Further Characterization of High School Pre- and Non-Engineering Students' Cognitive Activity During Engineering Design

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ABSTRACT

In response to STEM (science, technology, engineering, mathematics) educational reform, pedagogical approaches such as technological/engineering design-based learning (T/E DBL) have received increased emphasis as a means to enrich student learning and develop their higher-order cognitive competencies. Despite students exposure to the T and E of STEM as a means to make connections and improve learning (NAE & NRC, 2009), there still exists minimal evidence such experiences have a positive impact on their cognition and achievement (Honey, Pearson, & Schweingruber, 2014). Additionally, although research has well illustrated the design cognition of professional designers, and even students at the collegiate level, few investigations of high school students' cognitive activity during designing has been undertaken (Crismond & Adams, 2012; Hynes, 2012; Lammi & Becker, 2013). Furthermore, as researchers have begun to address this gap, broad coding schemes have been employed, describing students' cognitive efforts in terms of comprehensive categories such as formulation, analysis, and synthesis. However, as previous research has demonstrated nuances among existing categories (Purcell, Gero, Edwards, & McNeill, 1996), what has yet to be done is describe K-12 students' cognitive behaviors in terms of these underlying mechanisms.

The purpose of this study was to characterize students' cognitive processes during engineering design at a more distinct level, which can increase understanding and begin to address the minimal attempts to "connect research findings on how people design with what teachers need to understand and do to help K-16 students improve their design capability and learn through design activities" (Crismond & Adams, 2012, p. 738). The methodology of this study was informed by procedures of cognitive science and verbal protocol analysis. The primary form of data analyzed was audio and video recordings of the design task. The recorded data, in transcript form, was coded using the Purcell, Gero, Edwards, and McNeill (1996) framework. These coded data were then analyzed using descriptive and inferential statistics.

Findings from this study revealed that significant differences existed between high school seniors who took pre-engineering courses, and those who did not when engaged in Consulting Information about the Problem (Cp) and in considering System issues, which examined the problem from the point of view of the user. Additionally, Proposing a Solution (Ps), Postponing a Design Action (Pd), and Looking Back (Lb) approached a value of statistical significance in differences between the groups of participants. Findings also characterized how students exert the most and least amount of their cognitive effort in relation to the *Problem Domain: Degree of Abstraction* and *Strategy Classification* coding schemes.

Dedication

I would like to dedicate this dissertation to my wife Stacy, and son Thomas Michael. To Stacy, without your willingness and sense of adventure, I would not have made it to Virginia Tech. To Thomas, your birth served as the catalyst necessary to complete this endeavor. I hope you are fortunate enough to one day challenge yourself as I did. If so, perhaps the following poem by Robert Service will guide you, as it has me.

The Quitter

When you're lost in the Wild, and you're scared as a child,
And Death looks you bang in the eye,
And you're sore as a boil, it’s according to Hoyle
To cock your revolver and . . . die.
But the Code of a Man says: "Fight all you can,"
And self-dissolution is barred.
In hunger and woe, oh, it’s easy to blow . . .
It’s the hell-served-for-breakfast that’s hard.

"You're sick of the game!" Well, now that’s a shame.
You're young and you're brave and you're bright.
"You've had a raw deal!" I know — but don't squeal,
Buck up, do your damnedest, and fight.
It’s the plugging away that will win you the day,
So don't be a piker, old pard!
Just draw on your grit, it’s so easy to quit.
It’s the keeping-your chin-up that’s hard.

It’s easy to cry that you're beaten — and die;
It’s easy to crawfish and crawl;
But to fight and to fight when hope’s out of sight —
Why that’s the best game of them all!
And though you come out of each gruelling bout,
All broken and battered and scarred,
Just have one more try — it’s dead easy to die,
It’s the keeping-on-living that’s hard.

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CHAPTER I: INTRODUCTION

Current Educational Demands

Concerns related to national security, economic stability, and mediocre scores on international achievement tests continue to challenge the United States' ability to remain globally competitive (Augustine, 2007a; Provasnik, Gonzales, & Miller, 2009; Subotnik, Olszewski-Kubilius, & Worrell, 2011). In response, improvement recommendations have largely centered on increased innovation in STEM (science, technology, engineering, and mathematics) fields. Specifically, reports such as *Rising Above the Gathering Storm* (Augustine, 2007b) and *Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) Education for America's Future* (President's Council of Advisors on Science and Technology, 2010), are but a few that have recognized K-12 education as a viable vehicle for supporting STEM professions. As a result, one objective of STEM reform efforts is to foster students' interest and pursuit of STEM related careers (Roehrig, Moore, Wang, & Park, 2012).

Conversely, beyond an essentialist stance to ensure a sustainable workforce, proponents of current STEM *educational* reform are equally concerned with developing students' STEM literacy and 21st century cognitive competencies (Honey, Pearson, & Schweingruber, 2014). To do so, research findings support pedagogical approaches that promote a constructivist learning environment (Bruning, Schraw, Norby, & Ronning, 2004; Sanders, 2009). Such pedagogies include Problem-Based Learning (PBL), Project-Based Learning (PjBL), and Technological/Engineering Design-Based Learning (T/E DBL). Topically, there are similarities across all three methods, yet T/E DBL is central to Integrative STEM Education (I-STEM Ed) for the capability of intentionally teaching "content and practices of science and mathematics education concurrently with content and practices of technology/engineering education" (Wells & Ernst, 2012, para. 2). Wells (2012) identifies the goal of T/E DBL as promoting "integrative STEM thinking through the design of a product, system, or environment that provides solutions to practical problems" while embodying "habits of both hand and mind that together afford the learner knowledge and understanding necessary for developing appropriate solutions to human wants and needs" (para. 3). Design of a product provides teachers the opportunity to examine what students have learned (Sadler, Coyle, & Schwartz, 2000), while exposing them to engineering and technological practices. These practices can potentially improve student learning of mathematics and science and develop their cognitive abilities (Honey et al., 2014; NAE & NRC, 2009; Purzer, Moore, Baker, & Berland, 2014).

The recent release of the Next Generation Science Standards (NGSS), "raising engineering design to the same level as scientific inquiry" (NGSS Lead States, 2013, para. 1), also provides substantial support for T/E DBL at the K-12 level as science educators continue to use engineering design as an instructional strategy for teaching science concepts. Moreover, emphasis on student understanding of engineering and technology addresses the Technology and Engineering Literacy Framework, an addition to the National Assessment of Educational Progress (NAEP) that focuses on assessing technological and engineering literacy for all students. Collectively, attention towards engineering and technology has further reinforced the need to provide students effective engineering design experiences such as T/E DBL that can facilitate STEM learning and develop students' cognitive abilities.

Despite the notion that engineering design is a viable method for enhancing students' thinking capability (NAE & NRC 2009; NRC, 2012) and has been implemented by all four STEM disciplines (e.g. Crismond & Adams, 2012; Doppelt, Mehalik, Schunn, Silk, & Krysinksi, 2008; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Jacobson & Lehrer, 2000; Kolodner et al., 2003), minimal evidence indicates T/E DBL does indeed develop students' higher order thinking (Honey et al., 2014). Additionally, recent NAEP reports suggest students are proficient in lower-order thinking, but struggle with higher-order cognitive processes such as problem solving and design (De Miranda, 2004). Since a fundamental "purpose of teaching design is not to bring about change in the made world, but change in the student's cognitive skills" (Roberts, 1994, p. 172) it is vital to understand students cognitive processes during designing to improve instructional strategies. However, very few attempts (Wells, 2016) have been made to investigate and understand the actual cognitive processes K-12 students employ during engineering design. Thus, lack of research centered on students' cognitive processes during design has provided educators marginal support for creating effective instructional activities and determining to what extent T/E DBL experiences actually affect students' cognitive behavior. This lack of understanding and direction has prompted design cognition researchers to further explore students' cognitive processes as they attempt to solve design problems.

Background of the Problem

Although researchers have investigated design cognition across multiple disciplines and professions over the past 50 years, few studies have analyzed and characterized K-12 students' cognitive processes during T/E design-based activities.

Moreover, of the few existing K-12 research studies, investigators have captured only specific components of students' cognitive processes during design, such as analogical reasoning (Daugherty & Mentzer, 2008) and student modeling (Mentzer, Huffman, & Thayer, 2014). While these research investigations have revealed students' cognition during some phases of designing, other areas have been unexplored. Additionally, other coding schemes that have been employed are grounded on the notebooks of historical professional designers (Kelley, 2008) and may be outdated. Grubbs and Wells (2015) raise concerns whether these coding schemes fully describe all areas of K-12 students' cognitive processes during designing, are grounded in cognitive science, and are comprehensive enough to fully describe students' cognition.

Conversely, one approach to characterize students' design cognition that is more aligned with cognitive science and captures multiple cognitive phases of designing, is the widely accepted and validated Function-Behavior-Structure (FBS) ontology developed by John Gero (1990, 2004). Through the use of a design prompt, designers' verbal utterances are audio/video recorded, transcribed, and segmented based on the FBS ontology. Coded segments are then analyzed to describe how students' progress through eight design transformations. Coded design issues and design transformation processes can then be quantified through frequency counts to illustrate allocation of cognitive effort during engineering design.

Recent research findings using the FBS ontology indicate minimal cognitive differences exist between high-school students who have taken pre-engineering courses and those who have not taken them (Wells, Lammi, Grubbs, Gero, Paretti, & Williams, 2014). Results of this research suggest students at this level, with similar characteristics, either approach design tasks with general problem-solving skills or technology and engineering educators have had little effect on developing students' design cognition. However, the FBS ontology, using only eight processes to model students' cognition, subsumes additional descriptors of cognitive activity. These descriptors have previously been shown to describe an individual's mental activity during designing at a more detailed level. Describing K-12 students' cognitive activity more deeply can address the view that technology and engineering education researchers have examined students' cognition too broadly, and not at a deep enough level for practical application of technical skills (Zuga, 2004).

Two coding schemes have been previously used (e.g. Purcell, Gero, Edwards, & McNeill, 1996) to illustrate professional engineers' cognition during designing, but not K-12 students. These coding schemes further characterize specific phases of the FBS ontology that have not been explored by K-12 educational researchers. The first coding scheme, titled *Problem Domain: Level of Abstraction*, examines the problem formulation stage of the FBS ontology to a finer degree. Previous research indicates novice designers struggle to move past this phase, resulting in failure to generate solutions (Welch & Lim, 2000). Additionally, findings show K-12 students invest limited effort formulating the problem (Wells et al., 2014). Furthermore, problem formulation is a phase of designing that has not been previously explored and described by K-12 educational researchers and is recognized as a creative process (Csikszentmihalyi, 1994) that is beneficial to learning, and a fundamental outcome of T/E DBL. Therefore, understanding students' cognition during this phase can better aid teachers during the design of T/E DBL activities.

