thermodynamics) from a hotter to a colder object.
3. Distinguish between good insulating materials and good conducting materials.
4. Explain why, in terms of kinetic molecular theory, some materials are better insulators (preventing heat transfer) or better conductors (allowing heat transfer) than others.
5. Determine the most appropriate temperature scale to use, the independent and dependent variables, the constants, and the control associated with testing an insulating device.
6. Graph results from data collected from the testing of an insulating device.
7. Use an understanding of the concepts related to heat transfer to develop a justification for choosing the best solution for preventing heat transfer.
8. Use an understanding of the concepts related to heat transfer to design a technological device to prevent heat transfer.

The conventional direct instruction phase included the following lessons: 1) Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?, 2) Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter, and 3) Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?. Lessons during this phase of the curriculum unit will involve direct instruction, note taking with Frayer Models (Frayer, Frederick, and Klausmeier, 1969), whole group demonstrations, and guided inquiry. The lessons in this phase preceded any consideration of an actual design prototype by students.

The design challenge phase of the unit (independent variable) served as an extension and application of the lessons during the first phase of the unit. Lessons associated with the design challenge guided students through problem identification, brainstorming, generating potential prototype solutions individually, selecting a team prototype, building the prototype, testing the prototype, evaluating results, and considering how to refine and redesign their prototype.

The lessons during the design challenge phase were accompanied by design portfolio components according to the structure developed by Wells (2012). The design prompts served as an essential scaffold to support student learning throughout all components of the design challenge. The design prompts during the design challenge phase were designed to guide students through generating a problem statement, articulating pertinent background information and how it may affect or be affected by the design challenge, developing potential individual design solutions, selecting a final team solution, creating the prototype, testing the prototype and analyzing the data, and refining the design.

Although the current study did not involve examining students' alternative conceptions, as a matter of good practice, seven alternative conceptions identified in Schnittka (2009) and adapted from Erickson (1979) were explicitly addressed by incorporating whole class activities and several demonstrations to address the most common alternative conceptions found in Schnittka (2009). Alternative conceptions about heat transfer from Schnittka (2009) that were addressed in the curriculum intervention are:

1. Cold transfers in from cold to warm
2. Insulators generate heat
3. Insulators are warm, metal is cold
4. Insulators keep cold from transferring

5. Metal traps or absorbs cold

6. Heat is always warm or hot

7. Heat and temperature are equivalent

The lesson on "Kinetic Molecular Theory, Temperature, and Thermal Equilibrium" included an activity in which food coloring is placed in water at different temperatures as students observe that the kinetic energy of a substance is higher at higher temperatures (Caltech, 2013). The activity was designed to address alternative conceptions 1, 6, and 7 above (Schnitka, 2009, p. 110).

The lesson introducing "Heat Transfer: How does thermal kinetic energy move through different types of matter?" included two group activities from the *Save the Penguins* engineering unit developed by Schnittka, 2009. The first activity involved placing ice cubes in a metal and plastic spoon and having students hold the spoons and making predictions about the melting rates of the ice cubes. The second involved students touching trays, one metal and one plastic, making predictions about the temperature of the trays, and then viewing aquarium thermometers on the bottoms of the trays showing that both trays. Despite one tray feeling colder, students were shown that both trays were at the same temperature. These activities were designed to address alternative conceptions 3 and 5 (Schnittka, 2009, p. 110).

The lesson on "Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?" included a guided inquiry investigation as students chose a material, placed it in a container inside a pitcher of ice water, and measured temperature changes in regular time intervals over approximately 20 minutes. The activity was adapted from the *Cold Stuff* lab developed by Jefferson Lab's Office of Science Education (n.d.). After a review of the results of the tests of materials, students viewed the animation of the "sea of electrons" in metals from the University of Cambridge (2004-2015). Student groups were also guided to develop a model using balloons as electrons (adapted from Whys Guys, n.d.) and a written description to represent the structure of the atoms in good conductors and good insulators. These activities were designed to address alternative conceptions 2 and 4 (Schnittka, 2009, p. 110).

Table 4 below provides an overview of the lessons in each phase of the curriculum unit and how each was aligned with the learning objectives, Webb's (2002) Depth of Knowledge, the *Science Framework for the 2015 National Assessment of Educational Progress* (NAGB, 2014), and alternative conceptions about heat transfer based on Schnittka (2009). The lesson alignment was validated by a panel of three reviewers with at least one degree in science and at least ten years' teaching experience at the middle, secondary and/or post-secondary level. Reviewers indicated on a 5-point scale 98% agreement on the alignment to the associated parameters.

Table 4

Curriculum Unit Lesson Alignment

Lesson	Learning Objective	Webb's (2002) Depth of Knowledge	Cognitive Demand NAGB (2014)	Alternative Conceptions Addressed (Schnittka, 2009)
Conventional/Guided Inquiry Phase				
Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?	1	Level 1	Declarative	1, 6, 7
Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter?	1, 2	Level 1	Declarative	3, 5
Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?	3, 4	Levels 2 and 3	Declarative, Schematic	2, 4
Design Challenge Phase				
Problem Identification: What is the problem to be addressed in the design challenge?	8	Level 1	Declarative	None explicitly addressed
Brainstorming and Research: What do you know about the design challenge?	1-4	Level 4	Schematic Strategic	1-7
Potential Design Solutions: What are some possible designs for an insulating device?	7, 8	Levels 3 and 4	Procedural[a] Strategic	None explicitly addressed
Generate a Team Solution: What type of device will your team build and why?	7, 8	Levels 3 and 4	Procedural[a] Strategic	None explicitly addressed
Create the Prototype: How will your team build the prototype?	8	Level 4	Procedural[a], Strategic	None explicitly addressed
Test the Prototype: How will your prototype perform?	5, 6	Levels 1 and 2	Procedural[b]	None explicitly addressed
Refining the Design: What changes should be made to your team's design?	7, 8	Levels 3 and 4	Procedural[a] Strategic	None explicitly addressed

Note: [a]Procedural knowledge associated with technological design; [b]Procedural knowledge associated with scientific inquiry

Instruments

To answer the research question and to provide a measure of triangulation and corroborating evidence to validate results (Cresswell, 2007; Patton, 2002), two research instruments were utilized to collect quantitative and qualitative data about students' understanding of science concepts. The research instruments were the pre/post-1/post-2 test and prompts in the design challenge portfolio, which were designed to elicit student demonstrations of concept knowledge associated with declarative, schematic, and strategic cognitive demand.

Pre/Post-1/Post-2 Test

A test comprised of twenty-six questions was utilized to assess students' abilities to draw on knowledge of concepts associated with the various cognitive demands. The test items were mapped to the learning objectives in the curriculum intervention. (See Appendix C for the test). All but three of the 26 questions were drawn from validated sources, including five items from Fortus (2003, pp. 149-150); five items from *Holt Science Spectrum* (Dobson, Holman, & Roberts, 2008) (the test bank from the course textbook); two items from Organisation for Economic Co-operation and Development Programme for International Student Assessment [OECD PISA] (2006, p. 48); ten items from Schnittka (2009, pp. 320-321); and one item from Trends in International Mathematics and Science Study [TIMSS] (2011, p. 85).

The sources for the majority of the test questions (5 questions from Fortus, 2003 and 9 questions from Schnittka, 2009) reported evidence of the reliability and/or validity of the test items. Fortus established greater than 99% intercoder reliability with respect to the scoring of test items. Schnittka (2009, p. 111-113) established face, content, and construct validity and reliability of the test questions in her study. While information about the validity and reliability of the questions from *Holt Science Spectrum* (Dobson, Holman, & Roberts, 2008), Organisation for Economic Co-operation and Development Programme for International Student Assessment [OECD PISA] (2006, p. 48), and Trends in International Mathematics and Science Study [TIMSS] (2011, p. 85) are not published with the question samples, the assessments have been developed by peer review and have been implemented in large populations.

Six of the 26 test items were open-ended. Three of the open-ended questions were researcher-created. The other three open-ended questions were adapted from Fortus (2003, p. 150), Schnittka (2009, p. 321), and OECD PISA (2006, p. 48). The items were either originally multiple choice items and were adapted as open-ended items or were adapted to align with the scoring method of the other open-ended items.

In order to create an assessment of knowledge associated with declarative, schematic, and strategic knowledge, both multiple choice and open-ended questions were included in the pre/post-1/post-2 test. Although some types of test items are more likely to evoke knowledge associated with certain types of cognitive demand (i.e., multiple choice most likely evokes knowledge associated with declarative cognitive demand and open-ended most likely evokes knowledge associated with strategic cognitive demand), Li (2001) describes that the test item must be considered in terms of the task associated with the assessment item and the cognitive demand associated with each question (p. 153). Figure 3 below from Li (2001, p. 154) summarizes the types of assessment methods and tasks most often associated with knowledge from the four categories of cognitive demand.

Figure 3. Assessment Methods and Knowledge Categories

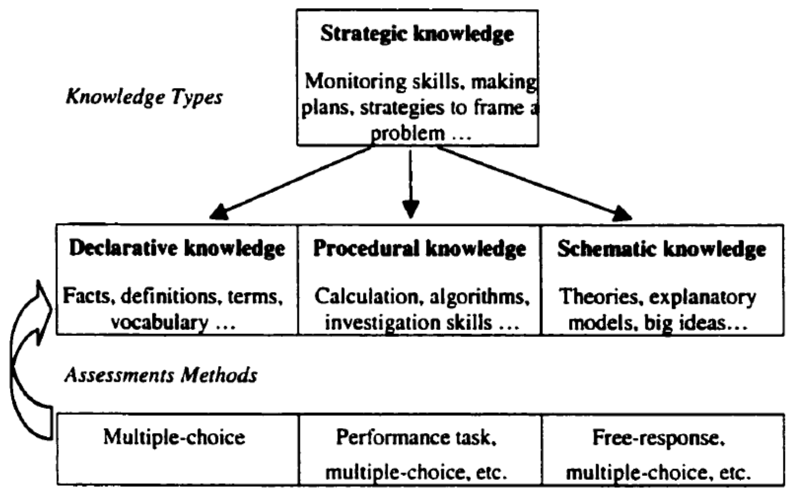

Figure 3. Components of the four types of knowledge and their links to assessment methods (Li, 2001, p. 154)

To code the test items for cognitive demand construct, the researcher utilized the framework developed by Li (2001) and applied in the 2015 *NAEP Science Assessment Framework*, to initially categorize each item on the test according to the task and cognitive demand evoked by the question. The coding of all test items for cognitive demand construct was validated by a panel of three experts (described further in Validity of Learning Objective and Cognitive Demand Construct section below). The number of questions associated with each category of cognitive demand is as follows:

1. Declarative Cognitive Demand – 9 multiple choice questions
2. Procedural Cognitive Demand – 3 open-ended questions require reading a graph to answer questions associated with Strategic Cognitive Demand
3. Schematic Cognitive Demand – 11 multiple choice questions
4. Strategic Cognitive Demand – 6 open-ended questions

Further, to code the test items for alignment to the learning objectives of the curriculum unit, the researcher also initially categorized each item on the test according to the learning objective. The coding of all test items for learning objective construct was also validated by a panel of three experts (described further in Validity of Learning Objective and Cognitive Demand Construct section below). The number of questions associated with each learning objective is as follows (some questions are associated with more than one learning objective):

1. Learning Objective One – Identify and describe the term heat; what temperature measures; and the processes of heat transfer through conduction, convection, and radiation – 10 questions
2. Learning Objective Two – Describe the direction of heat transfer (implied from 1st Law of Thermodynamics) from a hotter to a colder object – 5 questions
3. Learning Objective Three – Distinguish between good insulating materials and good conducting materials – 6 questions
4. Learning Objective Four – Explain why, in terms of kinetic molecular theory, some materials are better insulators (preventing heat transfer) or better conductors (allowing heat transfer) than others – 8 questions
5. Learning Objective Five – Determine the most appropriate temperature scale to use, the independent and dependent variables, the constants, and the control associated with testing an insulating device – assessed in design portfolio rather than on test
6. Learning Objective Six – Graph results from data collected from the testing of an insulating device – assessed in the design portfolio rather than on the test

7. Learning Objective Seven – Use an understanding of the concepts related to heat transfer to develop a justification for choosing the best solution for preventing heat transfer – 6 questions
8. Learning Objective Eight - Use an understanding of the concepts related to heat transfer to design a technological device to prevent heat transfer – 4 questions

Test items were chosen such that there was an approximately equal number of multiple choice questions that assess students' abilities to draw on knowledge associated with declarative and schematic cognitive demand, categories most often assessed with multiple choice science assessments (Li, 2001). In order to assess knowledge primarily associated with strategic cognitive demand, the researcher developed three open-ended questions and adapted three questions from Fortus (2003, p. 150), Schnittka (2009, p. 321), and OECD PISA (2006, p. 48). Following is a description of how the three open-ended questions from Fortus (2003, p. 150), Schnittka (2009, p. 321), and OECD PISA (2006, p. 48) were adapted.

One question adapted from Fortus (2003, p. 150) stated: "Why would tightly closed windows be a good design choice in cold climates but not a good design choice in hot climates?" Although this question was already initially coded by the researcher as one of strategic cognitive demand, it was adapted to align with the scoring methods associated with the other open-ended questions (described further below) in the following manner (modified text highlighted): "If you were a home owner, describe at least 2 reasons why you would want to have tightly closed windows in cold climates."

A multiple choice question from OECD PISA (2006, p. 48) that was originally categorized by the researcher as requiring knowledge associated with schematic cognitive demand stated:

Peter is working on repairs to an old house. He has left a bottle of water, some metal nails, and a piece of timber inside the boot of his car. After the car has been out in the sun for three hours, the temperature inside the car reaches about 40 ºC. What happens to the objects in the car? Circle "Yes" or "No" for each statement.

Does this happen to the object(s)? Yes or No?

They all have the same temperature. Yes / No

After some time the water begins to boil. Yes / No

After some time the metal nails begin to glow red. Yes / No

It was adapted by the researcher as an open-ended question in the following manner (modified text highlighted):

Imagine that you were working on repairs to a house on a 90 ºF day. At lunch time, you have some left over materials and would like to leave them in your car while you go to lunch. The materials are: a bottle of water, some metal nails, and a piece of wood.

- After lunch, which of the material(s) might be too hot to handle if left in the car while you go to lunch?
- Describe at least 3 reasons why the material(s) might be too hot to handle if left in the car while you go to lunch.

A multiple choice question from Schnittka (2009, p. 321) that was originally categorized as requiring knowledge associated with schematic cognitive demand stated:

You have a can of soda in your lunchbox that you want to keep cold. Which material will work best to keep it cold?

a. Aluminum foil wrapped around the soda because metals transfer heat energy easily.

b. A paper towel wrapped around the soda because paper soaks up the moisture.

c. Wax paper wrapped around the soda because wax paper traps the moisture.

d. Your wool sweater wrapped around the soda because wool traps air.

It was adapted by the researcher as an open-ended question in the following manner (modified text highlighted):

You have a can of soda in your lunchbox that you want to keep cold. You have the following materials to possibly use: aluminum foil, paper towels, wax paper, and a wool sweater.

1. Which material would be best to use to keep your soda cold?
2. Describe at least 3 reasons why you would choose that material.

Validity of Cognitive Demand and Learning Objective Construct. Assessment questions often require students to draw on knowledge associated with multiple cognitive demands (NAGB, 2014, pp. 88-89). However, as stated by the NAGB (2014, p. 89) it is a worthwhile goal in the development of assessment items, "Nevertheless, these related cognitive demands can be distinguished, and it is helpful to do so for item development and interpretation of student responses." Therefore, items in the pre/post-1/post-2 test were coded as representing a task associated with one of the four areas of cognitive demand (Li, 2001; NAGB, 2014). After the initial coding by the researcher, a panel of three reviewers who are current science educators with at least one science degree and ten years' experience at the middle school level reviewed the coding and indicated their agreement with the cognitive demand construct on a 5-point scale, with 5 indicating “assesses the learning objective exactly,” 3 indicating “assesses the learning objective somewhat,” and 1 indicating “does not assess the learning objective at all.”

According to Howel (2007), 80% and above is the preferred level of percent agreement representing consensus but agreement of 70% and above represents an acceptable level of consensus. Panelists indicated 100% agreement on the cognitive demand represented in 21 test items. On four test items the average rating was 4.7. Since 2 of 3 or approximately 70% of the panelists agreed on the cognitive demand for those four items, it was considered an acceptable level of agreement. On two items the average rating was 4.3. On these two items, panelists suggested that the question tasks could be associated with more than one cognitive demand. On those two items, 100% consensus on cognitive demand was reached after a second panel review was undertaken to clarify what the question asked and the primary cognitive demand required in the task of answering the question.

In order to ensure that all of the learning objectives for the curriculum unit were assessed, items were also coded as representing knowledge associated with each of the learning objectives. The researcher initially coded each item, including those from validated sources as well as researcher-created and adapted items, for learning objective based on the knowledge required of students to answer each question. After the initial coding by the researcher, a panel of three reviewers who are current science educators with at least ten years’ experience at the middle school level reviewed the coding and indicated their agreement with the cognitive demand coding on a 5-point scale, with 5 indicating “assesses the learning objective exactly,” 3 indicating “assesses the learning objective somewhat,” and 1 indicating “does not assess the learning objective at all.”

Panelists indicated 100% agreement on the learning objective represented in 15 test items. On five test items the average rating was 4.7. Since 2 of 3 or approximately 70% of the panelists agreed on the cognitive demand for those four items, it was considered an acceptable level of agreement. On one item the average rating was 4.3, with panelists indicating that the question may unintentionally relate to the density of air rather than to the phenomenon related to heat transfer from convection. On that item, 100% consensus on the learning objective was reached after choice "b" was changed in the following manner (change is highlighted):

On a sunny day, the upstairs rooms in a house are usually hotter than the downstairs rooms. Why?

a. Cool air is less dense than hot air.

b. Warm air rises and cool air sinks changed to "Warm air is less dense and rises and cool air is more dense and sinks"

c. The upstairs rooms are closer to the sun.

d. Heat rises.

(Schnittka, 2009, p. 321)

Readability of Test Items. All test items except those obtained from Fortus (2003) were developed for the middle school level. The four items from Fortus (2003) were developed for grades 9 and 10. To ensure readability for the four items from Fortus, and for all researcher-developed and adapted items, the Flesch-Kincaid readability assessment for Grade Level items was utilized. Based on the Flesch-Kincaid evaluation, all questions were verified to have a Flesch-Kincaid Grade Level no greater than 6.8 (Text Statistics Project, 2015).

Scoring of Test Items. Each multiple choice question was worth one point.

A scoring rubric (see Appendix D) was used to score the open-ended test items, each worth four points. The scoring method was based on the scoring method developed by Fortus (2003, pp. 169-170), who established interrater agreement for all of the rubrics used in his study at "better than 99%" (p. 65). Five of the six open-ended items relate to selection of a material for an application of heat transfer and reasoning based on the material selection. One point was provided for an appropriate material selection and one point each was provided for an acceptable answer as to the reasoning behind the material selection. One of the six open-ended items (adapted from Fortus, 2003, p. 150) related to open windows. In that item, students were asked to provide two reasons for why windows should remain tightly closed in winter. Each acceptable answer describing the scientific reasoning item was worth 2 points. A detailed description of the scoring method for each test item and acceptable sample answers are provided in Appendix D.

Design Portfolios

The second assessment instrument that was utilized was the student design portfolio. During the design challenge phase, students were guided through by a series of tasks to design, build, and test a working prototype insulating device to keep cold water from warming up. The design tasks were accompanied by prompts in the design portfolio. In each case, there was opportunity for students' responses to demonstrate "knowing when and where to use science knowledge in a new situation and reasoning through the novel task to reach a goal" (NAGB, 2014, p. 88). In terms of eliciting strategic knowledge, the prompts were open-ended by design such that if a response demonstrated a student's knowing how the science concepts pertained to the design challenge or when and where to draw on pertinent science knowledge in designing the prototype device, it was judged as a demonstration of strategic knowledge.

The design portfolio document is provided in Appendix A. The context for the design challenge is listed below:

Context. For millennia, human beings have been faced with the challenge of preventing food spoilage and safe storage of food. Some of the ways that human ingenuity has addressed the issue includes drying foods (such as fish and fruits), curing foods in salt to dehydrate them (such as in ham and bacon), freezing foods where the climate allowed, allowing foods to ferment as part of the natural process for developing the food (such as in cheese and sauerkraut), heating fruits with sugar or honey in preserves (such as jam and jelly), and in modern times storing food in iceboxes and eventually refrigerators (Nummer, 2002).

Challenge. You have been asked by Acme Manufacturing Company to design and build a prototype insulating device that will be used to serve as portable storage for a drink. Among the considerations for your device will be the materials to use in each area of the device to prevent heat transfer from conduction, convection, and radiation to the liquid that is to be kept cool.

Criteria. The design specifications for your prototype involve meeting two design criteria:

1. It must keep approximately 400 mL of cold liquid as cool as possible for at least 30 minutes in a room temperature environment.
2. The prototype must be designed in such a way that the liquid can be poured into the device and can be recovered later from the device without contamination.

Constraints. In addition, specifications involve the following design constraints:

1. Your team can use only the time allotted during class periods to build your device.
2. Your team can build your device only with any combination but only from the following materials provided: two 250 mL plastic cups, tape, hot glue, aluminum foil, rubber mulch, cotton balls, newspaper, and/or sand.

Design portfolio tasks were developed according to the *Technological and Engineering Design Folio Elements* framework developed by Wells (2012) and are listed in the Table 5 along with the corresponding lesson in the design challenge phase. (See Appendix A for the full student design challenge document and design prompts.)

Table 5

Lessons and Corresponding Design Portfolio Task

Design Challenge Lesson	Design Portfolio Task
Problem Identification: What is the problem to be addressed in the design challenge?	Written Problem Statement
Brainstorming and Research: What do you know about the design challenge?	Written background information on the following concepts and what you have learned about each of the following concepts and how they may affect or be affected by the problem identified in the design challenge: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium Background Information on Conduction, Convection, and Radiation Heat Transfer Materials that are Good Thermal Conductors and Good Thermal Insulators
Potential Design Solutions: What are some possible designs for an insulating device?	Individual Design Drawing and Written Summary
Generate a Team Solution: What type of device will your team build and why?	Team Design Solution and Summary
Create the Prototype: How will your team build the prototype?	Reflection on Building the Prototype

Test the Prototype: How will your prototype perform?	Prototype Test and Data Analysis
Refining the Design: What changes should be made to your team's design?	Reflection on the Performance of the Design

During a pilot study, students were introduced to the design based science pedagogical approach, the use of a pre/posttest format, and the use of a design portfolio. The pilot study was conducted at the beginning of the school year and structured through conventional instruction and a design challenge extension within the context of a "straw rocket" design challenge. The primary purpose of the "straw rocket" design challenge was to solidify an understanding of the practices associated with science and technological/engineering design as described in the K-12 Framework for Science Education (NRC, 2012, p. 41) and to serve as the students' first intensive experience with scientific inquiry and technological/engineering design.

Content Validity of Design Portfolio Prompts. The pilot study also served as an opportunity to scrutinize the design challenge prompts, which were developed to correspond to the content of the pilot study unit but structured according to the same framework as the prompts in the curriculum intervention for this dissertation study, Wells' *Technological and Engineering Design Folio Elements* (2012). Based on students' reception and responses to the prompts, modifications were made to the structure and/or wording of the prompts. The pilot study, therefore, addressed the following questions:

1. Do students' responses to the design portfolio prompts elicit the information they are designed to obtain?
2. Are there words or phrases that students find confusing about the design portfolio prompts or the sequence of the design process itself?

3. Is it feasible to utilize and code the portfolio responses as a source of data to assess the research question?

Content analysis of the design prompts (described under Data Collection below) in the pilot study revealed that the student responses elicited the information they were designed to obtain. All of the prompts were understood by students with the exception of the wording of the "problem identification prompt." The confusion with this prompt stemmed from students' literal reading of the word "problem" which caused them not to recognize that a "need" could also be interpreted as a problem. In addition, students frequently did not explicitly refer to both the design criteria and constraints addressed in the challenge. Based on students' confusion with that prompt and the fact that students often did not explicitly address both criteria and constraints in the challenge, the following highlighted words and emphases were added:

Problem Identification: What is the problem to be addressed in the design challenge? Each student will write a description of the problem including:

- a description of the need
- introduction and background about context
- a statement of the design challenge
- the design specifications including *criteria* and *constraints*.
- what additional information you need to know in order to accomplish the design challenge.