The *Problem Domain: Level of Abstraction* coding scheme illustrates the depth to which an individual decomposes the design problem. Within this coding scheme, the cognitive effort of the designer during the problem formulation stage is distributed between three categories: the system, subsystems, and detail levels of the problem. An individual who considers the problem from the point of view of the user focuses on the "system" level and does not fully deal with the complexity of the design problem. Conversely, an individual wholly approaching the complexity of the problem is contemplating the "detail" levels of a problem. Cognitive effort in the subsystems and detail levels of the problem requires higher-order thinking and increased application of background knowledge. In contrast, cognitive effort within the system level is tantamount to lower-order thinking and minimal incorporation of background knowledge. Therefore, employing the problem formulation coding scheme can further describe how students decompose a design problem they confront, distinguish whether students who are exposed to pre-engineering courses do so at a deeper level, and illustrate strategies successful students employ. Additional definitions and examples of this coding scheme will be presented in Chapter 2.

The second coding scheme, identified as *Strategy Classification*, further describes students' cognitive activity during the synthesis, analysis, and evaluation phases of the FBS ontology while also considering explicit strategies that students use during designing. Cross (2000) reports that these phases form the fundamental structure of a number of design models, making it easily comparable to other design cognition findings. Furthermore, these cognitive phases of designing are associated with critical thinking (Ennis, 1993), which is identified as a necessary cognitive competency of the 21st

Century. Also, recent studies (Lammi, 2011; Wells, 2016) suggest high-school students spend a significant amount of cognitive effort during these stages, yet there is insufficient understanding of what cognitive activity is occurring under the surface. Understanding how students' cognitively navigate these stages can aid educators in appropriately scaffolding learning experiences to enhance their critical thinking skills during designing and other challenging life experiences.

Whereas the FBS ontology captures students' overall effort during these phases, the *Strategy Classification* coding scheme depicts specifically cognitive issues students consider as they solve a design problem. For example, within each coding category (e.g. analysis, synthesis, evaluating), students may be postponing efforts such as making a design decision. This cognitive action is captured and distinguished by the *Strategy Classification* coding scheme whereas the FBS ontology still considers "postponing" as a broader category such as "analysis" and therefore would not capture differences between student groups. Students therefore may be directly dealing with analysis, while other students may simply be postponing the actual analysis of the design solution. Yet, use of the FBS ontology would not capture such differences. Additionally, within each category of the *Strategy Classification* scheme, specific strategies students use such as "performing calculations to analyze a proposed solution" are detailed whereas the FBS ontology does not distinguish at this level. Such categories are specifically related to goals of STEM educational reform, including developing students' higher order thinking, and may substantiate one pedagogical approach over another.

Compared to the FBS ontology, both coding schemes describe at a deeper level students' cognitive activity during engineering design. In turn, use of the *Problem*

Domain: Level of Abstraction and *Strategy Classification* coding schemes can result in a more refined understanding of how high school students' cognitively design, in addition may depict differences between high school students who take pre-engineering courses and those who have not taken them.

Rationale of the Study

A fundamental goal of STEM educational reform is to expose K-12 students to the T and E of STEM as a means to make connections between subject matter, improve learning, and enhance their cognition (NAE & NRC, 2009). Specifically, high school pre-engineering experiences are recognized as potentially viable learning pathways that can develop students' cognition and address current goals of STEM educational reform. In turn, the rationale for this study stems from the need to understand students' cognitive processes during these experiences (Barak & Hacker, 2011; Petrina, 2010; Ritz & Martin, 2012; Strimel, 2014; Zuga, 2004). Increased understanding of students' cognitive processes during designing may not only allow educators to identify and correct student learning problems (Bransford & Vye, 1989; Strimel, 2014), but also better determine if differences do exist between students who take pre-engineering courses, and students who do not.

Problem Statement

Although researchers have well illustrated the design cognition of professional designers and students at the collegiate level, few research investigations have examined high school students' cognitive activity during designing (Crismond & Adams, 2012; Hynes, 2012; Lammi & Becker, 2013). Moreover, as researchers have begun to address this gap, they have employed coding schemes comprehensively in terms of broad categories such as formulation, analysis, and synthesis. However, previous researchers have further characterized these broad descriptors of cognitive activity at a more detailed level (Purcell, Gero, Edwards, & McNeill, 1996). As a result, what have yet to be understood are K-12 students' cognitive processes in terms of underlying mechanisms during engineering design at a more distinct level.

Purpose of the Study

The purpose of this study is to further characterize high school pre- and non-engineering students' cognitive processes at a more distinct level, specifically the underlying mechanisms of broadly used classifications such as problem formulation, analysis, synthesis, and evaluation. Describing students' cognitive processes more clearly will establish greater understanding of students' cognitive activity during design, thereby addressing the lack of research based findings with what educators can do to enhance students design skills and learning ability (Crismond & Adams, 2012). Additionally, this line of research can result in greater understanding of novice designers' cognitive processes, which can support teachers in developing instructional tools that are grounded in findings of cognitive science. In turn, educators can more effectively cultivate students' 21st century cognitive competencies and better equip students to deal with challenging problems they will encounter throughout their life (Razzouk & Shute, 2012).

Research Questions

The following research questions were used to address the problem and purpose of this study.

1. How do 12th grade high school pre- and non-engineering students' distribute their cognitive efforts as they dissect the problem domain during engineering design tasks?
2. How do 12th grade high school pre- and non-engineering students distribute their cognitive efforts as they synthesize, analyze, and evaluate during engineering design tasks?
3. Do differences in cognitive processes emerge between 12th grade high school students who take pre-engineering courses and those who do not?

Delimitations

The participants of the current research investigation were 42 high school pre- and non-engineering students who took part in a previously conducted National Science Foundation (NSF) funded longitudinal study. The initial study, referred to as Understanding High School Students' Design Cognition (UHSSDC) and supported under NSF Grant No. 1160345, examined students' cognitive behaviors during engineering design tasks across a two year span (NSF, 2012). The initial population of 42 students was selected from three high schools across southwest Virginia and participated as Juniors and Seniors. The researcher of the current study purposefully selected extant data of the participants during their senior year to account for additional exposure to engineering instruction and content. In comparison, engineering students who participated during their Junior year may have only been enrolled for a short period of time, and therefore may not have been fully immersed to the engineering curricula.

Operational Definitions

21st Century Cognitive Competencies: "a blend of cognitive, interpersonal, and intrapersonal characteristics that may support deeper learning and knowledge transfer. Cognitive competencies include critical thinking and innovation; interpersonal attributes include communication, collaboration, and responsibility; and intrapersonal traits include flexibility, initiative, and metacognition" (Honey, Pearson, & Schweingruber, 2014, p. 35).

Cognition: the collection of mental acts, processes, and activities taking general terms such as perceiving, learning, remembering, thinking, understanding, remembering, and reasoning (Ashcraft, 1998; Menary, 2007).

Cognitive Effort: Refers to the amount or portion of limited attentional resources that are momentarily allocated to the processing of a task (Kahneman, 1973; Piolat, Olive, & Kellogg, 2005; Tyler, Hertel, McCallum, & Ellis, 1979).

Cognitive Processes: "A process is cognitive when it aims at completing a cognitive task; and it is constituted by manipulating a vehicle" (Menary, 2007, p.15).

Cognitive Task: "particular cognitive capacities such as remembering a date, solving a problem, learning to do something" and "exercising of cognitive capacities is directly tied to their successful completion" (Menary, 2007, p.15).

Design: Commonly viewed as a central or distinguishing engineering activity (Razzouk & Shute, 2012), design is "purposeful and the activity of designing is goal-oriented" (Gero, 1990). Often associated as a final description and referred to as a form of problem-solving (Freeman, 1980; Visser, 2009), "everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (Simon, 1969, p. 111).

Design Cognition: "analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and redesign" (Razzouk & Shute, 2012, p. 330).

Design-Based Learning: A teaching and learning approach, which requires students to use engineering design (Doppelt et al., 2008) to create products through facets of problem and project-based learning.

Engineering Design: Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints (Dym, Agogino, Eris, Frey, & Leifer, 2005, p. 104).

FBS Ontology: "The FBS framework represents designing by a set of processes linking function, behaviour and structure together" (Gero & Kannengiesser, 2004, p. 374).

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

Verbal Protocol Analysis (VPA): Research method used to elicit and capture students' cognitive thoughts and processes from either a concurrent or retrospective report.

CHAPTER II: LITERATURE REVIEW

Overview

The current research investigation stemmed from an interest in understanding high school students' cognitive processes during designing at a deeper level to better prepare teachers and educators in delivery of T/E DBL. To gain a greater understanding of existing research related to the problem and research questions of this study, the current study was informed by a comprehensive investigation of literature relevant to design cognition at the K-12 level. Therefore, the purpose of Chapter 2 is to "explain the topic of the research and to build a rationale for the problem that is studied and the need for additional research" (Mertens, 2014, p. 89). To develop an improved understanding of existing research and the topic at hand, this study reviewed and synthesized two interrelated areas that underpin design cognition research at the K-12 educational level including: (a) current STEM (science, technology, engineering, mathematics) educational reform and (b) previously conducted design cognition research. This literature review situated the current study within a broader context (Mertens, 2014) by reviewing STEM educational reform and provided clarity for examining students' cognitive processes during designing by examining existing K-12 design cognition research. As a result, Chapter 2 informed and guided the researcher as he investigated students' cognitive processes during designing.

STEM Educational Reform

Establishing a STEM Workforce

A key support for design cognition at the K-12 level is current STEM reform. Though the presently employed STEM acronym is of recent origin, arguably credited to

Judith Ramaley of the National Science Foundation (NSF) in the early 2000s (Chute, 2009), attention to STEM has been progressively established since the 1944 report *Science, the Endless Frontier* (Bush, 1945; Zollman, 2012). Anticipating future scientific and technological advancements, science and science education were cited in this 1944 report as being of immense importance in the postwar growth of the United States. This led to recommendations for a national research council to ensure scientific progress was attainable after "the deficit of science and technology students who, but for the war, would have received bachelor's degrees" (Bush, 1945, p. 7). Although a significant outcome of this report was the establishment of the NSF and subsequent attention to science *education*, rebuilding the STEM workforce was of principal concern at the time.

Following post-war reconstruction efforts, the launching of Sputnik in 1957 again energized STEM workforce concerns, invoking the creation of NASA to ensure technological progress at a time of competition with Russia during the Cold War. Concurrently, emphasis on science and technology was strengthened by the passing of the National Defense of Education Act (NDEA) of 1958. Although a primary intent of the NDEA was ensuring a strong pipeline of STEM professionals, improving student achievement in mathematics and science was also addressed (Scott & Sarkees-Wircenski, 2004). Subsequently, the space race and ensuing educational legislation continued support for science education, while introducing focus on mathematics. Largely a measure of national security, response to Sputnik, and anticipation of future technological advancements of Russia, the educational system was again viewed as vital for improving the STEM pipeline. Collectively, the primary intent of early STEM efforts, and even present concerns, was to ensure students were skilled for future careers. When viewed through this lens, the purpose of design cognition research at the K-12 level would be to examine students' mental activity to make them better designers. However, a second, parallel STEM stream reveals an alternative direction and fundamental goals.

General STEM Education Literacy

Although one guiding force behind past and current STEM educational reform is ensuring entry into STEM careers, remaining globally competitive will equally depend on the accumulated knowledge and skills of the general populace (President's Council on Advisors of Science and Technology, 2010). As a result, systemic change and preparing all students to be STEM literate was initially met by the publication *A Nation at Risk* (NCEE, 1983). This was a significant turning point for STEM education and a foundation for the *Excellence Reform Movement* (Berube & Berube, 2007). This report evoked concerns of a failing educational system by making calls for increased course content, specifically mathematics and science, improvement of graduation rates, teacher accountability measures that were more rigorous, and higher expectations of students.

Government and national education organizations responded to *A Nation at Risk* with the standards movement, which evoked a national policy shift from primarily emphasizing increased output of STEM graduates towards changes in pedagogical approaches and learning environments. Specifically, integration between subject areas and attention to experiential based, student-centered learning environments appeared most salient among educational reform efforts and provides considerable support for fostering students' design cognition. The significance of current STEM educational reform and the effect it has on investigating design cognition can be understood by examining the standards movements and the resulting changes to pedagogical practices.

Standards Movement: Calls for Integration

In response to *A Nation at Risk*, the standards movement prompted publications such as *Goals 2000* which recommended integrative frameworks and teaching through application based approaches (Humphreys, 2005). Mathematics education was the first discipline to respond with the publication *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989). This document, largely rooted in emerging constructivist views, criticized antedated learning environments that required lower level thinking such as memorization of facts and simple recall. Recommendations were made for more meaningful and student-centered learning opportunities such as problem solving of real world issues to develop students' higher-order cognitive processes including reasoning and critical thinking (NCTM, 1989).

The release of *Science for All Americans* (*SfAA*) (AAAS, 1990) through Project 2061, also challenged traditional approaches to teaching and learning while viewing educators as failing to provide students' opportunities to collaborate and illustrate to them the knowledge of math, science, and technology required to be scientifically literate. Committee members suggested the then current educational practices over emphasized "the learning of answers more than the exploration of questions, memory at the expense of critical thought, bits and pieces of information instead of understandings in context, recitation over argument" and "reading in lieu of doing" (p. 3). Subsequently, connecting knowing and doing was considered vital to student learning. As a result, design and the creation of technological artifacts were proposed as a viable approach to extend results of scientific inquiry while integrating science concepts.

Symbiotic to and extending *SfAA, Benchmarks for Science Literacy* (AAAS, 1993) made recommendations for what students should know to be scientifically literate while further endorsing use of design and technology projects as a method for exposing students to problem solving and student centered approaches to learning. As Wells (2008) suggests "the obvious intent of these AAAS publications was to teach through integration" (p. 7). Likewise, Todd (1999) posits that Project 2061 "underscores the need to integrate separate subjects and particularly science, mathematics, and technology" illustrating the "utility found in linking the three subjects helps students apply what they have learned to practical situations" (p. 28).

Similar themes of support for integrative, hands-on approaches to learning resonate through the National Research Council's (1996) *National Science Education Standards*. This is evident in the suggestion "there should be less emphasis on activities that demonstrate and verify science content" and more emphasis on those "that investigate and analyze science questions" (NRC, 1996, p. 113). As a result of criticizing rote learning and basic recall of facts, science education assisted in challenging the fragmented and isolated approaches of education while establishing at the national level formal adoption of STEM integration. Such calls shifted focus from lower order cognitive processes to higher-order thinking, embracing student led activities such as design for its integrative, hands-on, and authentic characteristics.

Technology education responded to the standards movement by producing the *Standards for Technological Literacy: Content for the Study of Technology* (*STL*) (ITEA/ITEEA, 2000/2002/2007). Harmonizing the integrative calls of science education, a central tenet of the STL was a constructivist approach with a strong focus on integration

(Becker, 2002) and developing all students to be technologically literate. The STL emphasized the design process for its ability to integrate multiple subject areas through the creation of a product to meet human needs and wants. The creation of a product represents what a student has learned or understands (Sadler, Coyle, & Schwartz, 2000) and provides a context to bridge knowing and doing. Directly supporting the *STL* belief that all students should become technologically literate to fully participate in society, the publication *Technically Speaking* (Pearson & Young, 2002) defined technological literacy as having three dimensions including, knowledge, ways of thinking and acting, and capabilities. Underpinning technological literacy is the interdependency of these three dimensions, specifically linking the capability dimension with hands-on, technological/engineering design, and problem solving (Pearson & Young, 2002).

Most recently, the release of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) has further evoked support for design as an approach to provide integrative, hands-on learning experiences for students. Extending publications such as *A Framework for K-12 Science Education* (NRC, 2012) that propose students should be adept in both science and engineering, a salient charge of the NGSS is to bring engineering design to the same level as scientific inquiry (NGSS Lead States, 2013). Milano (2013) suggests this amalgamation of scientific inquiry and engineering design in the NGSS affords students the opportunity to create technological products through incorporation of findings from scientific inquiry. Additionally, an expected outcome is the development of higher order cognitive processes such as critical thinking, problem solving, and reasoning for successful participation as future citizens.

Implications of Current STEM Educational Reform

Efforts of the standards movement reveal a central theme is implementation of authentic, integrative, active, and student-centered learning experiences (Becker & Park, 2011; Sanders, 2009, 2012; Wells, 2008, 2013; Zollman, 2013). Two primary goals of such experiences are to enhance students' STEM literacy and 21st century cognitive competencies (Honey et al., 2014). STEM literacy can be defined as "the ability to identify, apply, and integrate concepts from science, technology, engineering, and mathematics to understand complex problems and to innovate to solve them" (Balka, 2011, p. 7). While Honey et al., (2014) posit "critical thinking and innovation; interpersonal attributes include communication, collaboration, and responsibility; and intrapersonal traits include flexibility, initiative, and metacognition" as 21st century cognitive competencies (p. 35). In turn, research efforts aligned with the goals of current STEM educational reform should attempt to characterize students' design cognition at the K-12 level with the intent of developing students STEM literacy and their ability to develop 21st century cognitive competencies.

Designing and Design Cognition Research

Humans have engaged in designing to improve their environment for over 4000 years dating back to Hammurabi in 2000 BC (Gero, 1990). Evidence even suggests that Plato considered himself a designer of political societies (Winner, 2010). Although designing is viewed as a primary role of engineers (Dym, Agogino, Eris, Frey, & Leifer, 2005), Simon (1969) believed "everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (p. 111). Designing is often associated with a final product or sketch, while others classify designing fundamentally as a form of problem-solving (Freeman, 1980; Visser, 2009). Others consider designing to be more explicit than mere problem solving (Daly, Adams, & Bodner, 2012) for the “wicked” (Buchanan, 1992; Rittel & Webber, 1973) or ill-structured (Simon, 1973) problems that designers must solve. These problems parallel real life challenges (Gomez Puente, Van Eijck, & Jochems, 2013) and the demand complex cognitive activity (Dym, Agogino, Eris, Frey, & Leifer, 2005; Lammi & Becker, 2013) necessary for participating in a 21st century context. Yet, as many still consider designing a mysterious activity that is difficult to define (Dym, et al., 2005; Gero, 1990), distinguishing between the varying problem types can aid researchers in investigating the style of problems to present to students.

Problem Types

Presenting students challenging problems has long been employed as a teaching and learning approach in STEM education disciplines (e. g. Charen, 1963). Learning however is not the result of simply adding problems to classroom instruction. Rather, learning is grounded in a problem germane to students to illustrate the relevance of content through a real world context (Loyens, Kirschner, & Paas, 2012). Such a context contributes to students’ motivation and interest in the learning experience (Jones, et al., 2014). Though this approach is recognized as viable for preparing students for a 21st century world, a variety of problem types have been identified. Each problem type can be distinguished from one another by the cognitive demands placed upon the problem solver and carries implications for how students decompose it during designing. Attempts to classify problem types have brought to bear many representations distinguished by multiple characteristics. One commonly referred to is Jonassen’s (2011a) classification of problems by the features structuredness, complexity, and context. This has resulted in three types of problems including puzzle, well-structured, and ill-structured (Jonassen, 1997).

The first type of problems are puzzle-problems, which are typically not very complicated as a result of requiring little background knowledge to solve and demanding one correct solution (Chi & Glaser, 1985; Jonassen, 1997). These types of problems may be of little use for instructional designers as they are domain-independent and are "inconsistent with the nature of most situated real-world problem solving" (Jonassen, 1997. p. 67). Thus, the minimal demand of knowledge, specifically domain specific such as school subject matter provides little use and examination of puzzle problems.

Well-structured problems on the other hand are frequently presented to students at the K-12 level. These types of problems are typical of textbook questions requiring the "application of a finite number of concepts, rules, and principals being studied to a constrained problem situation" and are more dependent on domain and content knowledge (Jonassen, 1997, p. 68). An important feature of well-structured problems, also denoted as transformation problems, is that they are comprised of a clear initial state, an identifiable goal state, and a set of operators that can transform one problem state to another (Greeno, 1976, 1978; Jonassen, 1997). Students could essentially be taught specific paths for completing well-defined problems.

Conversely, ill-structured problems, commonly associated with designing, provide few aspects of the problem, requiring the solver to define the problem in their own terms. These types of problems are more typical of everyday real life problems that students will encounter. They are also referred to as wicked problems, in which the problem is not clearly identified (Rittel & Webber, 1973). Whereas high school students are accustomed to well-structured problems requiring convergent answers with well-established evaluation measures, resulting in learning strategies that concentrate on finding the correct answer, they have little experience and are unprepared for ill-structured ones (Jonassen, 2011b).

Understanding the difference between well-structured and ill-structured problems can have implications for instructional practices and student learning outcomes. This is in line with Jonassen's (1997) proposition that

> A primary purpose in distinguishing between well-structured and ill-structured problems results from the commonly held assumption that skills in solving well-structured, classroom problems will transfer positively to real world, situated, ill-structured problems. It is important to recognize that effects of well-structured problems in school contexts have limited relevance and transferability to solving problems that are situated in everyday contexts. (p. 70).

As ill-structured problems are most closely aligned with the real world ones students will encounter throughout their life, it is essential for educators and instructional designers to understand their cognitive processes as they attempt to solve them. Specifically, since a significant portion of the problem solving process consists of problem defining and shaping (Rowe, 1987), understanding this phase of designing is even more crucial to designing instructional activities and student learning outcomes. Findings can aid in creating adequate and effective instructional practices specifically designed for ill-structured problems. The following section will present research related to students' design cognition as they solve ill-defined problems to illustrate. The purpose of discussing selected K-12 design cognition research studies is to illustrate how previous research has not fully captured students' cognitive processes when solving ill-defined problems during designing.