With regard to the third design portfolio question addressed in the pilot study, content analysis was feasible based on the students' responses in portfolio prompts. Content analysis was conducted based on the preliminary coding scheme described below and a spreadsheet was created by the researcher to facilitate the collection and analysis of codes (see Appendix E). Content analysis is further discussed in the Data Collection section below.

Procedure

As described previously, the learning activities associated with the curriculum intervention was implemented during two segments of instruction: 1) phase 1 included a combination of conventional direct instruction/guided inquiry and 2) phase 2 included the design challenge itself. Therefore, the content knowledge test was administered as a pre/post-1/post-2 test at three times during the enactment of the curriculum intervention. The pre-test was administered immediately prior to the introductory lesson. Post-test 1 was administered after the final lesson in the conventional direct instruction/guided inquiry phase, "Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?" The post-test 2 was administered immediately after the final lesson during of the design challenge phase, "Refining the Design: What changes should be made to your team's design?"
For each administration of the test, the questions were randomly sorted within each of the test sections (declarative, schematic, and strategic questions).

Methodological triangulation Denzin (1970) (as cited in Cohen, Manion, Morrison, 2005) was employed by utilizing two different methods: quantitative assessment with the pre/post-1/post-2 test and qualitative assessment with the portfolio responses. Each assessment was a mechanism for gathering data about knowledge associated with declarative, schematic, and strategic cognitive demand. In addition, the study was implemented in and data collected from multiple class sections to avoid limitations from the subculture of an individual class section (due to IEP status, peer groups, attitudes). Although the assessment instruments were administered to every student enrolled in the course, data were used only from student participants who provided appropriate assent and consent letters.

A proposal was submitted to the Institutional Review Board of Human Subjects at Virginia Tech and approval of the research protocol was granted prior to collecting data (see Appendix F). Based on the approved protocol, a recruitment packet including an introduction to the study, student assent letter, and parent consent letter will be provided to each student enrolled in the Physical Science course.

Following is a summary of the precautions that will be undertaken in the study in order to maintain student confidentiality and anonymity:

- Hard copy of student assent and parent consent letters
    - Stored in locked file cabinet 1 (separate from student data documents), accessible only to researcher
    - Destroyed three years after completion of study
- Hard copy of students' data documents (tests and portfolio responses)
    - After classroom evaluation, names blackened out and replaced with ID code for participants
    - Stored in locked file cabinet 2 (separate from assent and consent letters), accessible only to researcher
    - Destroyed three years after completion of study
- Electronic file key to student study ID codes
    - Password protected
    - Stored on computer 1 (separate from data collection and recoding files), accessible only to researcher

    - Destroyed three years after completion of study
- Electronic files for data collection and recording
    - Password protected
    - Stored on computer 2 (separate from Key to Student ID Codes), accessible only to researcher
    - Destroyed three years after completion of study

Data Collection

Content analysis is a method for examining large amounts of qualitative text-based data in various types of documents, identifying patterns in the text, and inferring meaning about the patterns through either inductive or deductive analysis (Patton, 2002; Stemler, 2001). Content analysis was utilized in the study in a deductive manner to identify patterns in students' demonstrations in the portfolio reponses of the use of knowledge and compare those demonstrations to the existing structure from Li (2001) and NAGB (2014) of knowledge type associated with cognitive demand.

Weber (1990) describes eight steps associated with developing and utilizing a coding scheme for content analysis:

1. Define the recording units (word sense, an entire sentence, theme, paragraph or whole text)
2. Define the categories (mutually exclusive; narrow or broad)
3. Test coding on sample text
4. Assess accuracy or reliability
5. Revise the coding rules (if reliability is low or errors are present)
6. Return to step 3
7. Code all text
8. Assess achieved reliability or accuracy

To facilitate data collection, descriptive codes based on a "conceptual structure" (Miles & Huberman, 1994, p. 63) were developed based on the conceptual framework of cognitive demand developed by Li (2001). Although the codes were developed for coding "possible affordances and constraints of test items" in verbal responses during a "Think Aloud Protocol" associated with multiple choice, free response, and performance tasks in the TIMMS assessment (Li, 2001, p. 121), the type of knowledge and its corresponding description were utilized as a conceptual framework to develop a preliminary coding system for analyzing students' responses in the design portfolio in the present study. Following is each of the four knowledge types and a description and corresponding codes from Li (2001, p. 122):

Declarative Knowledge – Facts, memorized information, definitions, examples, comparisons, experience from everyday life and/or previous experiments

Procedural Knowledge – Application of algorithms, calculations, a set of steps (balancing chemical equations or making a solution), table/diagram interpretation, or visualization

Schematic Knowledge – Application of theories, principles, models, relationships, or justifications, explanations

Strategic Knowledge – Decisions of selecting knowledge, making sense of items, monitoring, making plans, or use of other types of strategies

Li further defined each knowledge type by developing subtypes under each category and describing and providing examples of demonstrations of such knowledge. The table below is a summary of Li's (2001) coding scheme by knowledge subtype (pp. 123 and 180).

Table 6

Coding Scheme by Knowledge Type and Subtype

Knowledge Type/*Subtype*	Description	Example
Declarative knowledge		
Fact	Statement of questions retrieving the memorized facts	Kidney is in the abdomen, stomach's in the abdoment, bladder's in the abdomen, and the heart is more in the thorax.
Definition/Term	Statements involving formal definitions or particular scientific terms	I know what hibernation is, sleeps for a long time, its metabolism slows down.
Statement	Retrieving propositions, phases, rules, or statements	I know that white reflects light and that black absorbs light.
Everyday Science	Statement or questions as recalling science knowledge based on everyday or requiring minimum scientific domain-knowledge	I know that engines really run hot and the combustion is, generates a lot of heat
Procedural knowledge		
Investigation method	Statement or questions addressing the methods for investigation, such as replication, measurement errors, or controlling variables	I need to make different water temperatures as my variable…So I think what I'll do is put down the paper towel and fold it up on the table to insulate it from the table so the water temperature doesn't change too much although it probably shouldn't and I've put the thermometer into the beaker.
Procedure	Student articulating the steps of a procedure	And then I will try to stir everything. I'll start timing by at the same time that I add…
Data collection/mea-surement/record-ing/reporting	Descriptions of the process of gathering and generating data, such as collecting, recording, or reporting data	What I'll be measuring is the water temperature at the beginning of the tablet dissoliving and at the end by the time it's dissolved…I'll have to record the times…And since I'm mixing two kinds of water here I'll give it a quick stir to make sure it's equilibrated all the way through.

(continued)

Table 6 continued

Knowledge Type/*Subtype*	Description	Example
Schematic knowledge		
Explanatory model	Explanations involving personal experience or everyday knowledge	I certainly have experience this, I've put things under hot water faucets to get them to open. I know what heat does is cause things to expand.
Theoretical model	Explanations or reasoning with specitif scientific models or theories	I just know from fluid dynamics that something that's flowing faster, when something's in a narrow channel it flows faster. When it's in a wide channel it flowers [sic] slower…
Strategic knowledge		
Framing a problem	Statement of questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks.	It says "digestive", so digestive means it does something changing the food, but I don't know what the chemistry is. Okay, so three and four are theoretical questions, which I will get to after the experimental one. I think [it is] a poorly worded question.
Planning	Statements or questions about what will or should happen next (steps or actions)	All right, I will make a chart, I know the fastest way to do is to make a chart, and I usually do so and figure out.
	Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	So let's try B and C. An I expect that this one's not going to be bright at all.
Monitoring	Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task)	So, I try to remember the differences between all these words. Something I learned a long time ago. Also from experience.
	Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	Did not feel compelled to check all other combinations because I know enough about how batteries work to know that I'm reasonably sure that the result I saw could only be explained by A and D being good and B and C being worn out.

(continued)

Table 6 continued

Knowledge Type/*Subtype*	Description	Example
Test Wiseness	Statement or question as an [*sic*] educated guessing, completely guessing, or eliminating options	So it seems like a reasonable guess.

Note. Adapted from Table 7.4 "Sub-Category Codes for Strategic Knowledge" p. 123 and Appendix 7.3 "Sub-category Codes for Declarative, Procedural, and Schematic Knowledge" p. 180 by M. Li, 2001, Unpublished doctoral dissertation. Stanford University, Stanford, California.

Li's coding scheme was adapted for the purpose of the present study into a provisional list of codes as recommended by Miles and Huberman (1994) by utilizing Li's conceptual framework and anticipating examples of the various knowledge types based on the learning objectives and concepts associated with the curriculum intervention. As recommended by Weber (1990) the coding recording units have been defined as phrases or whole sentences. Table 7 below combines the knowledge type and subtype and descriptions from Li's (2001) study and anticipated examples of demonstrations of knowledge that may be elicited in students' responses to the portfolio prompts into a provisional coding scheme for the present study.

Table 7

Provisional Coding Scheme for Design Portfolio Prompts

Knowledge Type/*Subtype*[a]	Code	Description[b]	Anticipated Portfolio Responses
Declarative Knowledge			
Fact	DEC-FAC	Statement of questions retrieving the memorized facts	Heat energy transfers by the motion of particles
Definition/ Term	DEC-DEF	Statements involving formal definitions or particular scientific terms	Temperature measures the average kinetic energy of the movement of molecules
Statement	DEC-STA	Retrieving propositions, phases [*sic*], rules, or statements	Metals are good conductors of thermal energy

(continued)

Table 7 continued

Knowledge Type/*Subtype*[a]	Code	Description[b]	Anticipated Portfolio Responses
Everyday science	DEC-EVE	Statement or questions as recalling science knowledge based on everyday or requiring minimum scientific domain-knowledge	A metal spoon becomes hot to the touch when it is left in a pot of hot soup
Procedural Knowledge			
Investigation method	P-INV	Statement or questions addressing the methods for investigation, such as replication, measurement errors, or controlling variables	Our thermos will be tested by looking at how well it prevents heat from transferring to the water inside
Procedure	P-PRO	Statement articulating the steps of a procedure	We will add 400 mL of water to our thermos for testing
Data collection, measurement, recording, reporting	P-DATA	Descriptions of the process of gathering and generating data, such as collecting, recording, or reporting data	The temperature of the water inside the thermos will be recorded every two minutes
Interpretation, predication, and conclusion	P-INT	Statements related to making sense of the data or results, such as prediction	Our results will be compared with other groups' results and the control
Schematic Knowledge			
Explanatory model	SCH-EXP	Explanations involving personal experience or everyday knowledge	I have a thermos that has a shiny metallic coating which must be for reflecting radiation
Theoretical model	SCH-THE	Explanations or reasoning with specific scientific models or theories	Metals are good conductors because the electrons are able to flow and transfer kinetic thermal energy
Strategic Knowledge			
Framing a problem	STR-FRM	Statement or questions recognizing/labeling the *features* of tasks, procedures, and projects or *making sense* of tasks	The criteria for the challenge are to design a thermos to keep the water cold over 30 minutes.

(continued)

Table 7 continued

Knowledge Type/*Subtype*[a]	Code	Description[b]	Anticipated Portfolio Responses
Planning	STR-PLAN	Statements or questions about what will or should happen next (steps or actions)	Rubber mulch was the best insulator in our tests, so our design has rubber mulch on the outside to prevent heat transfer.
	STR-PLAN	Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	I think my design will be successful at preventing heat transfer because the cotton balls form an insulating layer to prevent conduction of heat from the table top.
Monitoring	STR-MON	Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task)	Our final design was chosen because it combines each team member's ideas for preventing heat transfer.
	STR-MON	Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	I didn't think that his idea of putting one cup on top of the other would be needed.
Test Wiseness	STR-TW	Statement or questions as an educated guessing, completely guessing, or eliminating options	I think the I could eliminate the possibility that aluminum foil would be a good insulator

[a]From Appendix 7.3 "Sub-category Codes for Declarative, Procedural, and Schematic Knowledge" p. 180 by M. Li, 2001, Unpublished doctoral dissertation. Stanford University, Stanford, California.
[b]Adapted from Table 7.4 "Sub-Category Codes for Strategic Knowledge" p. 123 and Appendix 7.3 "Sub-category Codes for Declarative, Procedural, and Schematic Knowledge" p. 180 by M. Li, 2001, Unpublished doctoral dissertation. Stanford University, Stanford, California.

Validating Codes and Intercoder Reliability for Content Analysis. "In content analysis, validity may be demonstrated variously. The preferred validity is *predictive*, matching the answers to the research question with subsequently obtained facts" (Krippendorff, 2010, p. 238). Since the codes utilized in the pilot study were associated with a portfolio based on a completely different curriculum unit and concepts, the validity and reliability of the coding scheme was established during the actual study with a sample of students' portfolios according to the method described in Miles and Huberman (1994) and Wells (2015).

To validate the codes, the researcher and at least two additional coders with experience in science education and at least five years of teaching experience independently coded approximately 10% of the data from two portfolios in cycles until an acceptable level of agreement was reached. The panel was provided with the Content Analysis Data Collection Instrument (see Appendix E) and training (see Appendix G) prior to the collection of data. After independently coding the data, the generated codes were compared and percent agreement calculated. The generated codes from the first coding were arbitrated to ensure consistency and coherence and revised to develop a coding scheme to be utilized to code a second sample of approximately 10% of the data. After the second independent coding, a percent agreement among coders for the coding sceme was calculated and the process repeated until an acceptable level (>70%) of agreement was obtained (Howel, 2007). The revised coding scheme was then applied to code two student portfolios from each course section. The portfolios were chosen based on coherence, legibility, and extensiveness of responses in order to provide the most opportunity for analysis. The final percent agreement was obtained after the final independent coding and subsequent independent verified coding resulted in a percent agreement of greater than 70%, the benchmark representing an acceptable consensus (Howel, 2007).

Responses were coded following the procedures as described in Li (2001, p. 124). Response statements or phrases were color coded to represent one of the knowledge types and subtypes. After color coding phrases from the student portfolios, each coder entered into or selected the following data in the Content Analysis Coding Instrument (see Appendix F): the student's study code number, the portfolio page number, the portfolio prompt, the knowledge type (declarative, procedural, schematic, or strategic), and the knowledge subtype based on a conditional list of subtypes determined by knowledge type selected. The spreadsheet then generated the code that was assigned to the phrase in the final column to facilitate data analysis.

Data Analysis

The quantitative data from the pre/post-1/post-2 test was analyzed and corroborated with qualitative data from content analysis to answer the research question. To analyze a null hypothesis of no difference associated with data collected from the content knowledge, paired *t*-tests were conducted to compare the means of pretest vs. posttest 1, posttest 1 vs. posttest 2, and pretest vs. posttest 2.

Stemler (2001) cautions that codes should not be reduced simply to frequency counts but rather the characteristic that “makes the technique particularly rich and meaningful” is the reliance on coding and categorizing of the data in content analysis. Ryan and Bernard (2003) suggest that for text associated with “brief descriptions (1-2 paragraphs)” (p. 102), the most feasible and easy to implement analysis would include identifying “repetitions,” “similarities and differences,” and “cutting and sorting” patterns in the text. Therefore, to analyze portfolio responses to corroborate and elucidate results from pre/post-1/post-2 tests, qualitative content analysis included frequency counts for each cognitive demand category, descriptive statistics for the cognitive demand associated with each prompt, sorting patterns of knowledge demonstrated by cognitive demand across prompts, and descriptive qualitative evidence to corroborate findings in pre/post-1/post-2.

CHAPTER FOUR: RESULTS

The purpose of this study was to determine what relationships exist between engagement in DBS and changes in students' depth of understanding of the science concepts associated with the development of design solutions. Specifically, the study was designed to determine how students' abilities to demonstrate an understanding of the science concepts, required by assessments of different cognitive demand, change as they are engaged in a design-based science unit associated with heat transfer.

Two assessment instruments, pre/post-1/post-2 test and student design portfolio, were utilized to gather data to answer the research question: What changes in students' science concept knowledge (declarative, schematic, and strategic demand) are evidenced following engagement in design based learning activities?

The results in this chapter are organized by each assessment instrument. For each assessment instrument, evidence is presented for changes in students' science concept knowledge (declarative, schematic, and strategic demand) associated with the pre-instruction phase, conventional/guided inquiry instructional phase, and design challenge instructional phase.

Convenience Sample

Thirty students in the researchers' grade eight Physical Science course returned forms to voluntarily participate in the study. The sample represents 24% of the 124 students enrolled in the six course sections of the researcher's Physical Science class at the time the study commenced. There were equal numbers of males and females represented in the sample.

All students were provided with the opportunity to volunteer for the study; however, varying numbers students from each course section volunteered for the study. Table 8 below displays the numbers of students from each course section who volunteered for the study.

Table 8

Number of Students Volunteers by Course Section

Course Section	Student Volunteers	Percent (%)
1	4	13
2	2	7
3	7	23
4	6	20
5	3	10
6	8	27
Total	30	100

Having an unequal number of students volunteer from the six course sections was somewhat expected due to factors beyond the control of the researcher. Although students are grouped heterogeneously in science class, they are grouped by ability for math and English classes. The result is that some of the science course sections contain students of higher ability than others due to their schedule in other classes. Most of the study volunteers came from those course sections in which there were students of higher ability; therefore, the sample population can be considered to be higher than average in terms of ability in comparison to the entire population of 8th grade students (Table 9).

Students' 2014-15 Pennsylvania System of School Assessment (PSSA) scores for the 7th grade were examined. Since one student's scores were not available, the performance of 29 of 30 (97%) of the students is provided in Table 9 below.

Table 9

Sample Students' 2014-15 7th Grade PSSA Scores for Math and Reading

	Math Performance		Reading Performance	
Level	Count	Percent (%)	Count	Percent (%)
Advanced	8	27	8	27
Proficient	14	47	17	57
Basic	3	10	4	13
Below Basic	4	13	0	0
Not Available	1	3	1	3
Total	30	100	30	100

Based on students' 2014-15 math performance, 74% of students in the sample group are characterized as advanced or proficient, 10% are characterized as basic, and 13% are characterized as below basic. Based on students' 2014-15 reading performance, 84% of the students in the sample are characterized as advanced or proficient, 13% are characterized as basic in reading, and none are characterized as below basic. Two students in the sample had been provided with an Individualized Education Plan (IEP). One student's IEP was based on gifted support and one student's IEP was based on learning support needs. Since the majority of students in the sample were characterized as proficient in both math and science, one might predict that their initial scores on the pre-test may high. Further, on subsequent assessments, there may not be opportunity for realizing large gains in scores.

Assessment Instrument 1: Pre/Post-1/Post-2 Test

The pre/post-1/post-2 test was administered to gather evidence of students' demonstrations of declarative, schematic, and strategic knowledge. The test consisted of nine multiple choice questions coded as declarative, eleven multiple choice questions coded as schematic, and six open-ended questions coded as strategic.

The pretest was administered before all instruction in Physical Science, although some basic concepts associated with heat transfer are included in the 5th grade science curriculum. The post-1 test was administered approximately 2 weeks after the pretest and immediately after the conventional/inquiry phase of instruction. The post-2 test was administered approximately one week after the post-1 test and after the design challenge phase of the intervention. A maximum score of 44 points was possible on the test. Each time the test was administered, the test items were randomly reordered within each group of test items (declarative, schematic, and strategic). Table 10 below provides descriptive statistics for each enactment of the test.

Table 10

Descriptive Statistics for Pre/Post-1/Post-2 Test

Total Score	n	*M* (Maximum of 44)	Percent (%)	SD	Min	Max	Variance	Median
Pre	30	17.2	39	4.24	8	25	17.9	16
Post-1	30	23.1	53	6.33	12	35	40.1	23
Post-2	30	27.4	62	5.95	15	37	35.4	29

The pre-test was administered prior to all instruction, and students who were in the same district last encountered basic concepts associated with heat transfer three grades prior. Therefore, the results confirm that students retained very little knowledge of concepts prior to any instruction and gained the largest improvement in understanding after the conventional/inquiry phase of instruction. A smaller gain was realized between the post-1 and post-2 test, administered after the design challenge phase of instruction. Improvements in student scores after the design challenge, which was incorporated as an extension to the conventional/inquiry instruction, show that the activity did improve student understanding of concepts.

To test the null hypothesis of no difference between the means during each phase of instruction, paired *t*-tests were conducted to make comparisons between each pair of means for the entire test, pretest vs. posttest-1, posttest-1 vs. posttest-2, and pre-test vs. posttest-2. Table 11 below provides results of the matched pair *t*-tests for the entire test (all sections combined).

Table 11

Results of Matched Pair t-tests between Test Administrations

Test Administration	*M*	*SD*	*SEM*	*df*	*t*	*p*
Pre	17.17	4.24	0.77	29	6.22	0.0001*
Post-1	23.1	6.33	1.16			
Post-1	23.1	6.33	0.30	29	6.01	0.0001*
Post-2	27.4	5.95	1.09			
Pre	23.1	6.33	0.30	29	12.18	0.0001*
Post-2	27.4	5.95	1.09			

Note. n = 30
*p < .05, two-tailed, paired

At $\alpha = .05$, significant gains were found between each enactment of the test. However, given a total of 44 points possible on the test, all post-test means are low, even after the final phase of design based instruction. The low mean scores could be related to the level of thinking required in the schematic and strategic knowledge test items. In order to ascertain which types of questions resulted in the biggest gains in student knowledge, an analysis of test items of each type (declarative, schematic, and strategic) was conducted separately to examine changes in gains across each student knowledge type with each enactment of the test.

Pre/Post-1/Post-2 Test Assessment by Knowledge Category

As described previously, there were 20 multiple choice items on the test, each worth one point. Nine of the multiple choice test items were coded as declarative demand (knowing that) based on the knowledge designed to be elicited by the test item. Eleven of the multiple choice test items were coded as schematic demand (knowing why) based on the knowledge designed to be elicited by the test item. Six open-ended test items were coded as strategic demand (knowing when and where to apply knowledge) based on the knowledge designed to be elicited by the test item. Each open-ended strategic test item was worth four points and scored based on the scoring method described in Appendix D.

To assess how changes in students' declarative science concept knowledge were evidenced following engagement in design based learning activities, the declarative, schematic, and strategic test items were analyzed separately. Table 12 below summarizes the descriptive statistics for all administration points of the test per each knowledge category.

Table 12

Descriptive Statistics for Test Administration Points by Knowledge Category

Test Administration by Knowledge Category	n	Max. Pts.	*M*	Percent (%)	SD	Min	Max	Median
Declarative Items								
Pre	30	9	5.0	56	1.82	0	8	5
Post-1	30	9	6.8	76	1.74	3	9	7
Post-2	30	9	7.7	86	1.40	4	9	8
Schematic Items								
Pre	30	11	4.2	38	2.1	1	8	4
Post-1	30	11	5.5	50	2.5	0	10	5
Post-2	30	11	6.0	55	2.4	1	9	6
Strategic Items								
Pre	30	24	8.0	33	2.51	2	12	8
Post-1	30	24	10.8	45	4.24	4	19	11
Post-2	30	24	13.7	57	3.62	6	20	14

Note. Highlighted data compare means of mean test percentage score for each knowledge category, discussed further below.

The descriptive statistics for all administration points of the test per each knowledge category indicate that students obtained both the highest mean test percentage score and largest gain in mean test percentage score on the declarative items. The mean test percentage score on the schematic and strategic test items was only 55% and 57%, respectively. Further, the gain in mean test percentage score on the schematic and strategic test items was only 17% and 24%, respectively. These data further confirm that although there were gains across all test administrations, the higher order thinking questions continued to be difficult for students after each phase of instruction.

To test the null hypothesis of no statistical difference between the means of each test administration by knowledge category, matched pair *t*-tests were conducted. Table 13 below summarizes the results of the matched pair *t*-test for each test administration point and knowledge category.

Table 13

Results of Matched Pair t-tests for Test Administration by Knowledge Category

Test Administration by Knowledge Category	*M*	*SD*	*SEM*	*df*	*t*	*p*
Declarative Items						
Pre	5.0	1.82	0.33	29	5.30	0.0001*
Post-1	6.8	1.74	0.31			
Post-1	6.8	1.74	0.31	29	2.78	0.0094*
Post-2	7.7	1.40	0.26			
Pre	5.0	1.82	0.33	29	8.55	0.0001*
Post-2	7.7	1.40	0.26			

(continued)

Table 13 continued

Test Administration by Knowledge Category	*M*	*SD*	*SEM*	*df*	*t*	*p*
Schematic Items						
Pre	4.2	2.1	0.37	29	4.51	0.0001*
Post-1	5.5	2.5	0.45			
Post-1	5.5	2.5	0.45	29	1.75	.0909
Post-2	6.0	2.4	0.45			
Pre	4.2	2.1	0.37	29	5.64	0.0001*
Post-2	6.0	2.4	0.45			
Strategic Items						
Pre	8.0	2.51	0.46	29	3.96	0.0004*
Post-1	10.8	4.24	0.77			
Post-1	10.8	4.24	0.77	29	4.45	0.0001*
Post-2	13.7	3.62	0.66			
Pre	8.0	2.51	0.46	29	8.06	<0.0001*
Post-2	13.7	3.62	0.66			

Note. n = 30
*$p < .05$, two-tailed, paired

Declarative Knowledge Test Items. Analyzing the declarative knowledge test items separately reveals that although the total mean scores of the post-1 and post-2 tests were low, there was a 20 percentage point gain between pre and post-1 test and a further 10 percentage point gain between the post-1 and post-2. Further, the post-2 mean of the declarative knowledge items (86%) indicates that gains were realized in students' science concept knowledge associated with declarative (knowing that) cognitive demand after all phases of instruction.

Results of the matched paired *t*-tests indicate at $\alpha = .05$, that there were statistically significant gains between each enactment of the test associated with the declarative knowledge test items, with the largest gains realized between the pre-test (before instruction) and post-1 tests (after the conventional/inquiry phase of instruction). Therefore, students did gain concept knowledge associated with declarative cognitive demand during each phase of the curriculum intervention. Since knowledge associated with declarative cognitive demand is the lowest order thinking, gains in such knowledge are most likely the easiest to obtain, as they simply require students to "recall, define, represent, use, and relate" science concepts (NAGB, 2014, p. 88).

Schematic Knowledge Test Items. For the schematic test items, a 12 percentage point gain was obtained between pre and post-1 tests and a 5 percentage point gain was obtained between the post-1 and post-2, with a total gain of 17%. The mean score on the post-2 schematic knowledge test items was only 6.0 (55%), which is quite low as an overall indication of gains in schematic knowledge. Schematic knowledge, "knowing why," involves students' abilities to "explain and predict natural phenomena" and provide evidence-based explanations for scientific conclusions (NAGB, 2014, p. 88). Schematic knowledge is associated with much higher order thinking than declarative knowledge. Therefore, gaining knowledge associated with schematic cognitive demand would be expected to be more difficult to obtain.

At the $\alpha = .05$ level, statistically significant gains were found in schematic knowledge between the pre-test (before instruction) and post-1 test (after the conventional/inquiry phase of instruction) and between the pre and post-2 test (after the design challenge phase of instruction). These data suggest that schematic knowledge (knowing why), requiring a higher level of cognitive demand, was more difficult to develop in the student sample.

Strategic Knowledge Test Items. Data from the strategic knowledge, open-ended test items, showed a 12 percentage point gain was obtained between both the pre and post-1 test administrations, as well as the post-1 and post-2 test, with a total gain of 24%. The highest mean score on the open-ended items was only 57%, which occurred following the post-2 test administration. Strategic knowledge, "knowing when and where to apply knowledge" involves students' abilities to apply or transfer the knowledge of a science concept or phenomenon in a different context or to a different problem (National Assessment Governing Board, 2014, p. 88). As the highest order thinking level, it would be expected that acquiring knowledge associated with strategic cognitive demand would be difficult to acquire, as it indicates expertise associated with such knowledge. Given that the strategic knowledge test items were open-ended, students not only needed to be able to choose the correct material when presented with a novel problem scenario, but they also needed to draw on knowledge of science concepts to provide accurate explanations as to why those materials would function properly in the novel problem scenario.

With respect to technological/engineering design, Crismond (2001) suggested that what distinguishes expert designers is their ability to understand how science concepts are connected with the design problem and how to then utilize the science concepts in the context of developing the design solution. Therefore, developing such knowledge and expertise in 8th grade students would be expected to be difficult and require considerable time for immersion with experiences to develop schematic knowledge and extensive practice with design utilizing concepts associated with such knowledge.

At the $\alpha = .05$ level, statistically significant gains were found in strategic knowledge with every enactment of the test. These data suggest that although developing strategic knowledge (knowing when and where to apply knowledge) requires schematic knowledge and time for developing expertise, students in the sample did significantly improve their strategic knowledge during both the conventional/inquiry phase and design challenge phase of instruction.

Pre/Post-1/Post-2 Test Assessment by Test Item

In order to further analyze students' growth for each knowledge type on the test across each test administration, gains in scores on each test time were analyzed. Table 14 below summarizes the results of the analysis of gains after each test administration for each test item by knowledge category (see Appendix C for test).

Table 14

Gains for Test Administration by Assessment of Test Items

Test Item by Knowledge Category	Max. Pts.	*M* Pre	*M* Post-1	*M* Post-2	Gain (Pre/ Post-1)	Gain (Post-1/ Post-2)	Total Gain (Pre/Post-2)
Declarative Items							
D1	1	0.50	0.73	0.83	0.23	0.10	0.33
D2	1	0.33	0.57	0.50	0.24	-0.07	0.17
D3	1	0.50	0.90	0.87	0.40	-0.03	0.37
D4	1	0.40	0.53	0.63	0.13	0.10	0.23
D5	1	0.57	0.80	0.93	0.23	0.13	0.36
D6	1	0.60	0.70	0.87	0.10	0.17	0.27
D7	1	0.83	0.87	0.93	0.04	0.06	0.10
D8	1	0.53	0.83	0.90	0.30	0.07	0.37
D9	1	0.73	0.90	0.93	0.17	0.03	0.20
Schematic Items							
Sch10	1	0.17	0.33	0.50	0.16	0.17	0.33
Sch11	1	0.40	0.50	0.43	0.10	-0.07	0.03
Sch12	1	0.13	0.17	0.17	0.04	0.00	0.04
Sch13	1	0.37	0.37	0.37	0.00	0.00	0.00
Sch14	1	0.27	0.50	0.47	0.23	-0.03	0.20
Sch15	1	0.93	0.93	0.90	0.00	-0.03	-0.03
Sch16	1	0.67	0.80	0.70	0.13	-0.10	0.03
Sch17	1	0.47	0.63	0.73	0.16	0.10	0.26
Sch18	1	0.13	0.50	0.63	0.37	0.13	0.50
Sch19	1	0.27	0.43	0.57	0.16	0.14	0.30
Sch20	1	0.37	0.30	0.43	-0.07	0.13	0.06
Strategic Items							
Str21	4	0.10	0.83	1.43	0.73	0.60	1.33
Str22	4	0.90	1.47	1.83	0.57	0.36	0.93
Str23	4	1.83	2.17	3.20	0.34	1.03	1.37
Str24	4	0.27	0.77	1.00	0.50	0.23	0.73
Str25	4	2.10	2.20	2.97	0.10	0.77	0.87
Str26	4	2.80	3.27	3.30	0.47	0.03	0.50

Note. Highlighted data indicate highest and lowest mean scores and gains for test items by knowledge category, discussed further below.

An analysis of the results on the declarative test items reveals patterns in students' responses. The means of D2 and D4 were the lowest among the nine test items. Item D2 asked which mechanism of heat transfer should be considered when designing an arctic hut. Since the correct answer, "temperature reduction," was not a mechanism of heat transfer included in the learning objectives and with which students would be familiar, the low scores on this test item is not unexpected. Item D4 asked about the process by which heat reaches pins attached to a copper rod. The correct answer, "conduction," is one that was directly aligned with learning objectives and a major emphasis of instruction. However, the text of the question involved more than understanding conduction, it also involved interpretation of a graphic and procedural description that could have complicated the interpretation of this question. (See Appendix C for full descriptions.)

In terms of gains on the declarative items, item D4 did show moderate gains in mean scores across test administrations. However, items D2 and D7 resulted in the lowest gains in mean scores across test administrations. Item D2 (described in previous paragraph) concerned the mechanism of heat transfer in an arctic hut. Item D7 asked about kinetic energy and temperature, a topic with which students seemed to be very familiar prior to the test, as the mean score on the pre-test was 0.83. The data also indicate that declarative items D3, D5, and D8 had the highest gains in mean scores across test administrations. Items D3 was associated with the definition of temperature as the average kinetic energy of a substance, and item D5 was associated with the definition of heat as energy transferred between substances at different temperatures. Item D8 was associated with the definition of convection as the transfer of energy through liquids and gases. The data indicate that students' prior knowledge of these topics was low and gained considerably across each phase of instruction. (See Appendix C for full descriptions.)

An analysis of the results on schematic test items also reveals patterns in the students' responses to test items. On the post-2 test, the majority of students were able to correctly answer items Sch10 and 15-18 (see Appendix C), which related to schematic explanations of situations associated with temperature of materials, conduction in metals, and hot air becoming less dense and rising. The question with the highest mean score on the post-2 test was question 15, regarding why a metal spoon will become hot to the touch if placed into a pot of boiling water. On the post-2 test, the majority of students were unable to correctly answer questions Sch11-14 and 19-20 (see Appendix C), which related to schematic explanations of situations associated with the direction of heat transfer, insulators' preventing heat loss, and proportional heat transfer. The question with the lowest mean score was question 12, regarding why sweaters are worn in winter - to reduce heat loss rather than generating heat or keeping cold out. With the exception of one student, all students who incorrectly answered this question incorrectly selected "All of the above" as their answer. Results from the schematic knowledge test items bring into question whether these items were adequately aligned to the learning objectives. Further, it also begs the question as to whether students needed more opportunities to experience and explain natural phenomena, especially with regard to the direction of heat transfer and the mechanisms by which insulators function.

With regard to the strategic knowledge test items, the data suggest that despite low mean scores across test administrations, strategic knowledge was gained during each enactment of the test and students were better able to respond to the open-ended prompts which required them to both choose a material for a novel situation and justify their choice with scientific evidence.

Three strategic knowledge items resulted in the highest mean scores from among all strategic knowledge test items: Str23, Str25, and Str26 (see Appendix C). Item Str23 asked about the best material to use for cooking with the sun, Str25 asked about items that would be "too hot to handle" if left in a car on a hot day, and Str26 asked about the advantages for keeping windows closed in cold climates. Item Str24 (see Appendix C) resulted in the lowest mean score among all strategic knowledge items. Item Str24 asked about which materials to use to keep a can of cold soda cold from among four choices of materials: aluminum foil, paper towels, wax paper, and a wool sweater. Evaluating students' answer to justify their responses revealed that students frequently chose a material for this question for reasons other than the material's insulating properties. For example, some students' chose paper towels to collect condensation or wax paper since it would be readily available.

In terms of gains on strategic test items, the lowest gain in score from among all strategic knowledge items occurred on item Str26, the question on which students obtained the highest mean score. This question asked about the benefit of tightly closed windows in cold environments. The high mean score and low gain on this test item suggest that students had extensive prior knowledge relating to this situation, with little room for knowledge gain.

Items Str21, 23, and 25 resulted in the highest gains. Item Str21 asked about choosing a material for designing a pizza delivery box to keep hot pizza warm. Gains in the scores for item Str21 were second highest from among all strategic knowledge items and resulted after both phases of instruction, with slightly higher gains after the conventional/inquiry phase and slightly lower gains after the design challenge phase of instruction. Item Str23 asked about the best material to use for cooking with the sun. Str23 resulted in one of the highest mean scores (described previously) as well as the highest gain from among all strategic knowledge items.

Item Str25 asked about materials that would become "too hot to handle" if left in a car on a hot day and resulted in the third highest gain from among all strategic knowledge items. Of note, the largest gains for items Str23 and 25 occurred during administration of the post-2 test, indicating that students constructed knowledge about concepts relating to choosing a material and drawing on knowledge of science concepts to explain that choice with scientific reasoning was gained during the design challenge phase of the curriculum intervention.

Further analyses were conducted to gather additional information relating to the question of whether students' strategic knowledge changed specifically during the design challenge phase of instruction. To test the null hypothesis of no statistical difference between the means of all strategic knowledge items across each test administration, matched pair *t*-tests were conducted. Table 15 below summarizes the results of the matched pair *t*-test for each test administration point and knowledge category.

Table 15

Results of Matched Pair t-tests for Strategic Knowledge Test Items

Test Item	*M*	*SD*	*SEM*	*df*	*t*	*p*
Str21						
Pre	0.10	0.55	0.25	29	2.89	0.0072*
Post-1	0.83	1.21				
Post-1	0.83	1.21	0.30	29	2.01	0.0533
Post-2	1.43	1.81				
Pre	0.10	0.55	0.32	29	4.18	0.0002*
Post-2	1.43	1.81				
Str22						
Pre	0.90	1.19	0.31	29	1.83	0.0387*
Post-1	1.45	1.38				

(continued)

Table 15 continued

Test Item		*M*	*SD*	*SEM*	*df*	*t*	*p*
	Post-1	1.45	1.38	0.28	29	1.30	0.2031
	Post-2	1.83	1.79				
	Pre	0.90	1.19	.32	29	2.87	0.0075*
	Post-2	1.83	1.70				
Str23							
	Pre	1.83	0.87	0.16	29	2.07	0.0480*
	Post-1	2.17	1.09				
	Post-1	2.17	1.09	0.22	29	4.65	0.0001*
	Post-2	3.20	0.96				
	Pre	1.83	0.87	0.21	29	6.46	0.0001*
	Post-2	3.20	0.96				
Str24							
	Pre	0.27	0.83	0.23	29	2.14	0.0409*
	Post-1	0.77	1.45				
	Post-1	0.77	1.45	0.21	29	1.13	0.2694
	Post-2	1.00	1.60				
	Pre	0.27	0.83	0.27	29	2.75	0.0102*
	Post-2	1.00	1.60				
Str25							
	Pre	2.10	0.66	0.23	29	0.43	0.6692
	Post-1	2.20	1.19				
	Post-1	2.20	1.19	0.19	29	4.04	0.0004*
	Post-2	2.97	0.96				
	Pre	2.10	0.66	0.22	29	3.97	0.0004*
	Post-2	2.97	0.96				
Str26							
	Pre	2.8	1.24	0.18	29	2.54	0.0169*
	Post-1	3.27	0.98				
	Post-1	3.27	0.98	0.23	29	0.15	.8844
	Post-2	3.30	1.02				
	Pre	2.8	1.24	0.27	29	1.82	0.0787
	Post-2	3.30	1.02				

Note. Yellow highlights indicate those items for which there was a statistically significant gain between post-1 and post-2 tests, during the design challenge phase of instruction. Green highlights indicate the test item for which there was a statistically significant gain only between pre and post-1 tests.

Between pre and post-1 test administrations, results of the matched paired *t*-tests indicate at $\alpha = .05$ there were statistically significant gains on all strategic knowledge items except for Str25, which related to materials that would be too hot to handle if left in a car on a hot day. These results are not unexpected as the students had little prior knowledge about the scenarios prior to any instruction and the post-1 test was administered after two-weeks of instruction during the conventional/inquiry phase of instruction.

Between pre and post-2 test administrations (prior to instruction and after all instruction), results of the matched pair *t*-tests indicate at $\alpha = .05$ there were statistically significant overall gains for all strategic knowledge test items except for Str26, which related to advantages of closed windows in cold climates. Since there was a statistically significant gain for item Str26 between pre and post-1 test, the absence of a significant gain overall is somewhat unexpected.

Between post-1 and post-2 test administrations (after the design challenge phase of instruction), the results of the matched pair *t*-tests indicate at $\alpha = .05$ there were statistically significant gains for strategic knowledge items Str23 and Str25, which both related to metals in various ways and their conductive properties. Since the design challenge phase of the curriculum intervention took place between the post-1 and post-2 test, those results indicate that while it might be expected that gains in knowledge would be more difficult to obtain after the first gains during the initial phase of instruction, statistically significant gains in concept knowledge associated with strategic cognitive demand were obtained during the design challenge phase for those test items. Further, for item 25, the gain between pre and post-1 test administrations was not statistically significant, indicating that the only statistically significant gain in science concept knowledge relating to that test item was gained during the design challenge phase.

Assessment Instrument 2: Design Portfolio

Content analysis was conducted on a total of 12 portfolios, six from male students and six from female students. Although the original intention was to select two student portfolios from each course section for coding based on coherence, legibility, and extensiveness of responses, the number of volunteer participants from each course section was not equal and, therefore, made it impossible to select equal numbers of portfolios from each section.

Using the criteria of coherence, legibility, and extensiveness of responses, the portfolios that were ultimately selected for content analysis came from four course sections, which were those from which the highest number of students volunteered for the study. No portfolios were selected from the two course sections from which the fewest number of students volunteer for the study. Table 16 below is a comparison by course section of the number of student volunteers in the sample and the number of portfolios selected for content analysis.

Table 16

Number of Student Volunteers and Portfolios Selected for Content Analysis by Course Section

Course Section	Student Volunteers	Percent of Students in Sample (%)	Portfolios Selected for Content Analysis	Percent of Portfolios in Sample (%)
1	4	13	0	0
2	2	7	1	8
3	7	23	4	33
4	6	20	4	33
5	3	10	0	0
6	8	27	3	25
Total	30	100	12	100

As described previously, the course sections from which the highest number of students volunteered for the study were those that had higher abilities for factors beyond the control of the researcher. The resulting selection of portfolios came from students who were of advanced or proficient ability. Table 17 below summarizes the 2014-15 math and reading PSSA scores for the students whose portfolios were selected for content analysis.

Table 17

Portfolio Students' 2014-15 7th Grade PSSA Scores for Math and Reading

	Math Performance		Reading Performance	
Level	Count	Percent (%)	Count	Percent (%)
Advanced	8	67	8	67
Proficient	3	25	4	33
Basic	1	8	0	0
Below Basic	0	0	0	0
Total	12	100	12	100

Establishing Intercoder Reliability

To validate the codes, the researcher and two additional coders with experience in science education and at least five years of teaching experience independently coded one entire portfolio. The panel were provided with the Content Analysis Data Collection Instrument (see Appendix E) and training (see Appendix G) prior to the coding of data. After independently coding the first portfolio, all coders met to discuss and compare their generated codes. Code comparisons indicated the percent agreement among co-coders was found to be 53%, which is below an acceptable agreement level. To calculate percent agreement for each student phrase, a 1 was assigned to codes that agreed with the abitrated code and 0 for those codes that did not agree with the arbitrated code. Percent agreement was then calculated for each student phrase and the overall average percent agreement was then calculated. Table 18 provides a sample of the data and calculation of intercoder agreement for the first portfolio. See Appendix H for the full results of the coding of the first portfolio and calculation of intercoder agreement.

Table 18

Sample of Content Analysis of First Porfolio and Calculation of Intercoder Agreement

Student Phrase	Coder 1	Coder 2	Coder 3	Arbitrated Code	Agreement with Code[a]			% Agreement[b]
company is asking for an insulating device	STR-FRM	STR-FRM		STR-FRM	1	1	0	67
The only things we can use are…	P-PRO			P-PRO	1	0	0	33
We need to keep about 400 mL of cold liquid cold for 30 minutes…	STR-FRM		STR-FRM	STR-FRM	1	0	1	67
We need to use our knowledge about conduction, convection, and radiation to accomplish this task.	DEC-EVE		DEC-EVE	DEC-EVE	1	1	1	100
Kinetic molecular theory is when temperature rises…	SCH-THE	DEC-DEF	DEC-EVE	SCH-THE	1	0	0	33
Temperature is the average kinetic energy of an object.	DEC-DEF			DEC-DEF	1	0	0	33

[a]*Note*. A value of 1 is assigned to if original code agrees with arbitrated code, and 0 if original code does not agree with arbitrated code.
[b]Total % agreement for entire data set (Appendix H) calculated at 53%.

The generated codes from the first coding were then arbitrated and discussed to ensure consistency and coherence. One of the main co-coder issues with the first independent coding were discrepancies in the coding units, as some panelists combined sentences or did not code phrases separated from compound sentences. The other co-coder issue with the first coding were discrepancies in the interpretation of students' responses, particularly with regard to answers in which students were interpreting data and defining terms. After discussion about coding units , it was agreed that each sentence or phrase from compound sentences would be coded separately. In addition, it was agreed that phrases that involved a description of a formal vocabulary word would be coded as declarative-definition knowledge. Further, it was agreed that students' responses describing which materials were conductors and insulators, which were based on interpreting data from the inquiry phase of the curriculum unit, would be coded as procedural-interpretation knowledge.

After arbitrating the codes from the first independent coding, a second independent coding of approximately 10% of the data in a second portfolio was conducted. After independently coding the second data sample following clarified procedures for coding units of data and coding scheme, the generated codes were compared and percent agreement was calculated by assigning a 1 to codes that agreed with the abitrated code and 0 for those codes that did not agree with the arbitrated code. Percent agreement was then calculated for each student phrase and the overall average percent agreement was then calculated and found to be 83%. Table 19 below provides the full results of the second independent coding of 10% of the second portfolio document.

Table 19

Results of Second Independent Coding

Student Phrase	Coder 1	Coder 2	Coder 3	Arbitrated Code	Code Agreement[a]			% Agree-ment[b]
We are in need of an insulator to keep a drink cold that we can travel with.	STR-FRM	STR-FRM	STR-FRM	STR-FRM	1	1	1	100
We need 200 mL of liquid to stay as cool as can be for 30 minutes.	STR-FRM	STR-FRM	STR-FRM	STR-FRM	1	1	1	100
The liquid must be able to be poured into the insulator, then be poured back into the bottle later.	STR-FRM	STR-FRM	STR-FRM	STR-FRM	1	1	1	100
There must not be any contamination.	STR-FRM	P-INV	STR-FRM	STR-FRM	1	0	1	67
We can only use class time to build our device,	P-PRO	P-PRO	P-PRO	P-PRO	1	1	1	100
…we can only use the following materials…	P-PRO	P-PRO		P-PRO	1	1	0	67
Our insulator needs to keep foods hot, cold, and from spilling [*sic*].	STR-FRM	STR-FRM		STR-FRM	1	1	0	67
We need to know how to put an insulator together, what an insulator is, and how to create it so it meets the requirements.	STR-FRM			STR-FRM	1	0	0	33
Kinetic molecular theory - if the heat increases, the molecules will move faster.	SCH-THE	SCH-THE	SCH-THE	SCH-THE	1	1	1	100
Temperature - the measurement of how hot something is…student lists equations	DEC-DEF	DEC-DEF	DEC-DEF	DEC-DEF	1	1	1	100

[a]*Note*. A value of 1 is assigned to if original code agrees with arbitrated code, and 0 if original code does not agree with arbitrated code.
[b]Total % agreement calculated at 83%.

Upon conclusion of the second independent coding, a third independent coding of another approximately 10% of the data in the second portfolio was conducted to verify the level of agreement. Codes were arbitrated once more and the main discrepancies dealt with coding declarative statements as definitions or facts and how to intepret students' statements about materials tests. Statements describing formal vocabulary words were again clarified and it was agreed that they would be considered declarative-definition knowledge rather than any other declarative knowledge subtype. Statements that were associated with a scientific law would be coded as declarative-fact knowledge. Further, statements regarding the best conductors and insulators, which were dependent on accurate interpretation of data from the materials test laboratory would be considered procedural-interpretation . After independently coding the second data sample with the clarified coding scheme, the generated codes were compared and the percent agreement among co-coders. To calculate percent agreement for each student phrase, a 1 was assigned to codes that agreed with the abitrated code and 0 for those codes that did not agree with the arbitrated code. Percent agreement was then calculated for each student phrase and the overall average percent agreement was then calculated and found to be 70%, which is below the level of acceptable agreement. Table 20 below provides the results of the third independent coding.

Table 20

Results of Third Independent Coding

Student Phrase	Coder 1	Coder 2	Coder 3	Arbitrated Code	Code Agree-ment[a]			% Agree-ment[b]
I've learned that conduction is the transfer of heat between substances that are in direct contact with each other.	DEC-DEF	DEC-DEF	DEC-EVE	DEC-DEF	1	1	0	67
Convection is the up and down movement of gasese and liquids caused by heat transfer.	DEC-DEF	DEC-DEF	DEC-DEF	DEC-DEF	1	1	1	100
Radiation is when electromagnetic waves travel through space.	DEC-DEF	DEC-DEF	DEC-DEF	DEC-DEF	1	1	1	100
Heat always transfer from a warmer object to a colder object.	DEC-FAC	DEC-FAC	DEC-FAC	DEC-FAC	1	1	1	100
Conduction occurs in solid states of matter, convection occurs in gases and liquids	DEC-DEF	DEC-FAC	DEC-EVE	DEC-DEF	1	0	0	33
These concepts will effect [*sic*] the design challenge because radiation could warm up the drink through the air, conduction could warm up the drink if it touches something hot, and convection can warm up the drink by the air outside of the insulator.	STR-FRM	STR-PLAN	DEC-EVE	STR-FRM	1	0	0	33
The sand is a very good insulator and the aluminum foil was not.	P-INT	P-INT	DEC-EVE	P-INT	1	1	0	67
Anything that is hard to get though and doesn't get cold too easily will be a good insulator.	SCH-EXP	SCH-EXP	DEC-EVE	SCH-EXP	1	1	0	67
Air and metals are poor insulators.	P-INT	P-INT	DEC-EVE	P-INT	1	1	0	67

[a]*Note*. A value of 1 is assigned to if original code agrees with arbitrated code, and 0 if original code does not agree with arbitrated code.
[b]Total % agreement calculated at 70%.