Design Cognition Research

In consideration of the significance placed upon engineering-design based pedagogical approaches and design cognition, it is essential to understand the cognitive processes students employ during such tasks to provide effective instruction, adequate scaffolding, and appropriate feedback. Moreover, if an underlying purpose of teaching students design is to develop their cognitive skills (Roberts, 1994), careful examination of existing strategies is "critical to developing curriculum that develops technologically literate individuals" (Kelley, 2008, p. 51). Despite beliefs that designing has a positive impact on students' thinking capability, few research studies however have actually evidenced improvement of students' higher order cognition (Honey et al., 2014). One can argue this is attributed to few investigations of students' cognitive processes during designing which have provided marginal support (Crismond & Adams, 2012; Kelley, 2008; Lammi, 2011) for instructional practices. In turn, design cognition research methods have been formed to specifically target investigations of individuals' mental activity during design.

Despite the genesis of major design cognition research programs as early as the 1960s, investigations of the cognitive processes students employ at the K-12 level have not been as fruitful. Thus, research findings characterizing design professionals and university level students' cognitive processes during design may not adequately describe students' mental activity in K-12 educational settings. Furthermore, few attempts have been made to intentionally connect research on how individuals design with what teachers “need to understand and do to help K-16 students improve their design capability and learn through design activities" (Crismond & Adams, 2012, p. 738). Without knowledge of students’ cognitive processes during designing, teachers may not provide effective instruction and may also mistakenly teach students unproductive design behaviors, cognitive habits, or reinforce their misconception (Crismond & Adams, 2012; Hynes, 2012).

Cross (1999) breaks design research into three main categories that have up to this point been undertaken. First, design phenomenology, or the study of the products and their configurations. Second, design praxeology beginning in the 1960’s studied the process of design. Lastly, design epistemology beginning in the early 2000’s, studies the people or cognitive processes of design. Throughout the design epistemology stage, verbal protocol analysis studies have saturated research methodologies and have most often been used to examine designers’ cognitive processes (Atman et al., 2007; Daly, Adams, & Bodner, 2012). Two methods of verbal protocol analysis are commonly used, concurrent or retrospective approaches. While retrospective asks participants to recall past design experiences, concurrent protocol analysis captures cognitive thoughts during the solving of a design task.

K-12 Design Cognition Research

Although a wealth of research has been conducted to describe cognitive processes of practicing professionals and undergraduate students, only in recent years has design cognition research in the K-12 environment come to fruition. There have been even less contributions that adequately illustrate students underlying cognitive characteristics that direct or affect their cognitive behaviors. Furthermore, determining the effect of coursework on high school students' cognition, specifically those who have taken pre-engineering courses and those who have not, has not been adequately identified or described to better understand the impact such experiences might have on students overall cognitive abilities.

Of the existing design cognition research studies examining K-12 students many have illustrated students' cognitive processes in terms of broad categories. Kelley (2008) for example used 17 codes to capture high school students' cognitive processes during designing. This coding scheme was based on a 1973 (Halfin) study that categorized notable engineers' notebooks. Codes such as analyzing, communicating, computing, testing, and visualizing were used to describe students' cognitive processes. Although findings from this study illustrate the distribution of students cognitive efforts across each process, minimal description of the underlying cognitive processes students employ are presented. Secondly, one limitation is the use of a dated coding scheme that addresses expert designers' cognitive strategies. Lastly, identification of students' cognitive effort spent analyzing is a broad category that provides beneficial direction for educators but can still be broken down into subsequent strategies. Illustrating how students analyze a design task could very well be very different between novice and expert designers, as well as between different student populations.

FBS Ontology. Recently, Lammi (2011) examined high school students' design thinking using the Function-Behavior-Structure (FBS) ontology developed by Gero (1990). This widely accepted, well-grounded, and effective approach (Cascini, Del Frate, Fantoni, & Montagna, 2011) was created by John Gero and his associates to characterize an individual's design cognition and cognitive design style. Whereas Gero's (1990) initial FBS computational model assumed designing began with function, the Gero and Kannengiesser's (2004) situated FBS framework was a cognitive model that viewed designing as beginning with requirements (Kan & Gero, 2009). The addition of requirements account for use of the design activities in protocol studies as they begin with a set of requirements (Kan & Gero, 2009). Extending the initial computational model (Gero, 1990), Kan and Gero (2009) define the situated FBS ontology as

> making use of new concepts: the notion of situated cognition developed by Clancey (1997); the idea of constructive memory based on Dewey's (1896) and Bartlett's (1932) work; and the observation of designing as an "interaction of making and seeing" by Schon and Wiggins (1992). (p. 9).

The situated FBS ontology responds to developments in cognitivism and constructivism and is well aligned with T/E DBL pedagogical approaches currently being implemented as a result of current STEM education reform.

Six Design Issues. The FBS ontology represents three classes of variables including function, behavior, and structure (Kan & Gero, 2009). Gero and Kannengiesser (2004) define the following three classes as:

- Function (F) variables: describe the teleology of the object, i.e. what it is for.
- Behavior (B) variables: describe the attributes that are derived or expected to be derived from the structure (S) variables of the object, i.e. what it does.
- Structure (S) variables: describe the components of the object and their relationships, i.e. what it is.

Within these three classes of variables, Kan and Gero (2009) define the FBS coding scheme as consisting of five codes (F, Be, Bs, S and D) with two additional codes of requirement (R) and others (O) that did not fit within the original coding scheme. These seven codes represent cognitive design issues that are viewed as the basis of design cognition (Lee, Gero, & Williams, 2012). As an individual transforms the function of a design to a description, interaction between these design issues is the consequence of a series of processes between the FBS variables (Lee, Gero, & Williams, 2012). Figure 1 illustrates the six design issues of the FBS ontology in relation to the design of a mobile cell phone.

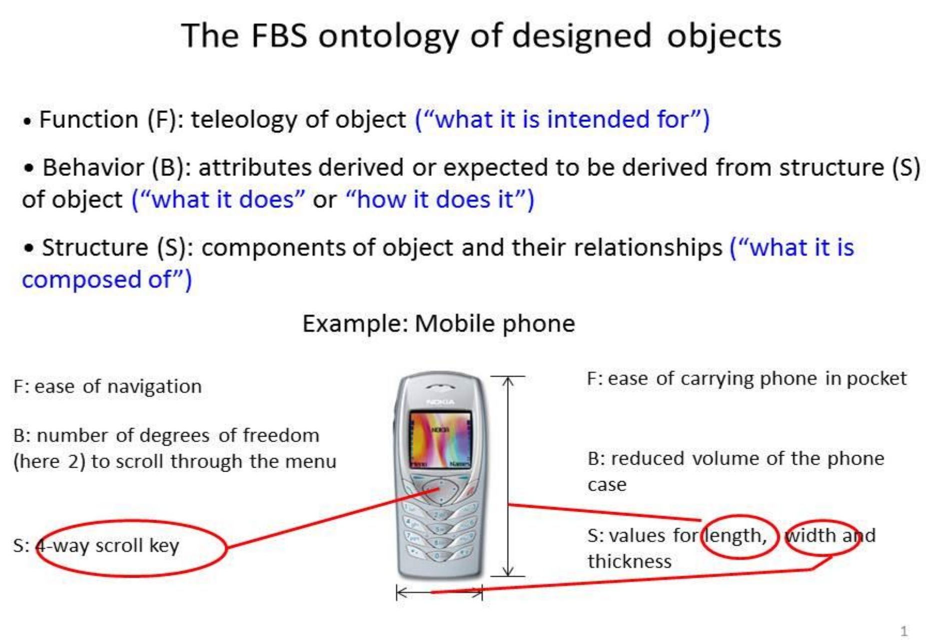

Figure 1. FBS Ontology-6 Design Issues. This figure illustrates and defines the six design issues of the FBS ontology. (Reprinted with permission from Dr. John Gero's training session of FBS ontology, July, 2012).

Eight Design Processes. Use of a design prompt requires students to solve a design task while concurrently being video recorded. Students' verbal utterances are transcribed and segmented based on the FBS coding scheme. After reaching agreement between researchers, final segmented codes of the smallest unit are analyzed to identify design transformations in relation to eight design processes. Gero and Kannengiesser (2004) identify the following eight processes as fundamental for all designing circumstances.

1. Formulation transforms the design requirements, expressed in function (F), into behaviour (Be) that is expected to enable this function.
2. Synthesis transforms the expected behaviour (Be) into a solution structure (S) that is intended to exhibit this desired behaviour.
3. Analysis derives the 'actual' behaviour (Bs) from the synthesized structure (S).
4. Evaluation compares the behaviour derived from structure (Bs) with the expected behaviour to prepare the decision if the design solution is to be accepted.
5. Documentation produces the design description (D) for constructing or manufacturing the product.
6. Reformulation type 1 addresses changes in the design state space in terms of structure variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory.
7. Reformulation type 2 addresses changes in the design state space in terms of behaviour variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory.

8. Reformulation type 3 addresses changes in the design state space in terms of function variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory. (p. 374-375).

The eight design processes listed above can be identified through connections that are made between the segments during designing and is captured in Figure 2.

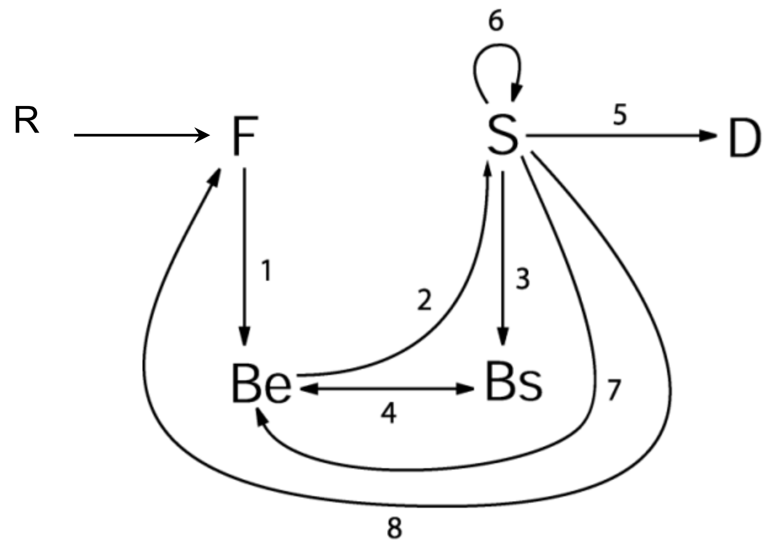

Figure 2. The FBS Ontology. – 8 Design Processes. This figure illustrates the 8 processes mapped from the six design issues of the FBS ontology.

Comparison of Pre- and Non Engineering Students. Wells et al. (2014), also employing the well-established and highly replicated Function-Behavior-Structure (FBS/sFBS) coding scheme developed by Gero and associates (1990, 2004), examined and compared high school students who took pre-engineering courses and those who did not. Findings from the first year of a two year longitudinal study illustrated no significant difference between participant groups of engineering and non-engineering, in both design issues and processes (Wells et al., 2014). The following sections describe in detail the original researchers' procedures for conducting their study which are the basis for the current investigation.

Participants. The participants examined in this dissertation were selected from an extant database (NSF, 2012) that included 42 high school seniors from three mid-Atlantic high schools in their second year of a longitudinal study. Researchers of the initial study used a purposeful sampling strategy to select students and assign them to one of two groups, those who took pre-engineering courses and those who did not. Students were self-selected into dyads, an arrangement of two participants that has been established as a valid approach to naturally stimulate verbal communication between collaborators when completing engineering design solutions (Kan & Gero, 2009; Lammi, 2011; Purzer, Baker, Roberts, & Krause, 2008; Wells et al., 2014). Lammi et al. (2014) reports that formal educational experiences of students' of the pre-engineering group varied from one year of coursework to only just beginning during their junior year, while students of the non-pre-engineering group had no prior coursework. Additionally, both the pre- and non-engineering student groups included a similar percentage of students in regards to gender distribution as the pre-engineering group was 64% male and 36% female, and the non-engineering group was 65% male and 35% female (Lammi, 2014, p. 2).

Data Collection. The primary source of data collected was students' verbalized utterances during their design session. Students were allowed up to 45 minutes to complete the design task, and were instructed to include any forms of detailed sketching on a dry erase board. The design task is presented in Appendix A. This process was captured through two high-powered audio recording devices directly feeding into two video recording devices. One of the video recording devices captured an overview of students' process while the other was positioned to specifically capture students' efforts at the white board. This also captured the final design students completed at the conclusion of the design task.

The data collected from the UHSSDC, study was originally analyzed using a well-established coding scheme, the Function-Structure-Behavior (FBS) ontological framework established by John Gero and associates (Gero, 1990; Gero & Kannengiesser, 2004). These data were first transcribed by documenting participant utterances verbatim. This was completed through Microsoft Excel and used alternative rows to depict each participant, while including timestamps as reference points for students' time designing (Wells et al., 2014).

Data Analysis. Final transcripts were then segmented by independent coders using the FBS ontology. As Wells et al. (2014) report, coders concurrently segmented and coded, "dividing the utterances until each individual segment contained a single code that reflected only one of the six possible design issues" (p. 6). Once each coder segmented and coded, final documents were merged into one protocol that was prepared for arbitration. Arbitration allowed each coder to compare, debate, and defend their codes until a finale agreed upon segmentation/code was reached.

After arbitration was complete, analysis of final protocols utilized LINKODER to provide descriptive statistics and analysis of probability of the FBS framework (Wells et al., 2014). These data were then examined to see if statistical differences existed between pre-engineering and non-engineering groups in terms of FBS design issues and syntactic processes. As findings from the first year of the longitudinal study indicate no significant differences between the pre-engineering and non-engineering groups existed, further analysis through a more distinct coding scheme can provided additional understanding for why such results were reported.

Underlying Cognitive Processes. The FBS ontology is a valid approach for capturing students' cognitive processes, yet previously established coding schemes have been documented to further characterize students' cognitive efforts (Purcell, Gero, Edwards, & McNeil, 1996). Specifically, two coding schemes have been developed that illustrate cognitive phases of designing not previously examined at the K-12 level. The following two sections describe these coding schemes and their ability to decompose the problem domain and other phases of designing at a more distinct level.

Problem Domain: Degree of Abstraction. As individuals progress through designing, their cognition is often represented as a search process across a problem space and solution space (Jiang, Gero, & Yen, 2012). As a result, their cognitive efforts can largely be divided between these two spaces (Kruger & Cross, 2001). For example, research findings indicate expert designers spend a considerable amount of cognitive effort constructing the problem, whereas novices do not (e.g., Atman, Chimka, Bursic, & Nachtmann, 1999; Ball, Ormerod, & Morley, 2004; Chi, Feltovich, & Glaser, 1981; Cross, 2006; Goel & Pirolli, 1992; Wagner, 2014). Specifically, Atman et al. (2007) report that novices spend less cognitive effort than experts qualitatively analyzing the problem they are presented. Additionally, of the few K-12 research investigations that have recently examined students' design cognition, most show high school students spend a small portion of their efforts formulating the problem (Lammi, 2011; Kelley, 2008; Wells et al., 2014). At the undergraduate level, findings have been reported that show freshman and senior engineering students spend most of their cognitive effort during the problem formulation stage on the details of the problem (Ting, 2014).

Wagner (2014) suggests problem formulation consists of deconstructing the problem into "component parts and looking for connections among those parts" (p. 22). Whereas expert designers are able to use prior knowledge to restructure the problem, novices focus on surface features as a result of minimal experience and knowledge (Lawson, 2004; Wagner, 2014). Additionally, McKenna and Hutchison (2008) found that when engineering students are presented well-structured problems, they demonstrated greater pursuits of information associated with the problem, greater connections to prior knowledge, and were more focused during their learning (Jonassen, 2011b). Conversely, when confronting ill-structured problems, students attempted fewer times to understand the problem, connect it to their prior knowledge, and vaguely gather information related to the problem. Jonassen (2011b) concludes that these characteristics demonstrate the challenges students have and their uncertainty for approaching ill-structured problems. Similarly, Welch and Lim (2000) have reported novice designers struggle to move past the problem phase, resulting in failure to generate solutions.

The problem formulation stage, recognized as a creative process, is often more significant than the final solution (Csikszentmihalyi, 1994) and can be beneficial to learning. However, researchers tend to examine cognition in regards to problem solution rather than formulation of a problem as indicators of areas such as creativity (Csikszentmihalyi, 1994). This has resulted in failure "to deal with one of the most interesting characteristics of the creative process' namely, the ability to define the nature of the problem" (Ibid, 1994, p. 138). Equally, in terms of problem solving capabilities, students' cognitive construction of the problem space is considered a crucial process (Jonassen, 2000). Consequently, problem formulation is a crucial phase of designing that guides ones actions. As an initial stage of the design process, lack of focus during this stage may impede students' ability to transition into other stages or restrict them from the deep, high-order thinking necessary to complete the challenge.

Despite the most recent research illustrating students' overall cognitive efforts while designing their cognitive activity during problem formulation (Wells et al., 2014), previous research has distinguished designers' cognitive activity during this phase at a more explicit level (Purcell, Gero, Edwards, & McNeil, 1996). Table 1 illustrates the Problem Domain: Degree of Abstraction coding scheme that describes to a more fine-grained extent how individual designers dissect the problems that they are presented or confront. In terms of depth, the Problem Domain coding scheme also documents the degree to which students cognitively approach solving an ill-defined problem and the complexity of the problem itself. This coding scheme categorizes how students' progress within the problem definition stages and which underlying processes they are attending to throughout the design process.

Table 1

Problem Domain: Degree of Abstraction

Category	Code	Definition	Example Utterances
System	0	The designer is considering the problem from the point of view of the user.	"OK let's just see so I've got an idea of what this backpack design looks like"
Subsystems	1	The designer is considering the problem in terms of the subsystems	"side mounted alright"

Detail	2	The designer is considering the details of the subsystems.	“what we’re going to do is we’re going to run these stays to em to this er this fitting here”

Note. Adopted from: Purcell, Gero, Edwards & McNeil, 1996.

Examining students’ cognitive processes as they decompose design problems can provide greater understanding for educators, researchers, and instructional designers to better aid students in moving past the problem formulation stage. Specifically, findings on how students formulate problems can assist instructors in developing students’ heuristics and strategies during designing which can support them in building more robust cognitive structures and increase their metacognitive processes to be more effective and accurate (Dixon, 2010; Wagner, 2014).

Cognitive Strategy: Underlying Cognitive Processes. Another coding scheme that has further distinguished students’ cognitive efforts is the Strategy Classification Scheme presented by Purcell, Gero, Edwards, and McNeil (1996). This coding scheme, presented in Table 2, captures students’ cognitive processes at a more distinct level, further breaking done such categories of the FBS model of analysis, synthesis, and evaluation, which are commonly identified as higher order thinking processes. Additionally, a fourth category, explicit strategies, is used to examine knowledge designers apply and strategies they are employing to complete a design task.

Overall, the cognitive strategy domains break down how designers spend their efforts in these processes. For example, evaluation, once captured in previous research as a broad category, is now expanded upon as it is separated into five distinct processes students employ that were specific to each dyad. This includes justifying a proposed solution, analyzing a proposed solution, postponing an analysis action, performing calculations to analyze a proposed solution, and evaluating a proposed solution (Purcell, Gero, Edwards, & McNeil, 1996). This study of professional engineers breaks design processes into more explicit descriptions of what designers do during each stage of design. Therefore, this study has the potential to provide not only additional data for understanding students' design cognition, but also the potential to provide insight into whether differences exist between pre- and non- engineering students at a more distinct level. If educators are expected to provide students instruction on how to design and guide them through the design process (Lammi & Becker, 2013), an understanding of the varying cognitive strategies students' use for each design stage needs to be further addressed.

Table 2

Strategy Classification Scheme

Category	Code	Definition	Example Utterance
Analysis Problem			
Analyzing the Problem	Ap	The designer is analyzing the problem.	"what is the system going to need to do…"
Consulting Information about the Problem	Cp	The designer is referencing external information they were provided.	As above but using external information
Evaluating the Problem	Ep	The designer is making an evaluation related to the problem.	"That's an important feature…."
Postponing the Analysis of the Problem	Pp	The designer decides to postpone analysis of the problem.	I can find that out later….."
Synthesizing Solution			
Proposing a Solution	Ps	The designer presents a proposal for solution.	"the way to solve that is"
Clarifying a Solution	Cl	The designer provides clarify for a solution they have proposed.	"I'll do that a bit neater"
Retracting a Previous Design Decision	Re	The designer suggests a previous decision should be retracted.	"That approach is no good what if I…."
Making a Design Decision	Dd	The designer makes a decision between multiple solution proposals.	"Ok. We'll go for that one…"
Consulting External Information for Ideas	Co	The designer consults external information for ideas related to the solution.	"What are my options…."
Postponing a Design Action	Pd	The designer decides to postpone analysis related to a design action.	"I need to do…later"
Looking Ahead	La	The designer anticipates what will need to be completed ahead of time.	"These things will be trivial (difficult) to do"
Looking Back	Lb	The designer reviews past decisions.	"Can I improve this solution?" –"do I need all these features"

(continued)

Table 2 Continued

Evaluating Solution			
Justifying a Proposed Solution	Ju	The designer decides to postpone analysis of the problem.	"This is the way to go because…."
Analyzing a Proposed Solution	An	The designer analyzes a proposed solution.	"That will work like this…"
Postponing an Analysis Action	Pa	The designer postpones the analysis of an evaluation.	"I'll need to work that out later"
Performing Calculations to Analyze a Proposed Solution	Ca	The designer performs calculations related to an evaluation of a proposed solution.	"That's seven inches time three"
Evaluating a Proposed Solution	Ev	The designer evaluates a solution.	"This is faster, cheaper etc…"
Explicit Strategies			
Explicitly Referring to Application Knowledge	Ka	The designer references knowledge specifically related to a final design.	"In this environment it will need to be…"
Explicitly Referring to Domain Knowledge	Kd	The designer references domain specific knowledge.	"I know that these components are…"
Explicitly Referring to Design Strategy	Ds	The designer references knowledge related to strategies that they are aware of.	"I'm doing this the hard way…."