Upon conclusion of the third independent coding with a level of agreement at 70%, a fourth independent coding of the remaining data (approximately 10%) in the second portfolio was conducted. Codes were arbitrated once more and the main discrepancies dealt with deciding how to code students' statements that were associated with evaluating the performance of the prototypes. Those statements were considered strategic monitoring statements since students were not merely interpreting data but evaluating the data in terms of how they met the design challenge. After independently coding the fourth data sample with the clarified coding scheme, the generated codes were compared and the percent agreement compared among the three co-coders. To calculate percent agreement for each student phrase, a 1 was assigned to codes that agreed with the abitrated code and 0 for those codes that did not agree with the arbitrated code. Percent agreement was then calculated for each student phrase and the overall average percent agreement was then calculated and found to be 78%. Table 21 below provides the results of the fourth independent coding of the approximately 10% sample of the portfolio.

Table 21

Results from Fourth Independent Coding

Student Phrase	Coder 1	Coder 2	Coder 3	Arbitrated Code	Code Agreement[a]	% Agreement[b]
The atoms are close together and moving/vibrating slowly. The electrons will transfer heat.	SCH-THE		SCH-THE	SCH-THE	1 0 1	67
The atoms would be close together and barely moving (vibrating) since most insulators are solid states of matter.	SCH-THE		SCH-THE	SCH-THE	1 0 1	67
In my design, I have one cup filled with sand.	P-PRO	P-PRO	P-PRO	P-PRO	1 1 1	100
It will not be too full though so you can see the drink inside.	P-PRO	P-PRO	P-PRO	P-PRO	1 1 1	100
You can tape them together and they will keep the drink cold. Make sure there aren't any cracks.	P-PRO	P-PRO	P-PRO	P-PRO	1 1 1	100
I chose sand because it was the best insulator.	STR-PLAN	STR-PLAN	DEC-EVE	STR-PLAN	1 1 0	67
The cotton balls might prevent the heat from staying out	STR-PLAN	STR-PLAN	P-INV	STR-PLAN	1 1 0	67
…or if the lid is not taped on well, the heat might get in.	STR-PLAN	STR-PLAN		STR-PLAN	1 1 0	67
Hopefully the sand won't move so the drink doesn't touch anything warm beneath it	STR-PLAN	STR-MON		STR-PLAN	1 0 1	67

[a]*Note*. A value of 1 is assigned to if original code agrees with arbitrated code, and 0 if original code does not agree with arbitrated code.
[b]Total % agreement calculated at 78%.

Upon obtaining a percent agreement of 78%, a fifth independent coding of the remainder of the second portfolio was conducted to verify the level of agreement. After independently coding the fifth data sample, a 1 was assigned to codes that agreed with the abitrated code and 0 for those codes that did not agree with the arbitrated code. Percent agreement was then calculated for each student phrase and the overall average percent agreement was then calculated and found to be 76%. Therefore, after co-coding two entire portfolio documents, the inter-coder reliaility of the coding scheme was found to be 76%, which constitutes an an acceptable level (>70%) of agreement (Howel, 2007). Table 22 below provides the results of the fifth independent coding.

Table 22

Results from Fifth Independent Coding

Student Phrase	Coder 1	Coder 2	Coder 3	Arbitrated Code	Code Agree-ment[a]	% Agree-ment[b]
The temperature of the water up 1.2˚ throughout the experiment.	P-INT	P-INT	P-INT	P-INT	1 1 1	100
It went from 6.3˚C-7.5˚C over the course of the 30 minutes.	P-INT	P-INT	P-INT	P-INT	1 1 1	100
We recorded the temperature every 2 minutes.	P-DATA	P-DATA	P-DATA	P-DATA	1 1 1	100
The water did not rise in temperature too much.	P-INT		P-PINT	P-INT	1 0 1	67
Our insulator was able to hold 400 mL.	STR-MON		P-INT	STR-MON	1 0 0	33
We could have made it much better so the temp. of the water didn't rise as much, but other than that we met all other requirements.	STR-MON	STR-MON	P-INT	STR-MON	1 1 0	67
I would somehow insulate the water more.	STR-MON	STR-MON	P-INT	STR-MON	1 1 0	67

[a]*Note*. A value of 1 is assigned to if original code agrees with arbitrated code, and 0 if original code does not agree with arbitrated code.
[b]Total % agreement calculated at 76%.

Content Analysis Results

After establishing the validity of the codes, the researcher conducted independent coding on the remaining ten portfolios using the agreed upon procedures and codes. Results of the remaining content analysis on the remaining ten portfolios are displayed in Appendix I. A total of 381 expressions were analyzed in a total of 12 portfolios (two portfolios coded by the panel and ten additional portfolios coded by the researcher). Frequency counts of each student participant's expressions of knowledge by declarative, procedural, schematic, and strategic knowledge type and subtype are listed in Table 23 below (see code descriptions in Appendix G).

Table 23

Frequency Counts of Expressions of Knowledge by Type and Subtype for Student Participants

	Declarative n=47				Procedural n=92				Schematic n=60		Strategic n=182			
Participant	FAC	DEF	STA	EVE	INV	PRO	DATA	INT	EXP	THE	FRM	PLAN	MON	Total
A	1	1	1	0	0	3	1	3	3	3	12	2	4	34
B	1	4	1	0	0	4	0	3	2	3	10	0	5	33
C	0	4	0	1	0	4	1	4	1	2	4	4	2	27
D	1	0	0	0	1	2	1	2	5	3	9	2	3	29
E	1	4	0	2	0	5	1	5	1	3	7	5	3	37
F	1	4	0	1	0	4	1	4	2	3	5	4	2	31
G	0	0	0	0	0	4	0	3	3	4	10	4	3	31
H	0	1	1	0	0	5	0	3	1	2	8	6	4	31
I	1	5	0	0	0	3	0	3	2	3	12	5	3	37
J	0	1	0	0	0	3	0	2	2	3	7	7	3	28
K	1	0	1	0	0	8	0	4	2	3	9	1	3	32
L	1	3	4	0	0	2	0	3	2	2	6	4	4	31
Total	8	27	8	4	1	47	5	39	26	34	99	44	39	381

The frequency count of knowledge type and subtype reveals that the most frequent knowledge type expressed in the students' responses was strategic knowledge, followed by procedural, schematic, and declarative. These results confirm that students were able to demonstrate their use of strategic knowledge during the design challenge phase. Further, the design challenge itself was a learning opportunity that elicited knowledge of all types, but particularly elicited strategic knowledge the context of designing an insulating device.

The data in Table 23 reveal that the most commonly expressed knowledge subtype within the declarative knowledge cognitive demand was definition, which is a statement associated with a formal definition of a term (Li, 20013, p. 123). There were few expressions of knowledge subtypes EVE “everyday science,” STA “statement - retrieving propositions, phases, rules, or statements,” and FAC “statement of questions retrieving the memorized facts” (Li, 2003, p. 123). Co-coding statements of declarative knowledge into knowledge subtypes proved very difficult in that coders were using agreed upon procedures rather than meaningful distinguishing characteristics to distinguish between declarative knowledge statements. Therefore, findings suggest that by collapsing all four of the declarative subtypes into a single declarative knowledge type would more accurately reflect this knowledge category.

Procedural knowledge was most commonly expressed as PRO “procedural,” which involves articulating the steps of a procedure, and INT “interpretation,” which involves interpretation of data (Li, 2003, p. 123). Procedural knowledge was not commonly expressed as INV “investigation method,” which describes “methods for investigation, such as replication, measurement errors, or controlling variables,” nor was it commonly expressed as DATA, “descriptions of the process of gathering and generating data, such as collecting, recording, or reporting data” (Li, 2003, p. 123). The content analysis results for procedural knowledge reveal that students involved in the design challenge were more frequently expressing information about the steps of the design challenge and results in terms of meeting design criteria than they were involved in thinking about the experimental design process. These results align with the learning objectives of the design challenge, which was treated as an extension of conventional instruction and inquiry activities. Therefore, the procedural knowledge sub type of investigation method and data gathering in the original coding scheme were not effectively utilized to code the students' responses in the design portfolios during the design challenge phase.

Schematic knowledge was most often expressed as THE "theoretical models," although EXP "explanatory models" were also expressed with nearly the same frequency. Taken together with the results from the pre/post-1/post-2 test, the data suggest that although students were utilizing schematic knowledge in their design portfolios, primarily through their articulations of kinetic molecular theory associated with temperature and atomic theory associated with models of heat conduction, perhaps those explanations were either not assessed properly in the test items or perhaps the knowledge associated with those explanations was not transferrable to the situations that students encountered on the test.

Strategic knowledge in the design challenge portfolio was most frequently expressed as FRM statements "recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks" (Li, 2003, p. 231). The strategic FRM knowledge subtype was more frequently expressed than all other knowledge subtypes combined. Framing the problem is a significant feature of design based learning and is seen as a desirable complement to inquiry based learning (Appleton, 1995; Barnett, 2005; Doppelt et al., 2008; Fortus et al., 2005; NGSS Lead States, 2013). Therefore, statements associated with framing the task would be expected to be an extensive feature of student thinking.

Strategic knowledge in the form of PLAN planning and MON monitoring were approximately equal in number. Strategic PLAN knowledge expressions describe "what will or should happen next (steps or actions)" or "specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)." Strategic MON knowledge expressions describe "noticing/regulating/checking the progress or lack of progress (an ongoing task)" or "conclusions at the end of the task (a completed or aborted task)" (Li, 2003, p. 231). The frequency of expressions of planning and monitoring confirms that design challenge provided students with the opportunity to use their knowledge in an application that was driven by the need to meet design criteria. Students were aware of those criteria and were able to hypothesize about design decisions and reflect on their design decisions based on results from the performance of their prototypes.

During the design challenge phase of the curriculum intervention, students responded to the following portfolio prompts (see Appendix A):

1. Problem Identification: Problem Statement
2. Brainstorming and Research: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium
3. Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer
4. Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators
5. Potential Design Solutions Summary: Individual Design
6. Generating a Team Solution: Team Design/Creating Design
7. Prototype Test and Data Analysis
8. Refining the Design

To further analyze students' expressions of knowledge in the design portfolios, frequency counts of students' expressions of knowledge by declarative, procedural, schematic, and strategic knowledge type and subtype for each portfolio prompt were analyzed. (See Appendix I for full content analysis results.) Table 24 below summarizes the number of student expressions by knowledge type and subtype for each portfolio prompt.

Table 24

Frequency Counts of Expressions of Knowledge Type and Subtype by Portfolio Prompt

	Declarative n=47				Procedural n=92				Schematic n = 60		Strategic n = 182			
Prompt	FAC	DEF	STA	EVE	INV	PRO	DATA	INT	EXP	THE	FRM	PLAN	MON	Total
P1	0	0	0	0	0	16	0	0	0	0	51	0	0	67
P2	1	10	4	4	1	0	4	0	5	11	18	3	0	61
P3	7	17	4	0	0	0	0	0	5	1	24	7	0	65
P4	0	0	0	0	0	0	0	26	1	22	0	1	0	50
P5	0	0	0	0	0	25	0	1	2	0	2	8	0	38
P6	0	0	0	0	0	6	0	1	2	0	4	25	1	39
P7	0	0	0	0	0	0	1	6	10	0	0	0	10	27
P8	0	0	0	0	0	0	0	5	1	0	0	0	28	34
Total	0	0	0	0	0	16	0	0	0	0	51	0	0	67

Note. Highlighted data indicate prompts and categories that elicited highest and lowest frequency counts of expressions of knowledge, described further below.

The frequency counts of student expressions of knowledge by portfolio prompt reveals that the prompt that elicited the most expressions (n = 67) of knowledge by students was prompt 1, Problem Identification. The second highest expressions of knowledge were elicited by prompt 3 (n = 65), prompt 2 (n = 61) , and prompt 4 (n = 50), which were all associated with brainstorming and describing what was known about concepts and how they were associated with the design challenge. Although FRM, PLAN, and MON are not typically indicators of strategic knowledge in the context of technological/engineering design, their categorization as strategic knowledge is based on conventions agreed upon during the co-coding process.

Declarative Knowledge. Prompts 3 elicited the most frequent expressions of declarative knowledge. Based on conventions agreed upon during the co-coding process, declarative knowledge was commonly expressed by students in these prompts through their descriptions of the definitions of the heat concepts and heat transfer mechanisms based on the agreed upon procedures developed during the co-coding process. In prompt 3, Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer, students expressed declarative knowledge by defining conduction, convection, and radiation heat transfer in the context of describing how those concepts could affect or be affected by their prototype.

Procedural Knowledge. Procedural knowledge was expressed most commonly in the form of procedure and interpretation of data in results (Li, 2001, p. 123). The prompts that most frequently elicited procedural knowledge was prompt 4, Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators, and prompt 5, Potential Design Solutions Summary: Individual Design.

Although prompt 4 was titled "brainstorming," a major emphasis was to review the results from the materials tests (see Appendix A, Design Portfolio Task 3) incorporated in the inquiry phase of instruction , interpret data, and conclude which materials were the best conductors and insulators based on those data. Therefore, those statements were coded as procedural-interpretation, "statements related to making sense of the data or results, such as prediction" (Li, 2001, p. 180), as they required students to interpret the temperature data from the materials tests to conclude what those data revealed about which materials were (smallest temperature change) and best conductors (largest temperature gain) compared to the temperature change for the control (air). For example, the mean temperature change for the air control test was -12.0˚C, compared to a mean temperature change of -11.7˚C for aluminum foil, and -2.0˚C for sand.

In prompt 5, students articulated how their design would be built and described the procedures associated with building their team prototypes. One example of such a procedural statement in this prompt is, “There will be a small hold on top for the thermometer.” Therefore, the prompt caused the students to not only plan the design but also develop procedures for executing the design given the materials available and the criteria for the challenge.

Schematic Knowledge. Schematic knowledge was most often expressed in prompts 2, 4, and 7. In prompt 2, Brainstorming and Research: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium, schematic-theoretical models were commonly expressed in students' descriptions of kinetic molecular theory. For example, “KMT is that if something has heat added, then the object's molecules will move faster.” In prompt 4, Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators, students expressed schematic-theoretical models in their descriptions of the atomic structure in thermal insulators and thermal conductors. For example, students commonly recognized that free electrons in the bonds of metals provided the mechanism for the transfer of heat (kinetic energy) in conductors. “(Atoms in thermal conductors) are in rows and columns, they also have a sea of electrons.” In prompt 7, Prototype Test and Data Analysis, students expressed schematic explanatory models through their descriptions of the direction of heat transfer in the test results. For example, “The heat transferred through the cup to the water.”

Strategic Knowledge. The prompts that elicited the most expressions of strategic knowledge were prompts 1, 6, and 8. In prompt 1, Problem Identification, strategic knowledge was expressed in terms of framing a problem, “statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks" (Li, 2001, p. 180). Commonly, expressions of framing the problem involved statements such as, "We need to use our knowledge about conduction, convection, and radiation to accomplish this task."

In prompt 6, Generating a Team Solution: Team Design/Creating Design, students commonly expressed in terms of planning, "statement or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)" (Li, 2001, p. 180). In prompt 6, students were given the opportunity to justify their final team prototype by describing the features of their design and how the features of the final team design would function during the prototype test ("hypothesizing or conjecturing") to meet the design criteria. For example, one student described the reason the team chose to have double layers of insulating materials featured in their team design by saying it would, "keep the heat out and keep the water colder longer." Another student described the importance of the team's decision about the placement of sand at the bottom of their prototype by conjecturing that if the sand is not fixed in place well, it would not worked as planned, "Hopefully the sand won't move so the drink doesn't touch anything warm beneath it."

In prompt 8, Refining the Design, students had the opportunity to think about their prototype results and describe successes, failures, and changes that would be made if they were to face the challenge again. Most expressions of strategic knowledge in response to this prompt came in the form of monitoring, "statement or questions noticing/regulating/checking the progress or lack of progress" for an "ongoing task" or at the end of a "completed or aborted task" (Li, 2001, p. 180). Expressions of strategic monitoring in prompt 8 consisted of statements such as, "We could add more rubber and sand to block more heat transfer." Another student recognized that the air at the top of the cup was problematic and stated that the team would "cut off the top of the cup, because it helps stop air flow (this also lowers the volume)."

Summary of the Findings

The convenience sample consisted of 30 students (15 male and 15 female) in the grade 8 Physical Science classroom of the researcher. Unequal numbers of participants volunteered from each course section; therefore, due to factors beyond the control of the researcher, the sample consisted of a majority of students who were above average in terms of mathematics and reading performance compared to the population of all students in the grade.

Quantitative data from the pre/post-1/post-2 test instruments provided evidence of statistically significant gains at $\alpha = .05$ in the mean scores between all administrations of the test (see Table 13). However, the mean percent scores on schematic and strategic knowledge items were low after all instruction according to results on the post-2 test (see Table 12). Despite the low mean percent scores, results indicate that gains were found in students' science concept knowledge associated with declarative and strategic demand after all phases of instruction. Statistically significant gains in students' science knowledge associated with schematic cognitive demand were found only between pre/post-1 and pre-post-2. Further, since there were gains in two of six strategic knowledge items between the post-1 and post-2 administrations of the test, students did gain strategic knowledge during the design challenge phase, particularly of concepts relating to the conductive properties of metals.

Qualitative data from content analysis of the design portfolios corroborates findings data from the pre/post-1/post-2 test. Most expressions of knowledge written by students in the design portfolio were coded as strategic, followed by procedural, schematic, and declarative.

Declarative knowledge was most often expressed in terms of formal definitions of terms of concepts. However, coding declarative statements to the level of knowledge sub-type proved difficult for co-coders and relied on conventions agreed upon during the coding process. In aggregate, the declarative knowledge results suggest that students were able to express knowledge associated with declarative demand, particularly in two Brainstorming, Research, and Ideation prompts - Prompt 2 (KMT, Temperature, and Thermal Equilibrium) and Prompt 3 (Conduction, Convection, and Radiation Heat Transfer) of the design portfolio. The declarative knowledge results confirm the relatively high mean post-2 test score for declarative items and the statistically significant gains in declarative test item means between each test administration.

Procedural knowledge was most frequently expressed in statements associated with the procedure for building prototypes. In addition, students frequently expressed statements coded as procedural, data interpretation statements from the materials tests from the inquiry phase of the curriculum intervention. Those statements were coded as procedural-interpretation, “statements related to making sense of the data or results, such as prediction” (Li, 2001, p. 180). However, procedural knowledge associated with the processes of investigation and data collection was not frequently expressed in the design portfolios, which is somewhat expected given that the design challenge did not emphasize the processes of developing experiments and procedures for data collection.

Schematic knowledge of theoretical and explanatory models was also expressed in design portfolios. Considering the low mean percentage scores in schematic knowledge items after the post-2 test and the statistically non-significant gain of schematic knowledge between the post-1 and post-2 tests, perhaps schematic knowledge was gained but the test assessment did not accurately assess that knowledge.

Strategic knowledge was most often expressed in the context of students' articulating the criteria and constraints associated with the design challenge. Those statements were expressed as strategic framing of problems. In addition, students frequently expressed strategic knowledge associated with making decisions about their design prototypes and evaluating how their prototypes performed and how they would make changes to improve their prototypes' performance. Those strategic statements were coded as strategic planning and monitoring progress. The results of the content analysis of portfolios suggest that students were able to express knowledge about relevant science concepts strategically in terms of explaining their designs, predicting how their prototypes would work, and explaining how their prototypes performed. Although the mean percentage score for strategic knowledge items on the post-2 test was low, statistically significant gains in strategic knowledge during the design challenge phase were found on two of the six strategic knowledge items between post-1 and post-2 tests. Therefore, results from the test assessment and design portfolio show that students did construct science concept knowledge during the design challenge phase at a level of higher order thinking that enabled them to know when and where to retrieve the knowledge and use it in an application associated with a novel situation.

CHAPTER FIVE: DISCUSSION, IMPLICATIONS, AND RECOMMENDATIONS

This chapter presents discussion of the research results and conclusions based on evidence in the previous chapter. In addition, the implications of the results and recommendations for further research are discussed.

Conclusions

This study addressed the need to examine DBS from the standpoint of its relationship to students' use of higher order thinking skills. This study addressed the need to investigate the ways in which students utilize their understanding of science concept knowledge associated with declarative, schematic, and strategic demand while engaged in DBS activities. The purpose of this study was to determine what relationships exist between engagement in DBS and changes in students' depth of understanding of the science concepts associated with the development of design solutions. Utilizing two data collection methods, a quantitative pre/post-1/post-2 test and qualitative content analysis of a student design portfolio, the study assessed how students' abilities to demonstrate an understanding of the science concepts, required by assessments of different cognitive demand, changed as they were engaged in a design-based science unit associated with heat transfer. The research question addressed in the study was: What changes in students' science concept knowledge (declarative, schematic, and strategic demand) are evidenced following engagement in design based learning activities?

Changes in Concept Knowledge: Conclusions from Quantitative Data Analysis

Conclusion 1. It can be concluded based on quantitative analysis that conventional/inquiry teaching approaches can foster students' understanding of science concepts associated with declarative, schematic, and strategic cognitive demands. Despite low mean scores in schematic and strategic knowledge on the post-1 test, students' declarative, schematic, and strategic knowledge grew after the conventional/inquiry phase of instruction. However, since the conventional/inquiry phase of instruction took place first and students had very little prior knowledge of the concepts, gains during this phase would be expected since they were built on very little prior knowledge. The conventional/inquiry instructional phase was two weeks in duration and incorporated a variety of conventional and inquiry learning activities, including direct instruction, demonstrations designed to address students' prior conceptions, and materials tests to investigate materials that are insulators and conductors.

Conclusion 2. Based on quantitative data analysis it can be concluded that technological/engineering design based teaching approaches utilized in science education can further foster student gains in knowledge of science concepts associated with declarative and strategic knowledge demands. Despite low mean scores in schematic and strategic knowledge on the post-2 test, students' declarative, schematic, and strategic knowledge grew after the design challenge phase of instruction, which was structured as an extension of the first phase of instruction and lasted approximately 1 week in duration. The design based learning phase of the curriculum intervention in this study included an open-ended design challenge with a practical context, criteria, and constraints. The design challenge was also accompanied by a design portfolio in which students were required to respond to prompts associated with problem identification; brainstorming, research, and ideation about kinetic molecular theory and conduction, convection, and radiation heat transfer; exploring possibilities and generating solutions; selecting a final solution and generating a prototype; testing and evaluating a prototype; and refining and redesigning a prototype. Therefore, implementation of similar teaching approaches should include such open-ended problems accompanied by a design portfolio with similar prompts in order to develop gains in student science concept knowledge.

Conclusion 3. Technological/engineering design based teaching approaches utilized in science education can foster students' growth of understanding of science concepts such that they are better able to utilize those concepts in the context of open-ended problem solving. The design challenge phase of instruction offered students the opportunity to further grow in their understanding of science concepts and use their knowledge in the context of open-ended problem solving. The design challenge phase of instruction took place second, as a learning extension, and was only one week in duration. As a result, gains during this phase had to be built on the knowledge gains already obtained in the first phase of instruction. As such, large gains during the design challenge phase would be expected to be more difficult to obtain. Gains in knowledge were made during the design challenge phase, however, in declarative and strategic knowledge. Further, the design challenge was particularly successful in eliciting gains in students' understanding of heat conduction in metals (items Str23 and 25) associated with strategic knowledge. Even though the concept of heat conduction in metals was introduced during the first phase of instruction and several models and demonstrations were utilized, gains in science concept knowledge associated with strategic cognitive demand were not statistically significant until after the design challenge phase of instruction. Therefore, the design challenge phase did provide students with the opportunity to construct higher order knowledge associated with the concept of heat conduction in metals such that the students were able to draw on their understanding strategically in novel design based learning situations that pertained to those concepts.