Note. Adopted from: Purcell, Gero, Edwards & McNeil, 1996

Summary of the Literature Review

The intent of Chapter 2 was to synthesize relevant and supporting literature related to investigating K-12 students' design cognition. This review is in harmony with Petrina's (2010) concerns for lack of agreement for what design cognition is, especially at the K-12 level, and lack of viable measures of analysis. Thus, the focus was to establish clarity for examining students' cognitive processes during designing which can aid in the identification of appropriate methods of examining. Two primary areas including: (a) current STEM (science, technology, engineering, mathematics) educational reform, and (b) design cognition research were reviewed to present underpinnings of examining K-12 students' cognitive processes during designing. This discussion informed and guided the researcher as he investigated students' cognitive processes during designing at a deeper level with the goal of understanding the effect T/E DBL has on student learning and thinking and what educators can do to enhance and improve instructional practices.

Collectively, the identification of previously conducted design cognition research investigations and the goals of current STEM educational reform were necessary to appropriately examine and understand K-12 students design cognition at a deeper level. As this review revealed, two overarching goals of current STEM educational reform are developing students 21st century cognitive processes and their STEM content knowledge. Additionally, designing is supported in the literature as a viable approach to address these goals. In turn, researchers have begun to investigate students' cognitive processes during designing at the K-12 level, yet, as this literature review revealed there has been minimal documentation provided for educators and teachers. Furthermore, the paucity of K-12 design cognition research and use of broad coding schemes has resulted in minimal understanding of students underlying cognitive processes during designing. As a result, this literature review revealed previously used coding schemes at the professional and undergraduate level that can be used to further characterize K-12 students design cognition. In conclusion, Chapter 3 will present the procedures for how students' underlying cognitive processes will be investigated using coding schemes not yet applied to investigations of secondary students.

CHAPTER III: METHOD

While researchers have made noteworthy attempts to illustrate the design cognition of professional designers and even students at the collegiate level, minimal investigation of high school students' cognitive activity during designing has been undertaken (Crismond & Adams, 2012; Hynes, 2012; Lammi & Becker, 2013). As researchers have begun to address the lack of research investigating high school students' design cognition, they have employed comprehensive coding schemes that describe students' cognitive efforts in terms of broad categories such as formulation, analysis, and synthesis. Yet, previous research has demonstrated nuances among these existing, broad coding categories (Purcell, Gero, Edwards, & McNeill, 1996). Therefore, what have yet to be understood are K-12 students' cognitive processes in terms of underlying mechanisms during engineering design at a more distinct level. As a result, the purpose of this study is to further characterize students' cognitive processes to a more distinguishable degree and to determine if differences exist between students who take pre-engineering courses and those who do not.

Categorizing the underlying cognitive processes of an individual during designing more clearly will address both calls to better link cognitive science and instructional practices (DeMiranda & Folkestad, 2000) and the few attempts to link research findings with what educators can do to enhance students' design skills and learning ability (Crismond & Adams, 2012). For example, findings can provide educators and researchers with strategies and heuristics to scaffold students' learning experience and ensure successful development of higher-order thinking (Bjorklund, 2008; Kelley & Rayala, 2011; Martinez, 2010; Petrina, 2010). Additional understanding can lead to improvements to students' overall performance, thereby triggering increased achievement and sustained motivation (Brookhart, 2010). Additionally, greater understanding can facilitate the development of specific cognitive skills through deliberate opportunities for practice, which can cultivate better problem solving skills, resulting in improved mental representations and meta-cognitive strategies (Alibali et al., 2009; Bjorklund, 2013; Cohen, Freeman, & Thompson, 1997).

Research Questions

To answer the research questions of this study, an exploratory sequential mixed methods design was chosen. This research design was chosen to accommodate a qualitative phase that explored and interpreted the cognitive processes of the participants, on a phenomenon that has had little research conducted on it (Creswell, 2013). Additionally, the need to quantify the qualitative data required a quantitative phase, warranting the use of a mixed methods study, specifically, exploratory sequential (Creswell, 2013). The quantitative phase included the computation of descriptive and inferential statistics to answer research questions 1, 2, and 3. The remaining contents of this section describe the setting for the current research study, the extant database that was investigated, and the procedures employed during the exploratory sequential mixed methods design.

Extant Data

This research investigation examined extant data made available through a previously conducted National Science Foundation funded longitudinal study supported under Grant No. 1160345 that explored and illustrated the cognitive activity of high school junior and senior level students who took formal pre-engineering courses and those who did not take such coursework (NSF, 2012; Wells, et al., 2014; 2016). Findings reported from the first year of this longitudinal research study, and initial findings of the second year, suggest lack of cognitive effort during the problem formulation stage. Also, students in both groups were reported as distributing a majority of their cognitive efforts during the analysis, synthesis, and evaluation phases. These findings are depicted in Figure 3.

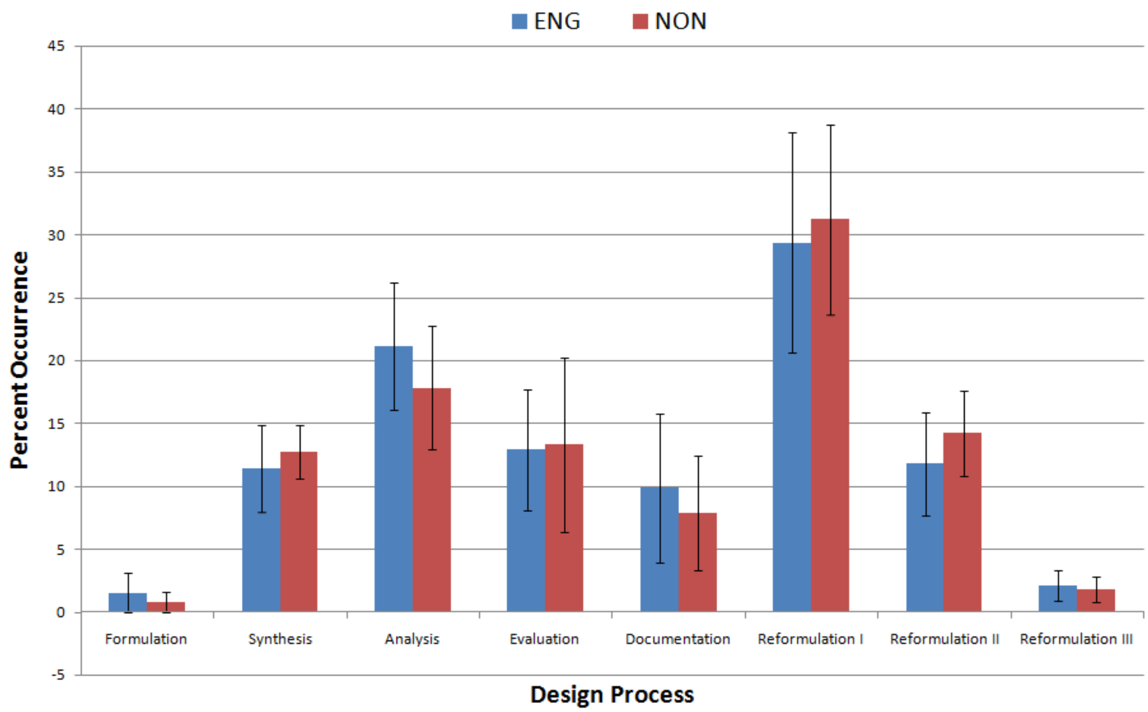

Figure 3. Percent Design Occurrences: High School Juniors who take pre-engineering courses (ENG) vs. students who do not (NON). This figure depicts differences in design cognition as reported by Wells et al., (2016), p.8.

Results from the original study also indicate no significant differences between student groups. Yet, as previously discussed, recent research investigations have made further distinctions in how individuals cognitively formulate a problem, analyze, synthesize, and evaluate (Purcell, Gero, Edwards, & McNeil, 1996). In turn, nuances may be revealed that were not noticeable through the use of a broad coding scheme, therefore warranting a second research investigation. This subsequent analysis also addresses the recent requests to conduct replication studies in educational research to improve the reliability and understanding of educational practices (Makel & Plucker, 2014).

Two separate coding schemes, the *Problem Domain: Degree of Abstraction* presented in Table 1 of Chapter 2, and the *Strategy Classification Scheme* presented in Table 2 of Chapter 2, are two mechanisms with the potential to further illustrate students' cognitive processes during designing and may extract cognitive differences between student groups that were not previously identified. The remaining sections describe the current research design and procedures for re-examining the original study using these additional coding schemes.

Research Design

For this follow up exploratory sequential mixed-methods study, all 40 participants from the second year were selected as a purposeful sample from the entire two year set of data from the original NSF research investigation. This sample resulted in 20 dyads consisting of: 10 pre engineering dyads that had taken pre-engineering courses and 10 dyads that had not. Though Chapter 1 indicated that 42 participants were part of the original study, two students relocated in between Year 1 and Year 2, resulting in only 40 students available for this study. The rationale for purposefully using this sub-set from the entire body of participants was to select participants that would be representative of students who had spent ample amount of time taking pre-engineering courses. Although students were participants over a two year span, directly observed once as a junior and once as a senior to complete a design task, the second year extant data was further examined in this study as a result of students having additional time in pre-engineering classes compared to possible minimal exposure during the first year. Dyads from both groups, pre- and non-engineering, received the same design challenge that tasked them with creating a device that would aid a wheelchair-bound individual when retrieving a jar from a shelving unit beyond their reach. Use of a purposeful sampling allowed the researcher to select specific elements (e.g. additional exposure to pre-engineering courses) that would best represent and inform the topic of differences between students who took pre-engineering courses and those who did not (McMillan, 1996). Purposeful sampling also allowed the researcher to "select cases that are likely to be information-rich with respect to the purpose of the study" (Gall, Gall, & Borg, 2007, p. 178). An example of the design challenge is provided in Appendix B. Figure 4 provides an illustration of the overall process of collecting and examining data.

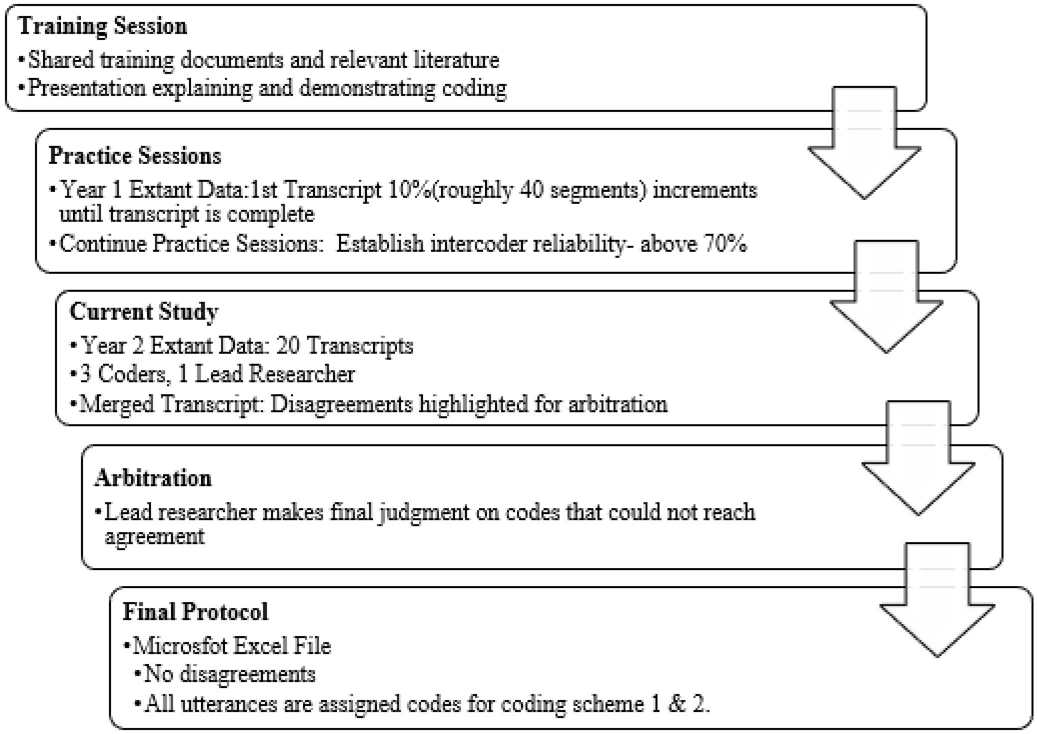

Figure 4. Research Procedures. This figure illustrates the process undertaken to train, code, and analyze the research data.

Procedures

Data Collection. To further characterize high school students' cognitive processes beyond the FBS ontology that was used in the UHSSDC study, the extant data set containing student dyad utterances during the engineering design challenge of Year 2 was obtained in transcript form with approval from the previous researchers to further analyze for this study. This approval letter is provided in Appendix C. Collected in the form of a Microsoft® Office Excel 2007® document, data was captured verbatim from the original verbalized cognitive thoughts of each student participant.

Coders. In addition to the lead researcher, the data of this study was segmented, coded, and arbitrated by three coding analysts. Two of the analysts were graduate research assistants for the UHSSDC study and therefore had experience segmenting, coding, and arbitrating with the FBS ontolgoy coding scheme. The third analyst had minimal experience with verbal protocol analysis, but had conducted similar qualitative research projects. All coding analysts were graduate students in the Integrative STEM Education doctoral program at Virginia Tech Unviersity. Prior to the training session, literature related to both coding schemes (e.g. Gero & McNeill, 1998; Purcell, Gero, Edwards, & McNeill, 1996) and how to conduct verbal protocol analysis studies were sent to analysts to prepare themselves. These journal articles provided an explanation of what the coding scheme captured, definitions of the codes used, and how the segmentation, coding, and arbitration process is undertaken. Use of relevant literature if a method that has been used in past verbal protocol analysis research studies (Lammi, 2011).

Training. The transcript data analyzed within the current study were segmented, coded, and arbitrated by four coders, while final data analysis was investigated by the lead researcher. Final data analysis included computation of descriptive and inferential statistics to answer research questions 1, 2, and 3 and is further discussed in a later section. Each analyst was trained by the researcher who was initially educated by investigators of the original NSF project from which data for this dissertation are being obtained. Preceding the qualitative (segmentation, coding, and arbitration) and quantitative (descriptive and inferential) analysis of data within this study, a training session provided background on both the *Problem Domain: Degree of Abstraction* and *the Strategy Classification Scheme* coding schemes employed by Purcell, Gero, Edwards and McNeil (1996). A presentation, depicted in outline form (Appendix D), was delivered on what each coding category represented, the individual codes that subsumed larger categories, and the procedures for segmenting and coding. Specifically, coders were taught how initial verbatim verbalized thoughts were segmented and coded to capture only one coding category. To do so, an example utterance was presented on a Microsoft PowerPoint slide (Appendix E) and the trainer detailed how the data was segmented down to represent only one single code, or cognitive process. Individuals were then given another example utterance to decompose until all units were segmented into single units. While in the presence of the trainer, feedback and assistance was provided.

Practice Sessions. Following the training session, a practice session took place for coding analysts to gain experience, discuss interpretations, and discover discrepancies between segmentation and coding. A previously transcribed Microsoft Excel document from the 1st year of the UHSSDC study was selected for the practice session. This transcript was chosen from the 1st year data set and contained near 450 segments. This number of segments was identified as an average from the dataset that was reported by Wells et al. (2014) and was chosen to ensure a robust enough sample was used for training purposes. The number of segments chosen was well beyond the number of 200 segments used in previous studies (Gero & Kan, 2009; Kan & Gero, 2010; Ting, 2014). The first 10% (roughly 40 lines) of this practice transcript was initially coded, yet agreement during this stage was captured but not analyzed. This method was used in past verbal protocol analysis studies (Wells et al., 2014) to resolve issues including coding definitions and procedures. Moreover, the rationale for choosing only a portion of the transcript segments is to focus efforts on reviewing why and how each analyst segmented and coded their transcript, not overwhelming coders on completing the entire transcript.

At each practice design session, disagreements between segmentation and coding were arbitrated until a final decision was reached. At times, if agreement was not reached, an external mediator, the lead author of this dissertation, who also coded and segmented during the practice sessions, provided final input. Following arbitration of the first 10% of segments from the transcript, the next 10% of segments were coded, segmented, and arbitrated. This continued until the entire transcript was completed. Any heuristics that were established during this process were recorded by the lead researcher of this study and were presented back to the coders to use as a guide for analysis of the actual transcripts examined for this study. Heuristics are guidelines that have been developed to account for interpretations of data that is ambiguous. For example, Trickett and Trafton (2009) discuss the use of "markers" to discern linguistic issues of transcribed documents. Without these "markers", coders segmented and coded problematic issues very differently.

Establishing Inter-Coder Reliability. After the training meetings and initial practice sessions, additional coding sessions were conducted to establish inter-coder reliability. Inter-coder reliability is a measure used to describe the quality of research conducted and whether the interpretation of content is recognized as valid (Cho, 2008). Specifically, it is the point at which multiple independent coders "agree on the coding of the content of interest with an application of the same coding scheme" (Cho, 2008, p. 345). To measure the agreement between/among coders, the percent agreement method was used to compute the average pairwise percent agreement (APPA) statistic. This statistic is computed by averaging cases of agreement between coders by all possible codes in the final protocol. This method is presented in Figure 5. A percentage agreement above 75%, an accepted measure in the social sciences (Klenke, 2008; Patton, 2002; Schloss & Smith, 1999; Stemler, 2004), was used as a benchmark to determine if coders had reached consensus in the context of the current study.

Time	Subject	Example Utterance	Coder A	Coder B	Final Agreed Upon Code	Coder Agreement Rate		Overall Agreement
4:43	A	I can see here for example that the length is 6	Ap	Cp	Ap	1	0	0
		"That's an important feature…."	Ep	Ep	Ep	1	1	1
5:00	B	"Ok. We'll go for that one…"	Dd	Dd	Dd	1	1	1
		Average Pairwise Percent Agreement (APPA):				Total Agreement		2
		= sum of overall agreement column/total cases				**APPA**		=2/3 =67%

Figure 5. Computing inter-coder reliability. This figure illustrates the process for computing inter-coder reliability.

Using Year 1 extant data, all four coding analysts' independently and concurrently segmented and coded transcripts using the *Problem Domain: Degree of Abstraction* and the *Strategy Classification Scheme* coding schemes. The lead researcher identified and chose transcripts that contained a sufficient number of segments as previously discussed in choosing training session transcripts. Use of Year 1 transcripts, which were based on a different design challenge, was also chosen to reduce bias when it came to coding the final Year 2 data set. Specifically, this method has been used in the past to reduce coder predisposition for final coding analysis (Trickett & Trafton, 2009).

Practice sessions continued to occur until final arbitration reached above 75%. Previous researchers have reported that to reach above 75% agreement, 3 to 5 transcripts need to be coded, segmented and arbitrated (Wells et al., 2016). Once practice sessions were completed, the analysts were tasked with coding the 20 transcripts from the 2nd year of the longitudinal study. Final data was analyzed by the researcher of this study and is further described through the remainder of this section.

Data Analysis

To answer research questions 1, 2, and 3, there were two phases of data analysis conducted. The first phase includes a qualitative component that interpreted and characterized students' cognitive processes during an engineering design challenge. Data from this phase was then quantified through descriptive statistics to answer research questions 1 and 2, while research question 3 was answered using inferential statistics. The following two sections begins by describing the qualitative analysis that occurred, followed by how the data was then quantified to answer the research questions of this study.

Qualitative Analysis

Co-coders now versed in the *Problem Domain: Degree of Abstraction* and the *Strategy Classification Scheme* coding schemes used by Purcell, Gero, Edwards and McNeil (1996) independently examined each transcript. They each concurrently transformed singular verbalized utterances into distinct units, called segments, which characterized only one of the available cognitive processes from each coding scheme. The definitions, codes, and example utterances are provided in Tables 1 and 2 of Chapter 2. The four coders then met to discuss and arbitrate assigned codes that were dissimilar for every segment until a majority of agreement, above 50%, was reached. Any segments that were below 50% were revisited to increase understanding and agreement among the four coders. This process of attaching meaning to a designer's cognitive activity is one that has been frequently used in past research investigations (Adams, Turns, & Atman, 2003; Atman et al., 2007; Chi, 1997; Cross, Christiaans, & Dorst, 1994; Gero & Lindemann, 2005; Lammi, 2011; Wells et al., 2014).

Arbitration allowed each coder to review and debate each other's codes until final agreed upon codes were assigned to each segment. Segments and codes that could not reach final agreement were then sent to final arbitration where ultimately a decision was reached by the lead researcher of this study. This final arbitrated protocol was then converted into a data set for final analysis using Microsoft Excel. An example of the segmentation, coding, and arbitration process is provided in Figure 6.