Changes in Concept Knowledge: Conclusions from Qualitative Data Analysis

Conclusion 1. Based on qualitative data analysis it can be concluded that technological/engineering design based teaching approaches fostered students' abilities to express science concept knowledge associated with declarative, procedural, schematic, and strategic cognitive demand. The design portfolio contained two prompts that specifically addressed schematic theories associated with kinetic molecular theory of heat and how metallic bonds contribute to the conduction of heat through metals. The schematic knowledge developed in responding to the prompts associated with theories of heat and conduction in metals most likely contributed to statistically significant gains in strategic knowledge assessments of those concepts between the post-1 and post-2 tests. Further, the design portfolio provided opportunities for students to express knowledge at varying levels of cognitive demand. There was evidence that students utilized strategic knowledge of science concepts to plan the design of their prototypes, make predictions about how their prototypes would function, and to explain their prototypes' performance. The learning activities associated with the design challenge and design portfolio resulted in the development of schematic and strategic knowledge associated with kinetic molecular theory and conduction in metals. Therefore, a design based learning approach accompanied with completion of a design portfolio such as that used in this study can elicit a variety of knowledge and require that students use higher order thinking in the context of open-ended problem solving.

Implications

Results of this study have a number of implications associated with technological/engineering design based learning and design based science instruction specifically. Relatively high mean scores were found on declarative knowledge test items and relatively low mean scores were found on the schematic and strategic knowledge test items. In addition, there was a lack of a statistically significant gain in schematic knowledge between the post-1 and post-2 administration of the test during the design challenge phase. These results may imply that students gain declarative knowledge more readily than knowledge associated with higher schematic and strategic demands. In terms of practical implications associated with structuring curriculum and instructional activities designed to develop declarative, schematic, and strategic understanding of science concepts, students may have needed additional time and learning opportunities to encourage the construction of schematic and strategic knowledge.

Despite evidence for statistically significant gains in science concept knowledge after each instructional phase, the mean scores on the schematic and strategic knowledge items were surprisingly low compared to the mean score on the declarative knowledge items after all test administrations. The disparity in the gains in knowledge of science concepts implies that modifications were needed in either: 1) the learning activities during the design challenge to better develop students' schematic understanding of the mechanism by which thermal insulators function and the direction of heat transfer based on the assessment of quantitative data or 2) the assessment in order to better assess the learning activities that *were* included in the design challenge.

The learning activities associated with the design challenge and design portfolio did result in gains in the mechanism by which metals conduct heat but did not result in the development of schematic and strategic knowledge associated with the direction of heat transfer and the mechanism by which insulators work. Therefore, to address the possible modification needed in the learning activities, prompts could have been added to the design portfolio in the Research, Brainstorming, and Ideation stage that required students to express theoretical and explanatory knowledge of the direction of heat transfer and mechanism by which insulators work in order to encourage the development of a schematic understanding of those concepts. To address the possible modification needed in the assessment, test items could have been aligned to the concepts associated with the prompts in the design portfolio.

Technological/engineering design based learning has been the subject of increasing interest in science education, particularly in light of recommendations to include both inquiry and design in the Next Generation Science Standards. In order to go beyond confirmation level inquiry in which students are merely collecting data to verify relationships between variables that are already known (Appleton, 1995; Barnett, 2005; Doppelt et al., 2008; Fortus et al., 2005), the Next Generation Science Standards (NGSS Lead States, 2013) have endorsed including both science inquiry and engineering design practices in science education. Including engineering design practices in science education increases the opportunity for contextual applications of science concepts and increases the likelihood of students encountering tasks that require knowledge at increasingly higher levels of cognitive demand. Utilizing design portfolios elicits knowledge at varying levels of cognitive demand, increasing the likelihood that students will engage in higher order thinking as they use their understanding of science concepts to frame problems, plan how to address problems, and monitor their progress based on their results of prototype testing. In addition, students have additional opportunities to draw on and utilize concept knowledge strategically in the context of explaining their design choices.

In light of new standardized tests based on Common Core Standards, incorporating portfolio instruments such as the design portfolio incorporated in the curriculum intervention in this study can be both a learning tool and an assessment instrument that necessitates that students think about concepts not only by using declarative knowledge, but also higher order schematic and strategic knowledge. Utilizing a design portfolio, therefore, can be a tool for learning or "design to understand" (Wells, in 2016b, p. 15) as well as an assessment instrument that ensures that learning objectives and concept knowledge are explicitly connected with the design challenge. Such portfolio tools would also be particularly useful for integrative curricula to ensure that concept knowledge from a variety of subjects are explicitly connected to and used in the design activity.

Finally, designing test assessments with questions structured to elicit knowledge at various levels of thinking is a hallmark of the NAEP Science Assessment. However, designing items to assess strategic knowledge is not as easily accomplished, and very few published test items are designed to evoke knowledge associated strategic cognitive demand. A further implication of this study is that developing assessments of higher order thinking that are closely aligned to an open-ended design challenge can be difficult. In order to develop test items, particularly items to assess knowledge associated with strategic cognitive demand, the items must be sufficiently complex, novel, and open-ended (Li, 2001). Published test items that meet those requirements while also maintaining sufficient alignment to the instructional activities are not readily available. Therefore, assessing higher order thinking in design based science requires much from educators, including drawing from a variety assessment tools, such as traditional test assessments and design portfolios, and potentially creating self-developed test items that are sufficiently aligned to concepts while requiring students to utilize their knowledge of science concepts in novel, open-ended situations. The assessment developed in this study could provide a model to educators for developing assessments with items aligned with knowledge associated with declarative, procedural, schematic, and strategic cognitive demand.

Limitations

The limitations and potential threats to the validity of this study included the researcher also functioning as teacher, the case study design, the convenience sample, and time constraints associated with the implementation of instruction and analysis of results. The study was a case study conducted in the classroom of the researcher during the implementation of an approximately three-week long curriculum intervention. Although case study research often involves in-depth observation over an extended period of time (Cresswell, 2007), the limited time over which the study will be implemented somewhat limits data collection. Since the researcher also functioned as the teacher, the opportunity to participate in the curriculum intervention was provided to all students enrolled in each course; therefore, the possibility of structuring the study to make comparisons between groups through an experimental or quasi-experimental design, though perceived as preferable (Campbell & Stanley, 1963), was not possible. Since the study utilized convenience sampling, it was not possible to collect data from a pre-determined demographic of students. Due to these limitations, none of the conclusions generated infer generalizability of the results.

Another major limitation and threat to the validity of the results of this study includes the assumptions of the instructional activities. It was assumed that the conventional/inquiry phase of instruction would provide the basis of knowledge associated with science concepts but that the open-ended nature of the design challenge phase of instruction would provide more of a context and opportunity within which students would construct strategic knowledge. Because of those assumptions and the structure associated with the curriculum intervention, there were most likely inherent approaches and biases associated with the researcher/teacher delivering and guiding instruction that could have contributed to error in and limitations of the validity of the results. Further, conclusions as to which instructional phase students constructed knowledge cannot be conclusively determined.

The test assessment utilized in this study was comprised of items published from other studies. Five items came from Fortus (2003, pp. 149-150); five items from *Holt Science Spectrum* (Dobson, Holman, & Roberts, 2008) (the test bank from the course textbook); two items from Organisation for Economic Co-operation and Development Programme for International Student Assessment [OECD PISA] (2006, p. 48); ten items from Schnittka (2009, pp. 320-321); and one item from Trends in International Mathematics and Science Study [TIMSS] (2011, p. 85). In addition, five of the six open-ended, strategic knowledge test items were developed by the researcher. Although the test items were validated in terms of the cognitive demand construct, those from published resources were deemed reliable only in the context of the populations for which those test items were originally developed. In addition, the reliability and content validity of the five open-ended, strategic knowledge test items was not determined.

Another limitation and threat to the validity of the results in this study includes the assumptions of the coding scheme utilized for content analysis. The coding scheme originally developed by Li (2001) was developed for use in the coding of knowledge evoked by test items as students verbally articulated a response to standardized test items found in the TIMMS science assessment. Therefore, a major limitation and threat to the validity of the results found in this study is the application of the coding scheme in design based learning and in the content analysis of students' written responses in design portfolios.

Another threat to the validity of the results in this study includes the conventions utilized in the co-coding of design portfolios. Content analysis of the design portfolios in this study resulted in the coding of knowledge expressions, such as framing the problem, being coded as strategic knowledge; however, those expressions would not normally be interpreted as strategic knowledge in the context of technological/engineering design based learning activities. The coding of those statements as strategic resulted from conventions agreed upon in the co-coding process. Further, statements that typically would not be considered procedural knowledge in the context of technological/engineering design based learning activities, such as statements associated with interpreting data, were coded as procedural knowledge. Again, those expressions would not normally be coded as procedural in the context of technological/engineering design based learning activities. Therefore, another major limitation in the interpretation of the qualitative results is the error associated with the co-coding process, particularly with regard to the coding of expressions associated with framing the problem as strategic knowledge and coding of expressions associated with data interpretation as procedural knowledge.

Recommendations

Despite students' improved abilities to answer questions and express knowledge of science concepts associated with various cognitive demands in their design portfolios, several statements revealed persistent alternative conceptions. The most frequent alternative conception was represented by expressions that "insulators keep cold from transferring" (Schnittka, 2009, p. 171). Schnittka (2009) did find improvements in students' conceptions relating to this and other alternative conceptions of heat transfer. However, since an assessment of conceptual change was beyond the scope of this study, there is no way to know the extent of these conceptions in this study prior to the design challenge phase. Therefore, one area for further research would be replication of this curriculum intervention with assessment of alternative conceptions based on the methods described in Schnittka (2009).

To understand students' cognitive processes, several researchers have used "think aloud" processes. Li (2001) used such a process to identify the cognitive demand elicited by test questions, and Kelley (2008) used such a process during a design challenge to describe student thinking during design challenges. Although it was not possible to incorporate a think aloud process in this study, further research could focus on utilizing techniques to elucidate student thinking in concert with the cognitive demand framework to learn more about how students think through design challenge tasks that require knowledge at various levels of cognitive demand, declarative, procedural, schematic, and strategic.

The majority of the convenience sample in this study consisted of average and above average students. Additional research is needed to determine how design based learning can be optimized for students with learning support needs. For example, what scaffolds are necessary for learning support students to be able to possess the concept knowledge to go beyond tasks associated with declarative knowledge and respond to tasks associated with schematic and strategic knowledge? Also, how can design challenges be differentiated sufficiently to provide learning support students with the prior knowledge that is so critical in navigating through open-ended problem solving?

The coding scheme utilized in this study resulted in data that were skewed in the areas of procedural and strategic knowledge based on statements that did not necessarily meaningfully reflect those types of knowledge in the context of technological/engineering design based learning and design based science. Therefore, another area of opportunity for further research would be to reexamine and revise the coding scheme for knowledge more appropriately. Perhaps delineating and revising categories for both technological/engineering design and scientific inquiry would provide a better mechanism for assessing students' written expressions of knowledge in the context of design based science.

Finally, another area of opportunity for further research would be in efforts to employ design challenges as an integration tool across subject areas as an interdisciplinary or transdisciplinary unit. Understanding more about models for implementation, how the design portfolio can be utilized to explicitly connect to learning objectives from multiple content areas, and encouraging higher order thinking in multiple content areas would help educators to implement such activities further. In addition, given the interest in STEM education, it would provide a better understanding about enhancing student learning through content integration.

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APPENDICES

Appendix A: Student Thermos Design Challenge

Student Thermos Design Challenge

Your Name:____ Period:______

Summary of Context
The following context is adapted from IEEE (n.d.). *Keep it Cool*. Retrieved from: http://tryengineering.org/lesson-plans/keep-it-cool

Insulation and Vacuums
Insulation is used for many purposes. Insulation is needed to protect fragile items from being damaged during shipping. It is used to keep cold air out of houses in the wintertime, it is used to separate electric wires, and it is used to keep cool items cool and hot items hot in a vacuum flask. Many materials are used as insulation from fabric to moss to plastic to fiberglass to animal skins. In the case of a vacuum flask, a vacuum serves as the insulation. A vacuum is created when a volume of space is essentially empty of matter, usually when air is pumped out. Light bulbs contain a partial vacuum, usually backfilled with argon, which protects the tungsten filament.

Heat Transfer
Heat can transfer in three ways: conduction, convection, and radiation. Conduction is the transfer of heat by direct contact of particles of matter. Metals such as copper, platinum, gold, and iron are usually the best conductors of thermal energy. Convection is the transfer of thermal energy due to the movement of molecules within fluids. Radiation is the transfer of heat energy in electromagnetic waves through empty space.

Vacuum Flasks
Invented in 1892 by Sir James Dewar, a scientist at Oxford University, the "vacuum flask" was first manufactured for commercial use in 1904, when two German glass blowers formed Thermos GmbH. They held a contest to name the "vacuum flask" and a resident of Munich, Germany submitted "Thermos," which came from the Greek word "Therme" meaning "heat." A vacuum flask is a bottle made of metal, glass, or plastic with hollow walls. The narrow region between the inner and outer wall is evacuated of air so it is a vacuum. Using a vacuum as an insulator avoids heat transfer by conduction or convection between the two walls. Radiative heat loss is reduced by applying a reflective coating to the surfaces such as silver.

Of course, the flask needs an opening to add or remove hot or cold liquids. Interestingly the most heat or cold loss happens at the stopper. Originally, the stopper would have been made of cork, with plastic being used later because it was more durable and could be formed in a shape to match the opening. A typical vacuum flask will keep liquid cool for about 24 hours, and warm for up to 8. Some vacuum flasks include a fitted cup, for convenience of use with drinks.

Context
For millennia, human beings have been faced with the challenge of preventing food spoilage and safe storage of food. Some of the ways that human ingenuity has addressed the issue includes drying foods (such as fish and fruits), curing foods in salt to dehydrate them (such as in ham and bacon), freezing foods where the climate allowed, allowing foods to ferment as part of the natural process for developing the food (such as in cheese and sauerkraut), heating fruits with sugar or honey in preserves (such as jam and jelly), and in modern times storing food in iceboxes and eventually refrigerators (Nummer, 2002).

Challenge
You have been asked by Acme Manufacturing Company to design and build a prototype insulating device that will be used to serve as portable storage for a drink. Among the considerations for your device will be the materials to use in each area of the device to prevent heat transfer from conduction, convection, and radiation to the liquid that is to be kept cool.

Criteria
The design specifications for your prototype involve meeting two design criteria:

3. It must keep approximately 400 mL of cold liquid as cool as possible for at least 30 minutes in a room temperature environment.
4. The prototype must be designed in such a way **that the liquid can be poured into the device and can be recovered later from the device without contamination.**

Constraints
In addition, specifications involve the following design constraints:

3. Your team can use only the time allotted during class periods to build your device.
4. The thermometer needs to be able to be placed in the top for the 30 minute test period.
5. Your team can build your device with a combination of the following materials provided in the quantities specified in class: two approximately 433 mL plastic cups, tape, hot glue, scissors, aluminum foil, rubber mulch, cotton balls, newspaper, and/or sand.

Time Requirements

1. Approximately 3 weeks for the entire unit
2. Time provided for each lesson: 42 minutes

PROBLEM IDENTIFICATION

Design Portfolio Task 1

1. Problem Identification: What is the problem to be addressed in the design challenge? Each student will write a description of the problem including:
   - a description of the need
   - introduction and background about context
   - a statement of the design challenge
   - the design specifications including *criteria* and *constraints*.
   - what additional information you need to know in order to accomplish the design challenge.

BRAINSTORMING, RESEARCH, AND IDEATION

Brainstorming and Research: What do you know about the design challenge?

Design Portfolio Task 1

KMT, Temperature, and Thermal Equilibrium

2. Write a paragraph (5-6 lines or more) describing what you have learned about each of the following concepts and **how they may affect or be affected by the problem identified in the design challenge:**
   - Kinetic Molecular Theory
   - Temperature (Fahrenheit, Celsius, and Kelvin temperature scales)
   - Thermal equilibrium

Design Portfolio Task 2
Conduction, Convection, and Radiation Heat Transfer

3. Write a paragraph (5-6 lines or more) describing what you have learned about each of the following concepts and **how they may affect or be affected by the problem identified in the design challenge:**
   - Conduction
   - Convection
   - Radiation
   - The states of matter through which the processes above occur
   - The predominant (main) direction of heat transfer through and between substances at different temperatures

Design Portfolio Task 3
Results from Cold Stuff Lab Materials Tests

4. Make two lists of the materials from our materials: 1) Good Thermal Conductors and 2) Good Thermal Insulators

5. In addition, each group will create two lists, one of materials that are good conductors and one of materials that are good insulators. With each list, groups will be prompted to add a written paragraph description of the structure of the atoms in thermal conductors (including metals) and a written description of the structure of atoms in thermal insulators based on the class simulations.

<u>List sources of information here :</u>

Materials that are Good Conductors of Thermal Energy:	Materials that are Good Insulators of Thermal Energy:

Description of the atoms in thermal conductors (including metals):	Description of the atoms in thermal insulators:
Drawing of the atoms in thermal conductors (including metals):	Drawing of the atoms in thermal insulators:

EXPLORE POSSIBILITIES AND GENERATE SOLUTIONS

Design Portfolio Task 4

What are some possible designs for an insulating device?

6. Given the materials that are available to the teams, each member of the group will be tasked with drawing a potential design for the prototype.

Individual Design Solution Drawing with Labels:

7. Along with the drawing, each member will develop a written paragraph describing the features of the prototype design that could affect its performance, such as:
   - the materials used
   - size of the device
   - the placement of the materials, etc.

SELECT FINAL SOLUTION AND CREATE THE PROTOTYPE

Design Portfolio Task 5

8. Team Design – Collectively develop one final team design and draw it below.

Team Design Solution Drawing with Labels:

9. Team members should describe the recommendations from each group member that played a part in the design:

10. Each team member will write a paragraph (5-6 lines or more) “argument” or “selling points” about the features associated with their team design that could affect its performance for preventing heat transfer and how they relate to the team design:

Design Portfolio Task 6
Create the Prototype: How will your team build the prototype?
Build your device.
11. Describe any issues you encountered during the building of your prototype:

12. Observe, measure, and record quantitative and qualitative information about their prototype in the table below:

Quantitative Data about your prototype (include appropriate units where measurements are used):	Qualitative Data about your prototype:

TEST AND EVALUATE
Design Portfolio Task 7
Prototype Test and Data Analysis

Time	Temperature	Notes
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13. What is the independent variable to be tested?

14. What is the dependent variable that will respond to the independent variable?

15. How will the dependent variable be measured (tools and scale to measure)?

16. What are the constants associated with the test?

17. What should the control be for the tests?

18. Conclusion: Describe the direction of heat transfer during thermos test and the performance of your group's prototype based on the team's results.

19. Graphing Task on Separate Graph Paper: Each team member should graph the data with appropriate title, axes labels, and units. Use a line of best fit to connect the data points in the scatter plot. Also graph the control data. Use a color-coding system to distinguish between lines. Include a key.

REFINE AND REDESIGN

Design Portfolio Task 8
Refining the Design
20. Describe what was successful about your design in terms of how you met the design criteria:

21. What could be improved about your design in terms of what you failed to meet in the design criteria?

22. Describe what you would change about your design to better meet the design criteria:

Appendix B: Heat Transfer Curriculum Unit

Curriculum Area: Grade 8 Physical Science

Applicable PA Science, Technology, and Engineering Academic Standards and Assessment Anchors:

Standard - 3.2.8.B4: Compare and contrast atomic properties of conductors and insulators.
Assessment Anchor - S8.A.2: Processes, Procedures, and Tools of Scientific Investigations
Anchor Descriptor - S8.A.2.1: Apply knowledge of scientific investigation or technological design in different contexts to make inferences to solve problems.
S8.A.2.1.1: Use evidence, observations, or a variety of scales (e.g., mass, distance, volume, temperature) to describe relationships.
S8.A.2.1.4 Interpret data/observations; develop relationships among variables based on data/observations to design models as solutions.
Anchor Descriptor - S8.A.3.2: Apply knowledge of models to make predictions, draw inferences, or explain technological concepts.
S8.A.3.2.2: Describe how engineers use models to develop new and improved technologies to solve problems.
Assessment Anchor - S8.C.2: Forms, Sources, Conversion, and Transfer of Energy
Anchor Descriptor - S8.C.2.1: Describe energy sources, transfer of energy, or conversion of energy.
S8.C.2.1.1: Distinguish among forms of energy (e.g., electrical, mechanical, chemical, light, sound, nuclear) and sources of energy (i.e., renewable and nonrenewable energy)
S8.C.2.1.2: Explain how energy is transferred from one place to another through convection, conduction, or radiation.

Applicable Next Generation Science Performance Standards:

MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.* [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup.] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.]
MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. [Clarification Statement: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.]
MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object. [Clarification Statement: Examples of empirical evidence used in arguments could include an inventory or other representation of the energy before and after the transfer in the form of temperature changes or motion of object.] [Assessment Boundary: Assessment does not include calculations of energy.]

MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [Clarification Statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.] [Assessment Boundary: Assessment is limited to qualitative applications pertaining to light and mechanical waves.]
MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Potential alternative conceptions about heat transfer to address:
Alternative conceptions relating to heat transfer that are explicitly addressed in the unit are 1-7 below from Schnittka (2009, p. 171):
Schnittka, 2009, p. 171:
1. Cold transfers in from cold to warm
2. Insulators generate heat
3. Insulators are warm, metal is cold
4. Insulators keep cold from transferring
5. Metal traps or absorbs cold
6. Heat is always warm or hot
7. Heat and temperature are equivalent
8. Heat always rises
9. Dark objects attract heat

Overall/Main Learning Objectives (SWBAT):
1. Identify and describe the term heat; what temperature measures; and the processes of heat transfer through conduction, convection, and radiation.
    - Assessed through responses to design portfolio prompts and on pre/post/post content knowledge test
    - Webb's DOK Level 1
    - NAEP Science Framework Declarative Cognitive Demand
2. Describe the direction of heat transfer (implied from 1st Law of Thermodynamics) from a hotter to a colder object.
    - Assessed through responses to design portfolio prompts and on pre/post/post content knowledge test
    - Webb's DOK Level 1
    - NAEP Science Framework – Declarative Cognitive Demand
3. Distinguish between good insulating materials and good conducting materials.

- Assessed through responses to design portfolio prompts and on pre/post/post content knowledge test
- Webb's DOK Level 2
- NAEP Science Framework – Declarative Cognitive Demand

4. Explain why, in terms of kinetic molecular theory, some materials are better insulators (preventing heat transfer) or better conductors (allowing heat transfer) than others.
   - Assessed through responses to design portfolio prompts and on pre/post/post content knowledge test
   - Webb's DOK Level 3
   - NAEP Science Framework Schematic Cognitive Demand
5. Determine the most appropriate temperature scale to use, the independent and dependent variables, the constants, and the control associated with testing an insulating device.
   - Assessed through responses to design portfolio prompts
   - Webb's DOK Level 1
   - NAEP Science Framework Procedural Cognitive Demand associated with science inquiry
6. Graph results from data collected from the testing of an insulating device.
   - Assessed through graph in portfolio
   - Webb's DOK Level 2
   - NAEP Science Framework Procedural Cognitive Demand associated with science inquiry
7. Use an understanding of the concepts related to heat transfer to develop a justification for choosing the best solution for preventing heat transfer.
   - Assessed through design portfolio prompts and pre/post/post content knowledge test
   - Webb's DOK Level 3
   - NAEP Science Framework Strategic Cognitive Demand
8. Use an understanding of the concepts related to heat transfer to design a technological device to prevent heat transfer.
   - Assessed through responses to design portfolio prompts
   - Webb's DOK Level 4
   - NAEP Science Framework Procedural Cognitive Demand associated with technological design
   - NAEP Science Framework – Strategic Cognitive Demand

Lesson Sequence

Required Prerequisite Knowledge, Lessons, DBL Portfolio Elements and Evaluation

Pre-requisite knowledge – In a previous unit and associated lessons, students will have been introduced to the topics of the nature of science and science inquiry, the nature of technology and technological design, independent and dependent variables, constants, controls, graphing, matter (atoms, molecules, and compounds), energy, and density. Students will have also experienced design-based learning and developed a T/E DBL portfolio with the same elements as those included in this unit during the pilot test and a straw rocket design challenge.

<u>Pre-test to be administered prior to the first day of instruction</u>

Lesson 1: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured? Students will be introduced to the concepts of heat, temperature, and temperature scales. During the activities, students will take notes with Frayer models (Fryer, Frederick, and Klausmeier, 1969). Thermal energy is the amount of thermal kinetic energy (motion) of the particles (subatomic particles, atoms, and molecules). Heat is the term that characterizes the flow of kinetic energy between substances; therefore, "heat" is not just a substance at a high temperature. Heat transfers from an area of high temperature to an area of low temperature until all of the particles of the substance have approximately the same kinetic energy (thermal equilibrium). Temperature is a measure of the average kinetic energy of the particles in a substance. There are three temperature scales commonly used and each is based on different reference points. The Celsius temperature scale is the SI scale used in science. Lesson will include materials from the following resource (Caltech, 2013): http://coolcosmos.ipac.caltech.edu/page/lesson_moving_molecules

- Learning Objective: 1
- Alternative Conceptions: 1, 6, 7

Lesson 2: Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter?
Whole class demonstration – set up ice cubes of the same size, one in metal spoon and one in plastic spoon and observer the rate of ice cube melting to address alternative conception (#5) about heat transfer (Schnittka, 2009). Predictions are made about rate of melting and discussion about mechanism causing the melting activates prior knowledge.

Whole class demonstration – ask students to feel two trays, one made of metal and the other of plastic under which aquarium thermometers have been affixed. Ask students to predict the temperature of each tray. Reveal the temperature of the trays and have discussion about why one feels colder to address alternative conception (#3) about heat transfer (Schnittka, 2009).

Students will be introduced to the processes of heat transfer through conduction, convection, and radiation and the states of matter through which those processes occur. During the activities, students will take notes with Frayer models (Fryer, Frederick, and Klausmeier, 1969). Conduction is the process of heat transfer when particles come into direct contact with each other and can occur in solids, liquids and gases. Convection is the process of heat transfer that occurs by currents of flowing particles through fluids (liquids and gases) caused by the differences in the densities of the particles at various temperatures. Radiation is the process of heat transfer through waves of radiation primarily in the infrared range when electrons in high energy levels go back to their ground state. Radiation does not require a medium to travel through. Lesson will include an animated demonstration developed by Jarvis and Simonson (2013), available at: http://www.wisc-online.com/Objects/ViewObject.aspx?ID=sce304

- Learning Objectives: 1, 2
- Alternative Conceptions Addressed: 3, 5

Lesson 3: Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?

Student groups will choose a material to test (steel wool, aluminum foil, newspaper, cotton balls, or rubber mulch) and test those materials by placing them inside a cup inside a pitcher of ice water. Temperature of the material will be taken every minute for approximately 20 minutes. Results will be pooled and graphed. Activity is based on "Cold Stuff" lab (Jefferson Lab, n.d.).

Results from the materials tests will be reviewed. Review will be undertaken of conduction through solids and why heat transfers as movement through some solids better than through others, facilitated by classroom activity to model the structure of atoms and electrons in a good conductor and in a good insulator utilizing students as atoms and balloons as electrons.
After viewing animation of the "sea of electrons" in metals from University of Cambridge (2004-2015) available from: http://www.doitpoms.ac.uk/tlplib/thermal_electrical/metal_thermal.php
Each group will develop a model of the structure of thermal conduction in metals utilizing students as atoms and balloons as electrons. Activity adapted from Whys Guys (n.d.) available from: http://www.cedarville.edu/personal/lee/project/demos/demo-sim-metallic-bond.pdf

- Learning Objectives: 3, 4
- Alternative Conception Addressed: 2, 4

<u>Post-test 1 to be administered after Lesson 3</u>

PROBLEM IDENTIFICATION
Lesson 4: Problem Identification: What is the problem to be addressed in the design challenge? Students will be introduced to the design challenge verbally according to the challenge statement above. Students will be introduced to the materials that they will have available to complete the challenge. Students will set up DBL Portfolio Elements (as per Wells Technological/Engineering Design Process: Portfolio Elements, 2012).
Design Portfolio Task: Problem Statement – Each student will write a description of the problem including a description of the need, introduction and background about context, a statement of the design challenge, and the design specifications including criteria and constraints. Students will also write a statement about what additional information they need to know in order to accomplish the design challenge.

- Learning Objective: 8 (associated with technological design)

BRAINSTORMING, RESEARCH, AND IDEATION
Lesson 5: Brainstorming and Research: What do you know about the design challenge? This lesson will consist of a combination of individual student writing, pair sharing, and whole group sharing of ideas about concepts learned and how they pertain to the design challenge.
Design Portfolio Task: KMT, Temperature, and Thermal Equilibrium – Each student will write a paragraph describing what they have learned about each of the following concepts and how they may affect or be affected by the problem identified in the design challenge: Kinetic Molecular Theory; temperature; Fahrenheit, Celsius, and Kelvin temperature scales; and thermal equilibrium.

- Learning Objective: 1
- Alternative Conceptions: 1, 6, 7

Design Portfolio Task: Conduction, Convection, and Radiation Heat Transfer – Each student will write a paragraph describing what they have learned about each of the following concepts and how they may affect or be affected by the problem identified in the design challenge: conduction, convection, radiation, the states of matter through which those processes occur, and the predominant direction of heat transfer through and between substances at different temperatures.

- Learning Objectives: 1, 2
- Alternative Conceptions Addressed: 3, 5

Design Portfolio Task: Materials that are Good Thermal Conductors and Good Thermal Insulators – Each student will write a paragraph about the results of their materials tests and how the results may affect the problem identified in the design challenge. In addition, each group will create two lists, one of materials that are good conductors and one of materials that are good insulators. With each list, groups will be prompted to add a written paragraph description of the structure of the atoms in thermal conductors (including metals) and a written description of the structure of atoms in thermal insulators based on the class simulations.

- Learning Objectives: 3, 4
- Alternative Conception Addressed: 2, 4

EXPLORE POSSIBILITIES AND GENERATE SOLUTIONS

Lesson 6: Potential Design Solutions: What are some possible designs for an insulating device? Given the materials that are available to the teams, each member of the group will be tasked with drawing a potential design for the prototype. Along with the drawing, each member will develop a written paragraph describing the features associated with the prototype design that could affect its performance, such as the materials used, size of the device, the placement of the materials, etc. Use the following words in the description: “heat transfer, conduction, convection, and radiation.”

Design Portfolio Task: Potential Design Solutions Summary – Each team member will develop a drawing and description of a solution. Each group member will write a paragraph description about the features associated with their individual prototype design that could affect its performance for preventing heat transfer and how they relate to the design.

- Learning Objectives: 7, 8

SELECT FINAL SOLUTION AND CREATE THE PROTOTYPE

Lesson 7: Generate a Team Solution: What type of device will your team build and why? Teams will collectively develop one final team design. Use an understanding of the concepts of conduction, convection, radiation, and thermal equilibrium to develop an argument for choosing the best solution for preventing heat transfer from among the team’s alternative design prototypes.

Design Portfolio Task: Team Design – Each group will develop a final design solution drawing. Team members should describe the recommendations from each group member that played a part in the design. Each team member will write a paragraph “argument” or “selling points” about the features associated with their team design that could affect its performance for preventing heat transfer and how they relate to the team design.

- Learning Objectives: 7, 8

Lesson 8: Create the Prototype: How will your team build the prototype? Materials available to each team will include two 20 oz. clear plastic cups, rubber mulch, newspaper, cotton balls, steel wool, aluminum foil, tape, scissors, and thermometer.

Design Portfolio Task: Creating the Prototype – Teams will describe any issues they encountered during the building of their prototypes. Teams will observe, measure, and record quantitative and qualitative information about their prototype.

- Learning Objective: 8

TEST AND EVALUATE

Lesson 9: Test the Prototype: How will your prototype perform? After the elements of the tests are described in portfolio (as indicated below), approximately 400 mL of water at approximately 4ºC will be added to each device. The initial temperature of the water will be recorded and temperature readings from the water will be recorded every two minutes for 30 minutes. Graphs of the results will be developed (electronically or by hand) with an appropriate title, labels, and units.

Design Portfolio Task: Prototype Test and Data Analysis – Each team will describe the independent variable to be tested, the dependent variable that will respond to the independent variable, how the dependent variable should be measured (tools and scale to measure), the constants associated with the test, and the control that should be utilized in the test. Data will be recorded in a data table with appropriate units. Graph the data with appropriate title, axes labels, and units. A conclusion will be written to describe the direction of heat transfer during thermos test and the performance of the group's prototype based on the team's results.

- Learning Objectives: 5, 6

REFINE AND REDESIGN

Lesson 10: Refining the Design: What changes should be made to your team's design? Reexamine the design criteria and describe how the prototype should be changed if your team were given the chance to redesign it.

Design Portfolio Task: Refining the Design – Describe what was successful about your design in terms of how you met the design criteria and what could be improved about your design in terms of what you failed to meet in the design criteria. Describe what you would change about your design to better meet the design criteria.

- Learning Objectives: 7, 8

<u>Post-test 2 administered after Lesson 10</u>

Appendix C: Pre/Post-1/Post-2 Test

Declarative Questions Section

D1. Heat conduction is:

a. the transfer of thermal energy from one place to another by a moving gas.
b. the transfer of thermal energy from one place to another inside a solid body.
c. the effect of heat on electric conduction inside a body.
d. the heat necessary in order to raise the temperature of a body by 1°C.

(Fortus, 2003, p. 149)
Learning Objective: 1
Lesson 2: Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter?

D2. Which of these is <u>not</u> a mechanism of heat transfer to be considered when designing the thermal isolation of an arctic hut?

a. Heat conduction.
b. Heat convection.
c. Radiation.
d. Temperature reduction.

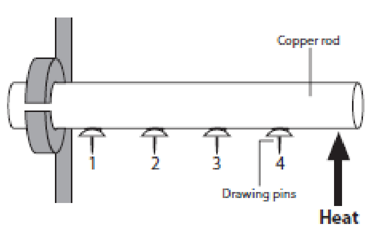
(Fortus, 2003, p. 149)
Learning Objective: 1
Lesson 2: Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter?

D3. An object's temperature is proportional to the:

a. average kinetic energy per molecule.
b. heat lost or gained by the object.
c. energy transferred to the object.
d. thermal conductivity of the object.

(Fortus, 2003, p. 149)
Learning Objective: 1
Lesson 1: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?

D4. A student attaches four drawing pins to a copper rod using candle wax as shown in the diagram. The rod is then heated continuously at one end and the pins fall off in the order 4, 3, 2, 1.



By which process does the heat reach the pins?

a. expansion
b. radiation
c. conduction
d. convection

(Trends in International Mathematics and Science Study [TIMSS], 2011, p. 85)
Learning Objective: 1
Lesson 2: Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter?

D5. The energy transferred between objects at different temperatures is

a. matter
b. heat
c. potential
d. cold

(Holt Science Spectrum, 2008)
Learning Objective: 1
Lesson 1: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?

D6. Heat always moves from an object of _____ temperature to an object of _____ temperature.

a. moderate, high
b. higher, lower
c. lower, higher
d. zero, high

(Holt Science Spectrum, 2008)
Learning Objective: 2
Lesson 1: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?

D7. As the kinetic energy (movement) of the molecules in a substance increases, the

a. temperature of the substance increases.
b. temperature of the substance decreases.
c. potential energy of the substance changes.
d. temperature remains the same.

(Holt Science Spectrum, 2008)
Learning Objective: 1
Lesson 1: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?

D8. The transfer of energy by the movement of liquids or gases with different temperatures is called

a. convection
b. conduction
c. contact

d. radiation

(Holt Science Spectrum, 2008)
Learning Objective: 1
Lesson 2: Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter?

D9. Which of the following substances is the best conductor of transferring energy as heat?

a. carbon dioxide gas
b. liquid water
c. iron metal
d. rubber

(Holt Science Spectrum, 2008)
Learning Objective: 3
Lesson 3: Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?

Schematic Questions Section

Sch10. You pick up a can of soda off of the countertop. The countertop underneath the can feels colder than the rest of the counter. Which explanation do you think is the best?

a. The cold has been transferred from the soda to the counter.
b. There is no heat energy left in the counter beneath the can.
c. Some heat has been transferred from the counter to the soda.
d. The heat beneath the can moves away into other parts of the countertop.

(Schnittka, 2009, p. 320)
Learning Objective: 2
Lesson 1: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?

Sch11. After cooking an egg in boiling water, you cool the egg by putting it into a bowl of cold water. Which of the following explains the egg's cooling process?

a. Temperature is transferred from the egg to the water.
b. Cold moves from the water into the egg.
c. Energy is transferred from the water to the egg.
d. Energy is transferred from the egg to the water.

(Adapted from Schnittka, 2009, p. 320)
Learning Objective: 2
Lesson 1: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?

Sch12. Why do we wear sweaters in cold weather?

a. To keep cold out.
b. To generate heat.
c. To reduce heat loss.
d. All of the above.

(Schnittka, 2009, p. 320)

Learning Objective: 4
Lesson 3: Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?

Sch13. Amy wraps her dolls in blankets but can't understand why they don't warm up. Why don't they warm up?

a. The blankets she uses are probably poor insulators.
b. The blankets she uses are probably poor conductors.
c. The dolls are made of materials that don't hold heat well.
d. None of the above.

(Schnittka, 2009, p. 320)
Learning Objective: 4
Lesson 3: Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?

Sch14. As water in a freezer turns into ice,

a. the water absorbs energy from the air in the freezer.
b. the water absorbs the coldness from the air in the freezer.
c. the freezer air absorbs heat from the water.
d. the water neither absorbs nor releases energy

(Schnittka, 2009, p. 320)
Learning Objective: 2
Lesson 1: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?

Sch15. If you put a metal spoon and a wooden spoon into a pot of boiling water, one will become too hot to touch. Why?

a. Metals conduct heat better than wood.
b. Wood conducts heat better than metals.
c. Metals pull in heat because heat is attracted to metals.
d. Wood isn't as strong as metals.

(Schnittka, 2009, p. 320)
Learning Objective: 3
Lesson 3: Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?

Sch16. On a sunny day, the upstairs rooms in a house are usually hotter than the downstairs rooms. Why?

a. Cool air is less dense than hot air.
b. **Warm air is less dense and rises and cool air is more dense and sinks**
c. The upstairs rooms are closer to the sun.
d. Heat rises.

(Schnittka, 2009, p. 321)
Learning Objective: 1

Lesson 2: Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter?

Sch17. When you hold a metal coat hanger in a camp fire to roast a marshmallow, the coat hanger might get too hot to hold. Why might the coat hanger get too hot?

a. The heat radiates along the coat hanger.
b. The heat builds up near the flame until it can't hold it anymore and then moves along the coat hanger.
c. Metal atoms vibrate with more energy when they get hot, and they collide with atoms near them, which makes the neighboring atoms vibrate too.
d. Since metals melt in fire, they react very strongly to fire and get hot easily.

(Schnittka, 2009, p. 321)
Learning Objective: 4
Lesson 3: Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?

Sch18. An aluminum plate and a plastic plate have been in the freezer all night long. When you remove them the next morning,

a. The plates have the same temperature.
b. The plastic plate has a higher temperature.
c. The plastic plate has a lower temperature.
d. The aluminum plate has a lower temperature.

(Schnittka, 2009, p. 321)
Learning Objective: 1
Lesson 2: Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter?

Sch19. A material that insulates well in cold weather will:

a. not insulate well in hot weather.
b. insulate well in hot weather.
c. have a very high density.
d. always be a good structural material.

(Fortus, 2003, p. 149)
Learning Objective: 4
Lesson 3: Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?

Sch20. For drinks during the day, Peter has a cup of hot coffee, at a temperature of about 90 ºC, and a cup of cold mineral water, with a temperature of about 5 ºC. The cups are of identical type and size and the volume of each drink is the same. Peter leaves the cups sitting in a room where the temperature is about 20 ºC. What are the temperatures of the **coffee** and the **mineral water** likely to be after 10 minutes?

a. 70 ºC and 10 ºC
b. 90 ºC and 5 ºC
c. 70 ºC and 25 ºC

d. 20 ºC and 20 ºC

(OECD PISA, 2006, p. 48)
Learning Objective: 2
Lesson 1: Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?
Lesson 2: Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter

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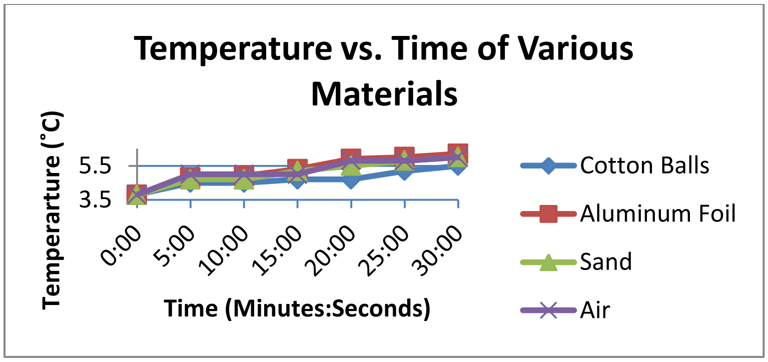
Strategic Questions Section



Using the data displayed in the graph above, please answer the questions 21-23 in complete sentences. Be sure to explain your reasoning.
Learning Objectives: 3, 4, 7, 8
Strategic Cognitive Demand (also requires Procedural Cognitive Demand)
Lesson 3: Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?
Lesson 5: Brainstorming and Research: What do you know about the design challenge?
Lesson 10: Refining the Design: What changes should be made to your team's design?

Str21. If you were designing a box for a pizza delivery company to keep hot pizza warm:

- Which material from the 4 choices in the graph above would you use in the box?
- Describe at least 3 reasons why you would choose that material.

Str22. If you were designing a heating pad to soothe aching muscles and needed to fill the pad:

- Which material from the 4 choices in the graph above would you use to fill the heating pad?
- Describe at least 3 reasons why you would choose that material.

Str23. If you were on a camping trip, ran out of fuel, and wanted to cook with the sun:

- Which material from the 4 choices in the graph above would you use to cook with the sun?
- Describe at least 3 reasons why you would choose that material.

Str24. You have a can of soda in your lunchbox that you want to keep cold. You have the following materials to possibly use: aluminum foil, paper towels, wax paper, and a wool sweater.
(Adapted from Schnittka, 2009, p. 321)
Learning Objective: 3, 4, 7, 8
Lesson 3: Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?
Lesson 5: Brainstorming and Research: What do you know about the design challenge?
Lesson 10: Refining the Design: What changes should be made to your team's design?

- Which material would be best to use to keep your soda cold?

- Describe at least 3 reasons why you would choose that material.

Str25. Imagine that you were working on repairs to a house on a 90 ºF day. At lunch time, you have some left over materials and would like to leave them in your car while you go to lunch. The materials are: a bottle of water, some metal nails, and a piece of wood.
(Adapted from Organisation for Economic Co-operation Programme for International Student Assessment [OECD PISA], 2006, p. 48)
Learning Objective: 1, 7
Lesson 3: Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?
Lesson 5: Brainstorming and Research: What do you know about the design challenge?
Lesson 10: Refining the Design: What changes should be made to your team's design?

- After lunch, which of the material(s) might be too hot to handle if left in the car while you go to lunch?

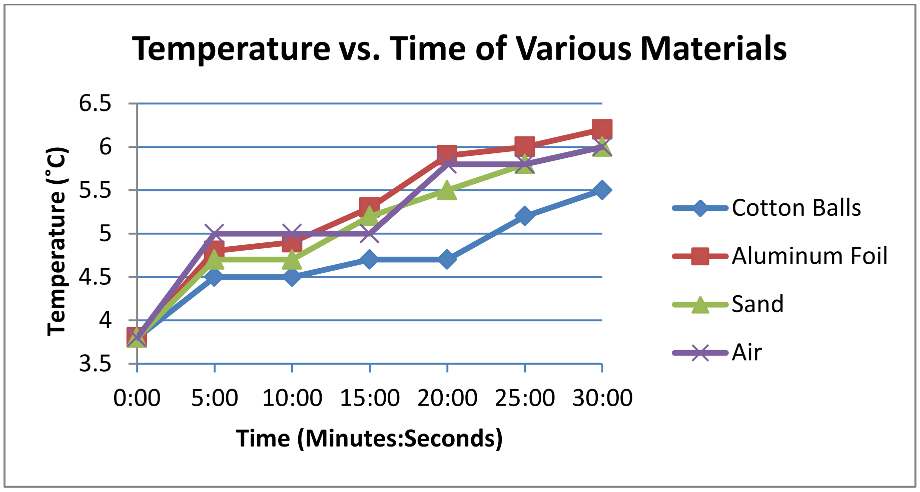
- Describe at least 3 reasons why the material(s) might be too hot to handle if left in the car while you go to lunch.

Str26. If you were a home owner, describe at least 2 reasons why you would want to have tightly closed windows in cold climates.

(Adapted from Fortus, 2003, p. 150)
Learning Objective: 2, 7
Strategic Cognitive Demand
Lesson 2: Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter?
Lesson 5: Brainstorming and Research: What do you know about the design challenge?
Lesson 10: Refining the Design: What changes should be made to your team's design?

Appendix D: Scoring of Test Items

Each multiple choice question worth one point.



Open-ended question worth four points:
Str21. Designing a box for a pizza delivery company to keep hot pizza warm:

a. Which material would you use in the box?
   i. Acceptable answer (1 point): cotton balls or sand
b. Describe why you would choose the material. Acceptable answer should include any 3 of the following components (3 points):
   i. The graph shows that cotton balls and sand have the smallest temperature gain over the 30 minutes.
   ii. Cotton balls and sand are the least conductive.
   iii. Cottons balls and sand are the best insulators.
   iv. The molecular structure of the cotton balls and sand makes them least able to transfer heat energy while being able to conform to the box shape.

Str22. Designing a heating pad to soothe sore muscles:

a. Which material would you use to fill the heating pad?
   i. Acceptable answer (1 point): sand
b. Describe why you would choose the material. Acceptable answer should include any 3 of the following components (3 points)
   i. The graph shows that sand heats up quickly.
   ii. Sand retains heat once it is heated up due to its molecular structure.
   iii. Sand would transfer continuous heat to the muscles.
   iv. Sand would be able to conform to the shape of the muscles.

Str23. Designing a device to cook with the sun:

a. Which material would you choose to cook with radiation from the sun?
    i. Acceptable answer (1 point): aluminum foil
b. Describe why you would choose the material. Acceptable answer should include any 3 of the following components (3 points)
    i. The graph shows that aluminum foil heats up very quickly.
    ii. Aluminum foil is very conductive.
    iii. Aluminum foil is a poor insulator.
    iv. The molecular structure of the aluminum foil makes it able to reflect radiation to the food while being able to be shaped into whatever size is needed to hold the food.
    v. The molecular structure of the aluminum foil makes it able to conduct heat to the food while being able to be shaped into whatever size is needed to hold the food.

Str24. You have a can of soda in your lunchbox that you want to keep cold. You have the following materials to possibly use: aluminum foil, paper towels, wax paper, and a wool sweater.

a. Which material would be best to use to keep your soda cold?
    i. Acceptable answer (1 point): The wool sweater
b. Describe at least 3 reasons why you would choose that material. Acceptable answer should include any of the 3 following components (3 points)
    i. The wool sweater does not heat up very quickly.
    ii. The wool sweater is the least conductive material.
    iii. The wool sweater is the best insulating material.
    iv. The molecular structure of the wool sweater makes it least able to transfer heat to the can of soda.

Str25. Imagine that you were working on repairs to an old house on a 90 ºF day. At lunch time, you have some left over materials and would like to leave them in your car while you go to lunch. The materials are: a bottle of water, some metal nails, and a piece of wood. (Adapted from Organisation for Economic Co-operation Programme for International Student Assessment [OECD PISA], 2006, p. 48)

a. After lunch, which of the material(s) might be too hot to handle if left in the care while you go to lunch?
    i. Acceptable answer: the metal nails
b. Describe at least 3 reasons why the material(s) might be too hot to handle after being in the care while you go to lunch. Acceptable answer should include any of the 3 following components (3 points)
    i. The metal nails will heat up very quickly.
    ii. The metal nails are very good conductors of heat.
    iii. The metal nails would conduct heat to your hand if they are handled.
    iv. The metal nails are poor insulators.
    v. The molecular structure of the metal nails makes them very good at transferring heat to your hand if they are handled.

Str26. Open-ended question worth four points: If you were a home owner, describe at least 2 reasons why you would want to have tightly closed windows in cold climates. (Adapted from Fortus, 2003, p. 150)

a. The air outside is colder than inside, or, The air inside is warmer than outside. (2 points)
b. The thermal energy from the inside will be transferred predominantly from the inside to the outside (undesirable) (2 points)
c. Opening windows lets colder outside air in (undesirable). (2 points)

Appendix E: Content Analysis Data Collection Instrument

	Highlighting Key:	Declarative	Procedural	Schematic	Strategic	
Student Code Number	Page Number	Portfolio Prompt	Enter Student's Phrase	Select Knowledge Type	Select Knowledge Subtype	Code

Appendix F: IRB Approval

VirginiaTech

Office of Research Compliance
Institutional Review Board
North End Center, Suite 4120, Virginia Tech
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE: January 5, 2016

TO: John Wells, Allison Felix

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires July 29, 2020)

PROTOCOL TITLE: Design Based Science and Higher Order Thinking

IRB NUMBER: **15-1187**

Effective January 5, 2016, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the New Application 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:	**January 5, 2016**
Protocol Expiration Date:	**January 4, 2017**
Continuing Review Due Date*:	**December 21, 2016**

*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.

Invent the Future

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Appendix G: Content Analysis Training for Coders

Below is a table describing the lessons in the lesson and the corresponding student design portfolio prompt tasks.

Lessons and Corresponding Preliminary Design Portfolio Prompts

Lesson	Design Portfolio Prompt
Kinetic Molecular Theory, Temperature, and Thermal Equilibrium: What is heat and how is it measured?	Design Portfolio Task 1: Background Information on KMT, Temperature, and Thermal Equilibrium – Each student will write a paragraph describing what they have learned about each of the following concepts: Kinetic Molecular Theory; temperature; Fahrenheit, Celsius, and Kelvin temperature scales; and thermal equilibrium.
Introduction to Heat Transfer: How does thermal kinetic energy move through different types of matter?	Design Portfolio Task 2: Background Information on Conduction, Convection, and Radiation Heat Transfer – Each student will add to the background information a written paragraph description of the processes of conduction, convection, and radiation, and the states of matter through which those processes occur. Students will also describe the direction of heat transfer through a substance and between substances.
Kinetic Molecular Theory and Conduction: Why are some materials insulators and some conductors of heat?	Design Portfolio Task 3: Results from Tests and Research of Materials that are Good Thermal Conductors and Materials that are Good Thermal Insulators – Students will write a paragraph conclusion about their materials tests including the direction of heat transfer during the tests and how their chosen material performed. To further research materials, groups will create two lists, one of materials that are good conductors and one of materials that are good insulators. With each list, groups will be prompted to add a written paragraph description of the structure of the atoms in thermal conductors (including metals) and a written description of the structure of atoms in thermal insulators based on the class simulations.

Problem Identification: What is the problem to be addressed in the design challenge?	Design Portfolio Task 4: Problem Statement – Each student writes a preliminary description of the problem including a problem statement with preliminary introduction and background, a statement of the design challenge, and the design specifications including criteria and constraints. Students will also write a statement about what additional information they need to know in order to accomplish the design challenge.
Potential Design Solutions: What are some possible designs for an insulating device?	Design Portfolio Task 5: Potential Design Solutions Summary – Each member's drawing and description will be scanned and included in the design portfolio. Each group member will write a paragraph description about the features associated with their individual prototype design that could affect its performance for preventing heat transfer and how they relate to the design.
Generate a Team Solution: What type of device will your team build and why?	Design Portfolio Task 6: Team Design – The final design drawing will be scanned and included in the design portfolio. Team members should describe the recommendations from each group member that played a part in the design. Each team member will write a paragraph "argument" or "selling points" about the features associated with their team design that could affect its performance for preventing heat transfer and how they relate to the design.
Create the Prototype: How will your team build the prototype?	Design Portfolio Task 7: Creating the Prototype – Teams will describe any issues they encountered during the building of their prototypes. Teams will observe, measure, and record quantitative and qualitative information about their prototype.

Test the Prototype: How will your prototype perform?	Design Portfolio Task 8: Prototype Test and Data Analysis – Each team will describe the independent variable to be tested, the dependent variable that will respond to the independent variable, how the dependent variable should be measured (tools and scale to measure), the constants associated with the test, and the control that should be utilized in the test. Data will be recorded in a data table with appropriate units. Graph the data with appropriate title, axes labels, and units. A conclusion will be written to describe the direction of heat transfer during thermos test and the performance of the group's prototype based on the team's results.
Refining the Design: What changes should be made to your team's design?	Design Portfolio Task 9: Refining the Design – Describe what was successful about your design in terms of how you met the design criteria and what could be improved about your design in terms of what you failed to meet in the design criteria. Describe what you would change about your design to better meet the design criteria.

Declarative, Procedural, Schematic, and Strategic Cognitive Demand (NAGB, 2014, p. 88)

"Knowing that" refers to declarative knowledge. This cognitive demand sets up the expectation that students should know and reason with basic science facts, concepts, and principles (e.g., density is mass per unit volume) and that they should be able to recall, define, represent, use, and relate these basic principles as appropriate. This cognitive demand corresponds most closely to the science practice of Identifying Science Principles.

"Knowing how" refers to procedural knowledge. This cognitive demand sets up the expectation that students can apply the science facts, concepts, and principles in doing science. For example, students should know how to perform simple (routine) and complex procedures such as systematically observing and recording which objects sink and float in water, using a balance scale, measuring an object's mass, calculating an object's density, and designing and interpreting the results of an investigation (e.g., manipulating one variable and holding others constant). Procedural knowledge underlies much of the science practice of Using Scientific Inquiry as defined in this framework.

"Knowing why" refers to schematic knowledge. This cognitive demand sets up the expectation that students can explain and predict natural phenomena as well as account for how and why scientific claims are evaluated, argued and justified, or warranted (ex-plaining and reasoning with principles and models). That is, this cognitive demand deals with students' understanding of how the natural world works (such as why some things sink and others float in water), why light is essential to the propagation of most plants, or why the Moon changes phases. This cognitive demand overlaps considerably with the science understanding expected in the practice of Using Science Principles and also in the practices of Using Scientific Inquiry and Using Technological Design.

The last cognitive demand, "knowing when and where to apply knowledge," or strategic knowledge, is commonly talked about as transfer of current knowledge to new situations (tasks or problems). Strategic knowledge involves knowing when and where to use science knowledge in a new situation *and* reasoning through the novel task to reach a goal. Strategic knowledge sets up the expectation that students can take their current knowledge and apply it to a somewhat novel situation. Such adaptation of knowledge to a particular problem and context underlies especially the practices of Using Scientific Inquiry and Using Technological Design.

Adapted Provisional Coding System for Design Portfolio Prompts

Knowledge Type (Li, 2001, p. 180)	Knowledge Subtype (Li, 2001, p. 180)	Code	Description (Li, 2001, p.123 and. 180)	Anticipated Examples in Design Portfolio Responses
Declarative Knowledge	Fact	DEC-FAC	Statement or questions retrieving the memorized facts	Heat energy transfers by the motion of particles
	Definition/ Term	DEC-DEF	Statements involving formal definitions or particular scientific terms	Temperature measures the average kinetic energy of the movement of molecules
	Statement	DEC-STA	Retrieving propositions, phases [*sic*], rules, or statements	Metals are good conductors of thermal energy
	Everyday science	DEC-EVE	Statement or questions as recalling science knowledge based on everyday or requiring minimum scientific domain-knowledge	A metal spoon becomes hot to the touch when it is left in a pot of hot soup
Procedural Knowledge	Investigation method	P-INV	Statement or questions addressing the methods for investigation, such as replication, measurement errors, or controlling variables	Our thermos will be tested by looking at how well it prevents heat from transferring to the water inside
	Procedure	P-PRO	Statement articulating the steps of a procedure	We will add 400 mL of water to our thermos for testing
	Data collection/ measurement/ recording/ reporting	P-DATA	Descriptions of the process of gathering and generating data, such as collecting, recording, or reporting data	The temperature of the water inside the thermos will be recorded every two minutes
	Interpretation, predication, and conclusion	P-INT	Statements related to making sense of the data or results, such as prediction	Our results will be compared with other groups' results and the control
Schematic Knowledge	Explanatory model	SCH-EXP	Explanations involving personal experience or everyday knowledge	I have a thermos that has a shiny metallic coating which must be for reflecting radiation
	Theoretical model	SCH-THE	Explanations or reasoning with specific scientific models or theories	Metals are good conductors because the electrons are able to flow and transfer kinetic thermal energy
Strategic Knowledge	Framing a problem	STR-FRM	Statement or questions recognizing/labeling the *features* of tasks, procedures, and projects or *making sense* of tasks	The criteria for the challenge are to design a thermos to keep the water cold over 30 minutes.

	Planning	STR-PLAN	Statements or questions about what will or should happen next (steps or actions)	Because we found rubber mulch to be the best insulator in our tests, our design has rubber mulch on the outside to prevent heat transfer.
		STR-PLAN	Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	I think my design will be successful at preventing heat transfer because the cotton balls form an insulating layer to prevent conduction of heat from the table top.
	Monitoring	STR-MON	Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task)	Our final design was chosen because it combines each team member's ideas for preventing heat transfer.
		STR-MON	Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	I didn't think that his idea of putting one cup on top of the other would be needed.
	Test Wiseness	N/A	Statement or questions as an educated guessing, completely guessing, or eliminating options	Not applicable since instrument does not involve test questions

Appendix H: Results of First Independent Coding and Interrater Agreement

Student Phrase	Coder 1	Coder 2	Coder 3	Arbitrated Code	Agreement with Code[a]			% agreement[b]
company is asking for an insulating device	STR-FRM	STR-FRM		STR-FRM	1	1	0	67
The only things we can use are…	P-PRO			P-PRO	1	0	0	33
We need to keep about 400 mL of cold liquid cold for 30 minutes…	STR-FRM		STR-FRM	STR-FRM	1	0	1	67
We need to use our knowledge about conduction, convection, and radiation to accomplish this task.	DEC-EVE		DEC-EVE	DEC-EVE	1	1	1	100
Kinetic molecular theory is when temperature rises…	SCH-THE	DEC-DEF	DEC-EVE	SCH-THE	1	0	0	33
Temperature is the average kinetic energy of an object.	DEC-DEF			DEC-DEF	1	0	0	33
We will be using Celsius for this challenge because it will be more accurate.	P-DATA		P-DATA	P-DATA	1	0	1	67
Thermal equilibrium is when you put a hot liquid in a room temperature area, eventually the liquid will reach the same temperature as the area.	DEC-EVE	DEC-EVE	DEC-EVE	DEC-EVE	1	1	1	100
What we need to do is make sure we don't reach that point [thermal equilibrium] and keep the liquid cold.	STR-FRM			STR-FRM	1	0	0	33
Radiation is the transfer of heat via transverse rays.	DEC-STA	DEC-DEF	DEC-DEF	DEC-DEF	1	1	1	100

Conduction is the transfer of heat through 2 solid objects in direct contact.	DEC-STA	DEC-STA	P-PRO	DEC-STA	1	0	0	33
The thermos will be placed on a table and if we use aluminum foil, it'll conduct heat warming up the thermos.	STR-PLAN	DEC-STA	DEC-FAC	STR-PLAN	1	0	0	33
Convection is the transfer of heat via the movement of gas or liquid.	DEC-STA	DEC-STA		DEC-DEF	1	0	0	33
If the thermos is by a window on a bright, sunny day, the rays will heat up the thermos eventually heating up the water.	STR-PLAN	SCH-EXP		STR-PLAN	1	0	0	33
The three best insulators were…	P-INT	STR-PLAN	DEC-EVE	P-INT	1	0	0	33
The worst insulators were…	P-INT	STR-PLAN		P-INT	1	0	0	33
Aluminum foil makes a better conductor than insulator.	P-INT	STR-PLAN		P-INT	1	0	0	33
Thermal Conductors - Sea of electrons	SCH-THE			SCH-THE	1	0	0	33
The cup with water will be placed in an aluminum foil mold…	P-PRO	P-PRO	P-PRO	P-PRO	1	1	1	100
The space in the mold will be filled with sand and/or rubber mulch.	P-PRO	P-PRO		P-PRO	1	1	0	67
The aluminum foil mold is filled [with] sand and rubber mulch which are great insulators according to our test.	STR-PLAN	P-PRO	STR-PLN	STR-PLAN	1	0	1	67

The space between the other cup (empty) and the one with water will be filled with the same materials.	P-PRO	P-PRO		P-PRO	1	1	0	67
The double layer mentality will keep the heat out and keep the water colder longer.	STR-PLAN	STR-PLAN		STR-PLAN	1	1	0	67
The heat of the materials went to the water...	SCH-EXP	P-PRO		SCH-EXP	1	0	0	33
...and heated it 1.9˚C in 30 minutes.	P-INT	P-DATA	STR-MON	P-INT	1	0	0	33
We could've had a bigger opening to pour in the water with no spilling allowing it to actually hold 400 mL.	STR-MON			STR-MON	1	0	0	33
We wouldn't make it as massive allowing less heat to get to the water.	STR-MON	P-INV	STR-MON	STR-MON	1	0	1	67

[a]*Note*. A value of 1 is assigned to if original code agrees with arbitrated code, and 0 if original code does not agree with arbitrated code.
[b]Total % agreement calculated at 53%.

Appendix I: Results of Coding Remaining Ten Portfolios with Arbitrated Coding Scheme

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
312	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	KMT says that if you warm up the temperature then the molecules will speed up.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
312	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	If we are trying to keep our drink cold, then we will try to keep the movement of the molecules slow.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
312	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	If the temerpature… warms up then that will affect our project because we are trying to keep the drink cold.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
312	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	we will be using Celsius	Procedural	Data collection/measurement/recording/reporting - Descriptions of the process of gathering and generating data, such as collecting, recording, or reporting data	P-DATA

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
312	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Thermal equilibrium says that if a cold substance is an environment that is medium or opposite of itself (also heat) it will warm up (or cool down for heat)…	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
312	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	…so if the temp is at room temperature than [sic] the drink will warm up so we have to create a substance that won't let that air get in.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
312	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Pretty much all of these processes occur in gas form.	Declarative	Statement - Retrieving propositions, phases, rules, or statements	DEC-STA
312	3	Problem Identification: Problem Statement	My group and I need to build and design a prototype insulating device that holds a drink	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
312	3	Problem Identification: Problem Statement	We must pick materials that will prevent the drink from becoming warm…	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
312	3	Problem Identification: Problem Statement	This design will hopefully keep the liquid cool. We must keep 400 mL of cold liquid as cold as possible for 30 minutes	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
312	3	Problem Identification: Problem Statement	Liquid cannot be contaminated.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
312	3	Problem Identification: Problem Statement	We can only use…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
312	3	Problem Identification: Problem Statement	One question is what is the best insulator.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
312	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Conduction is…	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
312	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	…so if the table is touching the cup, it may affect the temp.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
312	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	If the air is touch the cup, then the room temp. may also affect it (convection).	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
312	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Since we are near a window, the sun may cause radiation which would heat the liquid up.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
312	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Also, A light is above which may also cause radiation to heat up the liquid.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
312	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The main direction of heat transfer will be within the cold water because it is the coldes and the warmer object always goes to the colder object.	Declarative	Fact - Statement of questions retrieving the memorized facts	DEC-FAC
312	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Insulators…	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
312	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	conductors…	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
312	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in thermal conductors: freely moving electrons, arranged in a lattice, sea of electrons	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
312	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in thermal insulators: stationary electrons	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
312	6	Potential Design Solutions Summary: Individual Design	I will put two cups side by side…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
312	6	Potential Design Solutions Summary: Individual Design	I will put sand on the bottom, basically nothing will be showing except a whole [sic] in the top in the middle of each cup (for thermometer).	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
312	6	Potential Design Solutions Summary: Individual Design	The aluminum foil will keep it cool/you put it around cold sodas to keep them cold and will keep the water safe from radiation.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
312	6	Potential Design Solutions Summary: Individual Design	Sand is a good insulator and bright, to keep water safe from hot black surface.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
312	7	Generating a Team Solution: Team Design	All of these layers won't warm the water up and keep it safe from radiation.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
312	7	Generating a Team Solution: Team Design	All of these but aluminum foil are good insulators.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
312	8	Prototype Test and Data Analysis	The temperature went up .9 degrees in ten minutes.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
312	8	Prototype Test and Data Analysis	It worked relatively well.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
312	8	Refining the Design	We were within the criteria and our design relatively kept minimal heat transfer from happening.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
312	8	Refining the Design	We didn't keep the temperature down enough.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
312	8	Refining the Design	Not to put too much material on the cup.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
411	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	KMT is that if something has heat added, then the object's molecules will move faster.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
411	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Temperature is how much kinetic energy something has.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
411	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Thermal equilibrium is that if I put a glass of coffee outside, then it would cool down because the warmer air? particles go into the air.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
411	3	Problem Identification: Problem Statement	The problem I'm trying to solve is how to keep a liquid cold for 30 min….by building a thermos to accomplish it.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
411	3	Problem Identification: Problem Statement	…I have to build the thermos with a criteria of it has to hold 400 mL of a cold liquid for 30 min.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
411	3	Problem Identification: Problem Statement	…and can be poured out of an into it without contamination.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
411	3	Problem Identification: Problem Statement	The constraints are that it has to be built during class and can be built only by…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
411	3	Problem Identification: Problem Statement	You need to know (how) a basic thermos is made.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
411	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Conduction is the transfer of heat through….	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
411	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	It (conduction) would happen in the table and transfer to the water.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
411	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Convection is the transfer of heat…	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
411	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	It (convection) would happen in the room.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
411	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Radiation is the transfer of heat by means of rays.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
411	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	This (radiation) would happen from the sun to the outside of the thermos.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
411	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Conduction would happen in solids, and convection in liquids and gases.	Declarative	Statement - Retrieving propositions, phases, rules, or statements	DEC-STA
411	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Heat always goes from the warmer object to the colder.	Declarative	Fact - Statement of questions retrieving the memorized facts	DEC-FAC
411	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good insulators - …	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
411	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Bad insulators-…	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
411	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in thermal conductors: They are in rows and columns, they also have a sea of electrons.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
411	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in thermal insulators: has ver few, if any, free electrons and does not transfer energy well, if at all.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
411	6	Potential Design Solutions Summary: Individual Design	I am going to use rubber mulch, sand, cotton balls…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
411	6	Potential Design Solutions Summary: Individual Design	It will be medium sized.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
411	6	Potential Design Solutions Summary: Individual Design	It will have the walls lined with much and sand it it that is super glued.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
411	7	Generating a Team Solution: Team Design	Holds 400 mL	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
411	7	Generating a Team Solution: Team Design	Is very insulated	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
411	7	Generating a Team Solution: Team Design	easy to use/portable	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
411	8	Prototype Test and Data Analysis	Our group's prototype did well	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
411	8	Prototype Test and Data Analysis	the cold transferred from the water to the cup, to the lid, and then out.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
411	8	Refining the Design	it held 400 mL	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
411	8	Refining the Design	…only went up 1.4˚C	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
411	8	Refining the Design	…and was very insulated	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
411	8	Refining the Design	We could have put more aluminum foil on the thermos	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
411	8	Refining the Design	I would make the lid better insulated to hold in the cold.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
416	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Kinetic molecular theory is when temperature rises…	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
416	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Temperature is the average kinetic energy of an object.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
416	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	We will be using Celsius for this challenge because it will be more accurate.	Procedural	Data collection/measurement/recording/reporting - Descriptions of the process of gathering and generating data, such as collecting, recording, or reporting data	P-DATA

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
416	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Thermal equilibrium is when you put a hot liquid in a room temperature area, eventually the liquid will reach the same temperature as the area.	Declarative	Everyday Science - Statement or questions as recalling science knowledge based on everyday or requiring minimum scientific domain-knowledge	DEC-EVE
416	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	What we need to do is make sure we don't reach that point [thermal equilibrium] and keep the liquid cold.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
416	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Radiation is the transfer of heat via transverse rays.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
416	3	Problem Identification: Problem Statement	company is asking for an insulating device	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
416	3	Problem Identification: Problem Statement	The only things we can use are…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
416	3	Problem Identification: Problem Statement	We need to keep about 400 mL of cold liquid cold for 30 minutes at least.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
416	3	Problem Identification: Problem Statement	We need to use our knowledge about conduction, convection, and radiation to accomplish this task.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
416	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Conduction is the transfer of heat through 2 solid objects in direct contact.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
416	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The thermos will be placed on a table and if we use aluminum foil, it'll conduct heat warming up the thermos.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
416	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Convection is the transfer of heat via the movement of fas or liquid.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
416	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	If the thermos is by a window on a bright, sunny day, the rays will heat up the thermos eventually heating up the water.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
416	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	The three best insulators were…	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
416	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	The worst insulators were…	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
416	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Aluminum foil makes a better conductor than insulator.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
416	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal Conductors - Sea of electrons	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
416	6	Potential Design Solutions Summary: Individual Design	The cup with water will be placed in an aluminum foil mold…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
416	6	Potential Design Solutions Summary: Individual Design	The space in the mold will be filled with sand and/or rubber mulch.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
416	7	Generating a Team Solution: Team Design	The aluminum foil mold is filled [with] sand and rubber mulch which are great insulators according to our test.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
416	7	Generating a Team Solution: Team Design	The space between the other cup (empty) and the one with water will be filled with the same materials.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
416	7	Generating a Team Solution: Team Design	The double layer mentality will keep the heat out and keep the water colder longer.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
416	8	Prototype Test and Data Analysis	The heat of the materials went to the water...	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
416	8	Prototype Test and Data Analysis	...and heated it 1.9˚C in 30 minutes.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
416	8	Refining the Design	We could've had a bigger opening to pour in the water with no spilling allowing it to actually hold 400 mL.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
416	8	Refining the Design	We wouldn't make it as massive allowing less heat to get to the water.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
423	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The thermos should keep the cold in and not reach thermal equilibrium.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
423	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	It will be measured in Celsius.	Procedural	Data collection/measurement/recording/reporting - Descriptions of the process of gathering and generating data, such as collecting, recording, or reporting data	P-DATA
423	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The molecules in the cold water should be moving slowly.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
423	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	If the cold water is with a bad insulator, it will reach thermal equilibrium.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
423	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The temperature of the room should be room temperature for every so it can be a controlled experiment.	Procedural	Investigation Method - Statement or questions addressing the methods for investigation, such as replication, measurement errors, or controlling variables	P-INV
423	3	Problem Identification: Problem Statement	For this challenge we have to build an insulating device to keep water cold for the longest time.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
423	3	Problem Identification: Problem Statement	The liquid must be able to be poured into and out of the device without contamination.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
423	3	Problem Identification: Problem Statement	We can only use the materials provided for this challenge.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
423	3	Problem Identification: Problem Statement	At most, 400 mL of cold liquid must be kept cool for at least 30 minutes.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
423	3	Problem Identification: Problem Statement	We need to know which materials will keep the water [cool] the longest...	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
423	3	Problem Identification: Problem Statement	We need to know which are better insulators.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
423	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Heat will travel into the cold water because of conduction.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
423	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Convection will also occur because of the movement of the cold water and temperature of the environment around it.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
423	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The experiment near the windows will be affected by radiation.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
423	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Heat will travel from the things around it to the cold water.	Declarative	Fact - Statement of questions retrieving the memorized facts	DEC-FAC
423	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The heat from radiation will affect the experiment because the solid/liquid will heat up fraster.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
423	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good conductors - ….	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
423	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good insulators - …	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
423	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal conductors - The atoms start to move fast when in contact with heat. This causes the atoms on the other side to move fast and become hot.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
423	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal Insulators - The atoms are closely together. They are not moving as much. The outer electrons move freely	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
423	6	Potential Design Solutions Summary: Individual Design	The materials cannot be contaminating the water.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
423	6	Potential Design Solutions Summary: Individual Design	The sand and rubber mulch will be surrounding the water.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
423	6	Potential Design Solutions Summary: Individual Design	If the water cup is not covered, the water will be exposed to air and warm up quickly.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
423	7	Creating the Prototype	Not enough sand, trying to surround the cup with rubber mulch.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
423	7	Generating a Team Solution: Team Design	Thermometer opening, keeps water cold	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
423	8	Prototype Test and Data Analysis	The heat transferred from the room to the water.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
423	8	Prototype Test and Data Analysis	The coldness escaped and let the heat in???	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
423	8	Refining the Design	The hole for the thermometer made sand fall into the water/cup.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
423	8	Refining the Design	More layers of insulation, more mulch and sand surrounding the cup to insulate the water.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
427	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Kinetic molecular theory - if the heat increases, the molecules will move faster.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
427	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Temperature - the measurement of how hot something is…student lists equations	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
427	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Thermal equilibrium - If you set hot coffee out on a hot summer day, it will soon become cooler	Declarative	Everyday Science - Statement or questions as recalling science knowledge based on everyday or requiring minimum scientific domain-knowledge	DEC-EVE
427	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	If you set a hot cup of coffee out and a cup of iced tea and leave the overnight, they will be the same temperature by morning.	Declarative	Everyday Science - Statement or questions as recalling science knowledge based on everyday or requiring minimum scientific domain-knowledge	DEC-EVE

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
427	3	Problem Identification: Problem Statement	We are in need of an insulator to keep a drink cold that we can travel with.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
427	3	Problem Identification: Problem Statement	We need 200 mL of liquid to stay as cool as can be for 30 minutes.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
427	3	Problem Identification: Problem Statement	The liquid must be able to be poured into the insulator, then be poured back into the bottle later on.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
427	3	Problem Identification: Problem Statement	There must not be any contamination.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
427	3	Problem Identification: Problem Statement	We can only use class time to build our device,	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
427	3	Problem Identification: Problem Statement	…we can only use the following materials:…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
427	3	Problem Identification: Problem Statement	Our insulator needs to keep foods hot, cold, and from spilling [sic].	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
427	3	Problem Identification: Problem Statement	We need to knowl how to put an insulator together, what an insulator is, and how to create it so it meets the requirements.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
427	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	I've learned that conduction is the transfer of heat between substances that are in direct contact with each other.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
427	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Convection is the up and down movement of gasese and liquids caused by heat transfer.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
			radiation is when electromagnetic waves travel through space.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
427	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Heat always transfer from a warmer object to a colder object.	Declarative	Fact - Statement of questions retrieving the memorized facts	DEC-FAC
427	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Conduction occurs in solid states of matter, convection occurs in gases and liquids, and radiation occurs in gases???	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
427	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	These concepts will effect [sic] the design challenge because radiation could warm up the drink through the air, conduction could warm up the drink if it touches something hot, and convection can warm up the drink by the air outside of the insulator.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
427	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	The sand is a very good insulator and the aluminum foil was not.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
427	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Anything that is hard to get though and doesn't get cold too easily will be a good insulator.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
427	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Air and metals are poor insulators.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
427	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal Conductors - The atoms are close together and moving/vibrating slowly. The electrons will transfer heat.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
427	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal Insulators - The atoms would be close together and barely moving (vibrating) since most insulators are solid states of matter.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
427	6	Potential Design Solutions Summary: Individual Design	In my design, I have one cup filled with sand.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
427	6	Potential Design Solutions Summary: Individual Design	It will not be too full though so you can ssee the drink inside.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
427	6	Potential Design Solutions Summary: Individual Design	You can tape them together and they will keep the drink cold. Make sure there aren't any cracks.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
427	6	Potential Design Solutions Summary: Individual Design	I chose sand because it was the best insulator.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
427	7	Generating a Team Solution: Team Design	The cotton balls might prevent the heat from staying out	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
427	7	Generating a Team Solution: Team Design	…or if the lid is not taped on well, the heat might get in.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
427	7	Generating a Team Solution: Team Design	Hopefully the sand won't move so the drink doesn't touch anything warm beneath it	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
427	7	Generating a Team Solution: Team Design	…and if the lid isn't on well then radiation could happen and the drink might not be insulated well	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
427	8	Prototype Test and Data Analysis	The temperature of the water up 1.2˚ throughout the experiment.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
427	8	Prototype Test and Data Analysis	It went from 6.3˚C-7.5˚C over the course of the 30 minutes.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
427	8	Prototype Test and Data Analysis	We recorded the temperature every 2 minutes.	Procedural	Data collection/measurement/recording/reporting - Descriptions of the process of gathering and generating data, such as collecting, recording, or reporting data	P-DATA
427	8	Refining the Design	The water did not rise in temperature too much.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
427	8	Refining the Design	Our insulator was able to hold 400 mL.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
427	8	Refining the Design	We could have made it much better so the temp. of the water didn't rise as much, but other than that we met all other requirements.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
427	8	Refining the Design	I would somehow insulate the water more.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
522	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	If you increase the temperature of something, its molecules will move faster and have more energy.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
522	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	We need to know this because we don't want to use an object that is hot as our insulator, because it will increase heat of substance, and it will move faster (molecules).	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
522	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	We should use Celsius for our temperature scale…because it is used for scientific experiments.	Procedural	Data collection/measurement/recording/reporting - Descriptions of the process of gathering and generating data, such as collecting, recording, or reporting data	P-DATA
522	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Thermal equilibrium says that if you leave a substance in a room of different temp, they will both eventually be the same temp.	Declarative	Everyday Science - Statement or questions as recalling science knowledge based on everyday or requiring minimum scientific domain-knowledge	DEC-EVE
522	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The temp. will be the avg. KE of molecules.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
522	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Convection is heat transfer through gases and liquids.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
522	3	Problem Identification: Problem Statement	The goal is to keep water cold for a long period of time….The prototype must keep water cold for at 30 minutes in room temp.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
522	3	Problem Identification: Problem Statement	You have to build a prototype insulating devices to serve as a portable storage for a drink.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
522	3	Problem Identification: Problem Statement	The liquid cannot get contaminated.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
522	3	Problem Identification: Problem Statement	You can only work on prototype during class and can only use provided materials.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
522	3	Problem Identification: Problem Statement	You should be educated about insulating, conduction, convection, and heat.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
522	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Conduction is heat transfer from when objects (solids) are touching.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
522	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Radiation is electromagnetic waves transferring through space.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
522	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	These can affect our project and potentially make our water warmer.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
522	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The heat will transfer into the water at a colder temperature.	Declarative	Fact - Statement of questions retrieving the memorized facts	DEC-FAC
522	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	It would be best to close the blinds so radiation doesn't effect [sic] our results.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
522	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good conductors - ….	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
522	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good insulators - …	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
522	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal conductors - have free electrons, create a sea of electrons, form a pattern	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
522	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal insulators - many different types of atoms so they can bond and stay connected. Tightly bound so they can't transfer heat as well.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
522	6	Potential Design Solutions Summary: Individual Design	For the inner cup, it will be cut apart, then glued back together at a smaller size to fit inside the normal cup with more room.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
522	6	Potential Design Solutions Summary: Individual Design	In between the cups, rubber mulch will be there to insulate.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
522	6	Potential Design Solutions Summary: Individual Design	On top, a plastic bag will be on top to prevent warm air from getting in.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
522	6	Potential Design Solutions Summary: Individual Design	The bag will be taped down.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
522	7	Generating a Team Solution: Team Design	Rubber mulch and sand (the best insulators) will fill the space in the double cup design.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
522	7	Generating a Team Solution: Team Design	Plastic is a good insulator, so when the materials come together, it makes a great product.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
522	7	Generating a Team Solution: Team Design	The hot glue is sure to keep the cold in.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
522	8	Prototype Test and Data Analysis	The heat went to the ice water in the cup.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
522	8	Prototype Test and Data Analysis	Our prototype was okay, but not the best insulator.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
522	8	Refining the Design	Our cup insulated well, and only went up by 2˚C.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
522	8	Refining the Design	We needed our cup to hold 400 mL, and it only held 300 mL.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
523	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The temperature has to stay the same inside whether it will be in ˚F, ˚C, or K.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
523	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	This should happen even if the atmosphere and it (the thermos) aren't in thermal equilbirum.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
523	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	This is when the atmosphere is at the same temperature as the inside of the insulating device	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
523	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	, but we don't want it to be (at same temp. as surroundings).	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
523	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The KMT will be affected because the molecules will not have much room to move around inside the device.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
523	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The temperature must stay cool, and since the molecules aren't conducting heat well, the will keep the inside at about the same temp.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
523	3	Problem Identification: Problem Statement	You need to keep the water cold.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
523	3	Problem Identification: Problem Statement	You don't necessarily meed to refrigerate something to keep it cold.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
523	3	Problem Identification: Problem Statement	We need to build a prototype to keep out the outside temperature, keeping out the chances of conduction, convection, and radiation for 30 minutes.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
523	3	Problem Identification: Problem Statement	The liquid needs to be able to be poured into the device, but can be retrieved without damage.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
523	3	Problem Identification: Problem Statement	We can do this only in and with the time and materials provided.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
523	3	Problem Identification: Problem Statement	I might need to know information about professional insulators.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
523	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The device should not be able to be affected by conduction, convection, or radiation.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
523	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	It has to stay in the same state of matter, too. If it gets hot, the liquid will start evaporating. If it gets too cold, it will freeze.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
523	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Heat cannot leak into the device from the outside.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
523	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Insulators…	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
523	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	conductors…	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
523	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal conductors - sea of electrons, electrons free flowing, atoms in a checkerboard pattern	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
523	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal insulators - tightly bound electron tied to an atom.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
523	6	Potential Design Solutions Summary: Individual Design	I used two plastic cups, aluminum foil, tape, and hot glue.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
523	6	Potential Design Solutions Summary: Individual Design	It can hold about 400 mL.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
523	6	Potential Design Solutions Summary: Individual Design	The two cups are upside down on the top of each other and tpaed together. Aluminum foil is glued to the outside of the cups with hot glue.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
523	7	Generating a Team Solution: Team Design	Aluminum foil will block out heat from inside.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
523	7	Generating a Team Solution: Team Design	Sand is a great insulator.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
523	7	Generating a Team Solution: Team Design	The bag covers the top	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
523	7	Generating a Team Solution: Team Design	The mulch insulates the bottom of the 2 cups.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
523	7	Generating a Team Solution: Team Design	Having 2 cups creates better coverage	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
523	8	Prototype Test and Data Analysis	The heat transferred through the cup to the water.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
523	8	Prototype Test and Data Analysis	The prototype did well.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
523	8	Refining the Design	We used ony the materials allowed.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
523	8	Refining the Design	We should have had more insulating items, put more things on the outside of the cups.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
525	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Thermal equilibrium is when 2 objects of different temperatures reach the same temperature by heat transfer.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
525	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Temperature is the measurement of the average kinetic energy in an object.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
525	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	…(temp) usually measured in ˚F, ˚C, or K.	Declarative	Statement - Retrieving propositions, phases, rules, or statements	DEC-STA
525	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	They may affect our project because heat is going to make the cold water warm.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
525	3	Problem Identification: Problem Statement	We need to build an insulating device that can keep water cold for a certain amount of time.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
525	3	Problem Identification: Problem Statement	We have to keep 200 mL of water cold for 30 minutes.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
525	3	Problem Identification: Problem Statement	…and the liquid has to be poured from the device.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
525	3	Problem Identification: Problem Statement	We only get the time in class to build and have the following materials:	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
525	3	Problem Identification: Problem Statement	We should know about what is the best insulator and the best structural design.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
525	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Conduction can affect our project because if the cup is warm, it can make the water warmer.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
525	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Radiation will also affect us because we sit by a window, and sun rays can make our water warmer also.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
525	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Convection can affect too, because the air will be warmer than the water.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
525	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	We will be careful not to touch the cup or breathe to [sic] close to it.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
525	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	I think sand will be the best insulator because it can hold the temperature for the longest time.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
525	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Also, rubber might be good because it can hold the temperature for the second longest time.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
525	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Air and aluminum foil are really bad insulators.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
525	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	We are going to use sand for our insulators because it had the best results.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
525	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in Thermal conductors: heat can pass through these atoms very easily, they are in a pattern.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
525	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in thermal insulators: electrons are bound to their respective atoms, allow no heat transfer.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
525	6	Potential Design Solutions Summary: Individual Design	I am going to use…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
525	6	Potential Design Solutions Summary: Individual Design	The device will be the size of the cup…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
525	6	Potential Design Solutions Summary: Individual Design	I am going to wrap it because that will hold in the coldness longer.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
525	6	Potential Design Solutions Summary: Individual Design	The sand will line…hot glue and tape will hold..	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
525	7	Generating a Team Solution: Team Design	The sand will insulate the inner and outer cups.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
525	7	Generating a Team Solution: Team Design	The plastic will also insulate.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
525	7	Generating a Team Solution: Team Design	The tape will hold in the sand.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
525	7	Generating a Team Solution: Team Design	All the insulators will work together to insulate the water.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
525	8	Prototype Test and Data Analysis	Our device did okay, it held in the temperature and held in the coolness.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
525	8	Refining the Design	It held in the coldness better than the control, but not the best in our class.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
525	8	Refining the Design	We could have used foil instead of cotton balls, because then it woul hold the temp. longer.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
525	8	Refining the Design	I would make it out of foil instead of cotton balls to hold in the cold better.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
526	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	KMT is when molecules move faster when the are heated up.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
526	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	If the insulator fails, then the molecules will move faster.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
526	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Temperature is the measure of heat/average kinetic energy.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
526	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	This (temperature) will be changed jurastically [sic] if the insulator fails.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
526	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Thermal equilibrium is when the material reaches the same temperature as the room.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
526	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	This (thermal equilibrium) will try to happen, but hopefully the insulator will stop it.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
526	3	Problem Identification: Problem Statement	The need is to create a device that will keep liquid cold for 30 minutes.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
526	3	Problem Identification: Problem Statement	The design challenge is to create a portable storage for a drink.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
526	3	Problem Identification: Problem Statement	It needs to be able to hold 200 mL of cold liquid cold for 30 minutes.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
526	3	Problem Identification: Problem Statement	The liquid also needs to not be contaminated while in the device.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
526	3	Problem Identification: Problem Statement	The constraints are that we are only allowed to use time alloted during class…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
526	3	Problem Identification: Problem Statement	…and we are only allowed to use…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
526	3	Problem Identification: Problem Statement	It is also known that the most energy loss happens at the top of by the stopper.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
526	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Conduction is…	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
526	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The heat from table/cup might transfer to the water.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
526	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Convection is..	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
526	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	This (convection) might affect us because the air temperature might make the water meet thermal equilibrium.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
526	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Radiation is…	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
526	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	This (radiation) might affect us because of the sun's heat coming through the window.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
526	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The higher temp. will transfer to the lower temp.	Declarative	Fact - Statement of questions retrieving the memorized facts	DEC-FAC

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
526	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	This (transfer of heat) will affect our project because the warm air will warm up the water.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
526	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good insulators - …	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
526	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good conductors - ….	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
526	5	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Atoms in thermal insulators - electrons are many and bonded, tightly bond, not a lot of free electrons and atoms, not arranged orderly	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
526	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in thermal conductors - have free electrons, sea of electrons, moving fast, evenly spaced	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
526	6	Potential Design Solutions Summary: Individual Design	I think it will work because the double cups insulate like vacuum flasks.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
526	6	Potential Design Solutions Summary: Individual Design	Also, rubber mulch will fill the whole space except for the top, which will be filled with sand…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
526	6	Potential Design Solutions Summary: Individual Design	These are the 2 best insulators, and sand is the best.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
526	6	Potential Design Solutions Summary: Individual Design	So, sand will be at the top because the most energy loss happens at the top of the insulator.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
526	6	Potential Design Solutions Summary: Individual Design	Then, the whole device will be tightly taped with a plastic bag, because plastic is a good insluator.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
526	7	Generating a Team Solution: Team Design	Rubber mulch and sand (the best insulators out there) will the space in the double cup design.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
526	7	Generating a Team Solution: Team Design	Plastic is a good insulator, so the whole thing is covered by plastic.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
526	7	Generating a Team Solution: Team Design	The hot glue sealing the sand in is sure to keep the cold in.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
526	8	Prototype Test and Data Analysis	The heat transferred through the cup to ice water.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
526	8	Prototype Test and Data Analysis	Our insulator wasn't great, but it was alright.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
526	8	Refining the Design	It is insulated and we used the right materials…the cup only held 300 mL	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
526	8	Refining the Design	Make the water cup bigger	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
813	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The kinetic molecular theory is that when it heats up the molecules move faster.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
813	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The temperature is the average kinetic energy.	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
813	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	We are trying to stop the temperature from rising.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
813	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	We need to stop kinetic molecular theory from happening.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
813	3	Problem Identification: Problem Statement	I would need to know the starting temperature eand the amount of material that I have.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
813	3	Problem Identification: Problem Statement	We have to design a portable storage device to keep a drink cool.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
813	3	Problem Identification: Problem Statement	We can't contaminate the water…	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
813	3	Problem Identification: Problem Statement	…and we have to use a certain volume of liquid.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
813	3	Problem Identification: Problem Statement	We have limited time	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
813	3	Problem Identification: Problem Statement	…and we can only use the materials given.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
813	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	If we touch the container, that will heat it up	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
813	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	…and the cup touching the table (will heat it up)	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
813	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The convection will happen if the hotter air touches the water it will heat it up.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
813	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	If you are near the window, radiation will effect [sic] it.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
813	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The heat will transfer to the container.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
813	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	conductors…	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
813	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Insulators…	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
813	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal conductors - the atoms are close together and have a sea of electrons.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
813	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Thermal insulators - the atoms are farther apart, electrons are not free to flow.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
813	6	Potential Design Solutions Summary: Individual Design	I will stack the cups on top and blue the mulch to the cup. Also I will rap the thing in foil.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
813	7	Generating a Team Solution: Team Design	The aluminum foil will reflect the radiation.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
813	7	Generating a Team Solution: Team Design	The sand will keep the heat from the table table to the cup.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
813	7	Generating a Team Solution: Team Design	The cotton balls will help insulate it.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
813	7	Generating a Team Solution: Team Design	The plastic bag to insulate it again, mulch to help.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
813	8	Prototype Test and Data Analysis	The heat was trying to transfer into the cup	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
813	8	Prototype Test and Data Analysis	but we did pretty good over time.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
813	8	Prototype Test and Data Analysis	I think the plastic bag wrapped around the design did good.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
813	8	Prototype Test and Data Analysis	We followed the criteria pretty well	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
815	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The KMT is the hotter the substance, the faster the electrons move in the substance.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
815	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	This (KMT) could affect our project because we don't want the particles in the water to get hotter and faster.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
815	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Temp could affect our water because we want to keep it cool	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
815	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Thermal equilibrium can affect our projct because…	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
815	3	Problem Identification: Problem Statement	We need to create a thermos that keeps cold air in.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
815	3	Problem Identification: Problem Statement	We only have a few materials to get the job done.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
815	3	Problem Identification: Problem Statement	It needs to hold cold water for 30 minutes.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
815	3	Problem Identification: Problem Statement	We only have time in class…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
815	3	Problem Identification: Problem Statement	We need to know do, not , not what to do.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
815	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Conduction can be affected if we touch the water.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
815	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Convection can be affected because you want to keep air out	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
815	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	…and convection is transferred through gases and liquids.	Declarative	Statement - Retrieving propositions, phases, rules, or statements	DEC-STA
815	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Radiation from the sun could affect and warm up the water in the cup.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
815	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	The direction of the heat will go into the cup.	Declarative	Fact - Statement of questions retrieving the memorized facts	DEC-FAC
815	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good insulators - …	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
815	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good conductors - ….	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
815	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in thermal conductors: electrons are not connected to a single nucleus, they move from one nucleus to another.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
815	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in thermal insulators: connected to one atom and don't move to other nuclei.	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
815	6	Potential Design Solutions Summary: Individual Design	The materials I am using are…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
815	6	Potential Design Solutions Summary: Individual Design	My cup is going to be inside a larger cup.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
815	6	Potential Design Solutions Summary: Individual Design	The cup of water I'm using is a regular sized cup (holds 470 mL).	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
815	6	Potential Design Solutions Summary: Individual Design	Tape will go on top of both cups…	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
815	7	Generating a Team Solution: Team Design	With a cup on top of the cup with water and tape on the crease, the air flow will be minimum.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
815	7	Generating a Team Solution: Team Design	The bag around our cup will be filled with newspaper …	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
815	7	Generating a Team Solution: Team Design	There will be a small hold on top for the thermometer	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
815	8	Prototype Test and Data Analysis	The heat went into the surrounding materials and out of the cup into the air.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
815	8	Prototype Test and Data Analysis	The performance of our design was ok	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
815	8	Prototype Test and Data Analysis	Our temp. started at…and went up to…	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
815	8	Refining the Design	At first, the temp of the water stayed constant.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
815	8	Refining the Design	Cold air stayed inside the cup.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
815	8	Refining the Design	We need to keep cold air in our cup for a longer time.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
815	8	Refining the Design	Cut off the top of the cup, because it helps stop air flow (this also lowers the volume)	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
818	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	KMT is the theory that tempererature of an object is proportional to the average kinetic energy	Declarative	Statement - Retrieving propositions, phases, rules, or statements	DEC-STA
818	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Heat always goes from a hotter object to a colder one.	Declarative	Fact - Statement of questions retrieving the memorized facts	DEC-FAC
818	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	We must make sure that the heat doesn't transfer in/out of the container.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
818	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	The temperature of the inside water should change minimally.	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
818	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Thermal equilibrium is when 2 objects are the same temperature.	Declarative	Statement - Retrieving propositions, phases, rules, or statements	DEC-STA
818	3	Brainstorming and Research: KMT, Temperature, and Thermal Equilibrium	Maybe if the container is the same temperature as the water, it won't change temperature.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
818	3	Problem Identification: Problem Statement	We need to make a container that will keep cold water cold for as long as possible…	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
818	3	Problem Identification: Problem Statement	We have limited materials and time.	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
818	3	Problem Identification: Problem Statement	We must be able to keep 200 mL of cold water as cold as possible for 30 minutes, and be able to add and remove water without contamination	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
818	3	Problem Identification: Problem Statement	We must know what a good insulator is and how heat transfer works	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
818	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Conduction is heat transfer…	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
818	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	We want this (conduction) to happen very little	Strategic	Framing a problem - Statement or questions recognizing/labeling the features of tasks, procedures, and projects or making sense of tasks	STR-FRM
818	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Convection is heat transfer…	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF
818	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	… and radiation is heat from waves…	Declarative	Definition/Term - Statements involving formal definitions or particular scientific terms	DEC-DEF

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
818	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	…(radiation), occuring in all states of matter.	Declarative	Statement - Retrieving propositions, phases, rules, or statements	DEC-STA
818	4	Brainstorming and Research: Conduction, Convection, and Radiation Heat Transfer	Most heat will go from a hotter object to a colder one.	Declarative	Statement - Retrieving propositions, phases, rules, or statements	DEC-STA
818	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good insulators - …	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
818	4	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Good conductor	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
818	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in thermal conductors: sea of electrons	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
818	5	Brainstorming and Research: Materials that are Good Thermal Conductors and Good Thermal Insulators	Atoms in thermal insulators: tightly packed atoms that don't have freely moving electrons	Schematic	Theoretical Model - Explanations or reasoning with specific scientific models or theories	SCH-THE
818	6	Potential Design Solutions Summary: Individual Design	Materials:	Procedural	Procedure - Student articulating the steps of a procedure	P-PRO
818	7	Generating a Team Solution: Team Design	The sand will make the temperature change very little.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
818	7	Generating a Team Solution: Team Design	The rubber will also help because it is a good insulator.	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN

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818	7	Generating a Team Solution: Team Design	It (the rubber) will counteract the aluminum foil	Strategic	Planning - Statements or questions about what will or should happen next (steps or actions); Statements or questions related a plan to a condition or specifies the basis for choosing between alternative plans (hypothesizing or conjecturing)	STR-PLAN
818	8	Prototype Test and Data Analysis	Heat from the air transferred into the water.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
818	8	Prototype Test and Data Analysis	The rubber and sand blocked some of this (heat transfer) from happening.	Schematic	Explanatory Model - Explanations involving personal experience or everyday knowledge	SCH-EXP
818	8	Refining the Design	The design did a good job insulating the old water.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
818	8	Refining the Design	The temperature did not change much.	Procedural	Interpretation, predication, and conclusion - Statements related to making sense of the data or results, such as prediction	P-INT
818	8	Refining the Design	The water was uncontaminated.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON
818	8	Refining the Design	We met all of the criteria.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON

Student Code Number	Page Number	Portfolio Prompt	Student's Phrase[a]	Knowledge Type	Knowledge Subtype	Code
818	8	Refining the Design	We could add more rubber and sand to block more heat transfer.	Strategic	Monitoring - Statement or questions noticing/regulating/checking the progress or lack of progress (an ongoing task); Statement or questions concerning the conclusions at the end of the task (a completed or aborted task)	STR-MON

[a]Note. Highlighted cells indicate statements that express student misunderstanding or mistake.