Time	Subject	Example Utterance	Coder A		Coder B		Final Code	
			Scheme 1	Scheme 2	Scheme 1	Scheme 2	Scheme 1	Scheme 2
4:43	A	I can see here for example that the length is 6	1	Ap	2	Cp	1	Ap
		"That's an important feature...."		Ep		Ep		Ep
5:00	B	"Ok. We'll go for that one..."	2	Dd	2	Dd	2	

Figure 6. Concurrent segmentation and coding process. This figure presents an excerpt from an Excel document, detailing how the transcript was concurrently segmented and coded.

Figures 7 and 8 depict the conversion of the final concurrent coding transcript into two separate documents. Figure 7 illustrates how the codes were prepared for final analysis in regards to the *Problem Domain: Degree of Abstraction* coding scheme, while Figure 8 depicts how the codes were prepared for final analysis for the *Strategy Classification Scheme*.

Time	Subject	Example Utterance	Coder A	Coder B	Final Code
			Scheme 1	Scheme 1	Scheme 1
4:43	A	I can see here for example that the length is 6. "That's an important feature…."	1	2	1
5:00	B	"Ok. We'll go for that one…"	2	2	2

Figure 7. Coding Scheme 1 Process. This figure presents an excerpt from an Excel document, detailing how the transcript was prepared for analysis of the Problem Domain: Degree of Abstraction.

Time	Subject	Example Utterance	Coder A	Coder B	Final Code
			Scheme 2	Scheme 2	Scheme 2
4:43	A	I can see here for example that the length is 6	Ap	Cp	Ap
		"That's an important feature…."	Ep	Ep	Ep
5:00	B	"Ok. We'll go for that one…"	Dd	Dd	Dd

Figure 8. Coding Scheme 2 Process. This figure presents an excerpt from an Excel document, detailing how the transcript was separated to account for the Strategy Classification Scheme.

Quantitative Analysis

Descriptive Statistics. Following completion of arbitration, codes were analyzed using descriptive statistics including frequency counts, percentage occurrences, and measures of central tendency. This was used to answer research questions 1 and 2 which were:

1. How do 12th grade high school pre- and non-engineering students' distribute their cognitive efforts as they dissect the problem domain during engineering design tasks?

2. How do 12th grade high school pre- and non-engineering students distribute their cognitive efforts as they analyze, synthesize, and evaluate during engineering design tasks?

For each coding scheme, which concurrently captured different elements of designing, individual codes were tallied and then percentage occurrences were calculated by dividing by the total quantity of codes used for that coding category. Percent occurrences were calculated as a means of accounting for protocols of differing lengths, which increases the validity of the study and allows for comparison of differences between dyads (Ting, 2014). Percentage occurrences were then used to calculate measures of central tendency for each code of each participant group. These descriptive statistics were used to answer research questions 1 and 2, by characterizing how both students were distributing their cognitive efforts during designing. These final statistics were then used for tests of significance, which allowed the researcher to make comparisons between the pre-engineering group and the non-pre engineering groups to determine if differences do indeed exist between 12th grade students' cognitive efforts during designing.

Inferential Statistics. Descriptive statistics, specifically the percentage occurrences of each code of each coding scheme, were then analyzed using a *t*-test to compare means of the pre- and non- engineering students' cognitive efforts between both coding schemes. This analysis supported answering of research question #3 of the overall dissertation which was:

3. Do differences in cognitive processes emerge between 12th grade high school students who take pre-engineering courses and those who do not?

The *t*-test was used to determine whether the means of the pre- and the non-engineering groups were statistically different than each other. For example, for coding scheme 1, mean averages of each code within each coding scheme, of the pre-engineering group was compared against the same means for the non-pre-engineering group using a *t*-test. To determine statistical significance, a *t*- statistic was calculated using the two sample means, variances of the groups, and the sample size (McMillan, 2012). This statistic was then used to find a level of significance that was used to reject or accept the null hypothesis that there was indeed a difference between the two groups.

Summary of Method

This study received an IRB approval from Virginia Tech Institutional Review Board, 15-732 (Appendix F). The researcher applied an exploratory sequential mixed methods design to answer research questions 1, 2, and 3. The verbal protocol data collected from an extant data base from the UHSSDC study were used to describe and compare high school students who took pre-engineering courses and those who did not. The verbal protocol data from the original UHSSDC study were segmented and coded using the previously developed *Problem Domain: Degree of Abstraction* and *Strategy Classification* coding schemes. This study qualitatively and quantitatively characterized the design thinking of both pre-engineering students and non-pre-engineering students from a cognitive science perspective and measured the differences between the cognition of pre-engineering students and non-pre-engineering students. Findings add to the knowledge base of developing students' higher order thinking skills at the K-12 level and can be used to better aid students during design based learning activities.

CHAPTER IV: FINDINGS

The purpose of this research study was to characterize high school students' cognitive processes during engineering design to a deeper extent than previously conducted (e.g., Lammi, 2013; Wells et al., 2016). Additionally, the researcher sought to determine if statistically significant differences existed between students who experienced high school pre-engineering (ENG) courses and students who did not (NON), when examined through the lens of finer grained coding schemes. Thus, Chapter 4 presents findings of data analysis from applying the *Problem Domain: Degree of Abstraction* and *Strategy Classification* coding schemes.

This chapter begins with a description of the sample examined, including participant demographics and characteristics from year one and year two of the UHSSDC study. Then, a report on how the coder analysts were trained and participated in practice sessions to establish inter-coder reliability. Lastly, findings from the main study are presented, detailing the qualitative analysis that was undertaken to interpret students' cognitive processes, followed by the quantitative procedures employed to answer the research questions of this study. Specifically, the descriptive statistics that were computed to answer research questions one and two, and inferential statistics that were calculated to answer research question three.

Sample Description

The participants of this study were originally drawn by researchers of the UHSSDC research project from a convenience sample of students attending one of three rural mid-Atlantic high schools all offering the same 9th through 12th grade Project Lead the Way (PLTW) pre-engineering course sequence (Wells et al., 2016). Each of the participating schools had student populations of similar size. Within each school, there were two groups of participants. The experimental group (ENG) was comprised of students who had experienced formal PLTW pre-engineering courses, whereas the control group participants were those who had not taken PLTW pre-engineering courses (NON). Wells et al. (2016) report that each participant was recruited by the teacher in the school and both the teacher and student received a small monetary incentive. Since the original research study was longitudinal, the same students from the first year (juniors) were participants in the second year (seniors).

Participants Demographics

Although students' senior year data were the primary points of investigation used to answer the research questions of this study, the lead researcher of this project also utilized participants' junior year data for practice sessions and to establish inter-coder reliability among the research team. A justification for why the senior year data was chosen is found in Chapter 3.

First Year: Practice Sessions. As Wells et al. (2016) report, student participants in the experimental group (ENG) identified that they had varying experience in PLTW. For example, they either were enrolled in their first PLTW course, or had one full year of coursework. Additionally, students were given the opportunity to self-select into dyads, or groups of two. Wells et al. (2016) report that of the 20 dyads, 60% were mixed-gender, with the experiment group distributed at 64% male and 36% female, whereas the control group was 65% male and 35% female.

Second Year: Main Study. The same students who participated in the first year of the UHSSDC research project were also participants in the second year. These students were placed in the same dyads that they self-selected in the first year. The only reported difference for demographic data for all three sites was that all pre-engineering participants from year 1 had taken their second or third PLTW course in their senior year.

Establishing Reliability

As discussed in Chapter 3, a series of trainings and practice sessions (see Appendix G for the calendar and schedule) were considered essential to develop reliability for each coding scheme. Specifically, consistency in how the analysts interpreted, segmented, coded, and arbitrated the design sessions. One training, and multiple practice meetings, afforded the researchers and coders the opportunity to establish a vernacular among each other and create markers for each code. The process and resultant addendum is described throughout the next section.

Training Session

An initial training session was used to prepare the coders on how coding scheme 1 (*Problem Domain: Degree of Abstraction*) and coding scheme 2 (*Strategy Classification*) were to be used to examine and characterize students' cognitive processes during engineering design. This training session provided the coding analysts details on each scheme and example utterances (Appendix H). This assisted the researcher in gaining additional experience and understanding of each coding scheme while also establishing reliability of the coding and arbitration processes. Furthermore, the training and practice sessions allowed other coders to demonstrate their abilities in rating the transcripts in comparison to other analysts.

To establish inter-coder reliability for this study, the lead researcher conducted the training session with a PowerPoint presentation describing the purpose of the study, how to segment and code, and the definitions of each cognitive issues for each coding scheme. Though all three co-coders were adept in qualitative research studies, only two had previously used the FBS coding scheme. Both coders who previously used the FBS ontology, shared that they saw usefulness in exploring the design sessions with alternate coding schemes to capture nuances that may not have been previously detailed.

Practice Sessions

In preparation of the main study, the lead researcher and three coders individually reviewed, interpreted, segmented, and coded each design session. The codes were segmented, coded, and arbitrated in roughly 10%, or 30 line, increments. This process, in comparison to sample, or interval, data coding (e.g., Lammi, 2011), affords each coder the opportunity to cover the entire transcript, witnessing all cognitive issues throughout the design session, and discussing issues with other coders. Once complete, they submitted their codes to the lead researcher who merged all documents into one transcript. Video recordings were available for each participant if they needed to compare the text transcript for additional clarification. This was also referred to during arbitration to support an individual's segmentation and code selection and on many occasions changed the selected code of the analysts.

As Table 3 illustrates, agreement rates were captured at three points across the transcripts. First, a value was computed prior to arbitration, second, following arbitration for each section, and third, overall agreement across the entire transcript. Table 3 reveals that agreement consistently rises between entering arbitration and concluding arbitration for each session, as well as for each coding scheme. Additionally, the overall agreement for the entire transcript rose for each coding scheme.

Table 3

Inter-coder Reliability Percentage Established During Practice Session 1

	Date	Coded	Arbitrated	**Agreement***		**Agreement****		**Agreement*****	
				CS # 1	CS #2	CS # 1	CS #2	CS # 1	CS #2
1	8/30/15	1-30	1-30	41%	13%	73%	59%	73%	59%
2	9/6/15	31-80	31-80	49%	19%	84%	61%	80%	60%
3	9/13/15	81-150	81-150	45%	30%	81%	69%	80%	64%
4	9/20/15	151-200	151-200	60%	40%	80%	71%	80%	68%
5	9/23/15	201-250	201-250	46%	38%	74%	72%	78%	66%
6	9/27/15	251-330	251-330	44%	32%	75%	68%	78%	67%

Note. * Entering Arbitration – Session, ** Concluding Arbitration-Session, ***Concluding Arbitration-Overall. Yellow highlight indicates overall agreement for the entire transcript.

Despite the satisfactory agreement rate of coding scheme 1, depicted in column three of the Table 3, coding scheme 2 only nears the threshold of 70%. Therefore, an additional transcript and practice session was deemed necessary to establish inter-coder reliability and increase understanding among coding analysts. In comparison to the first practice sessions, practice session two was coded in its entirety, and arbitrated in two passes, roughly 50% each meeting. As Table 4 illustrates, final overall agreement for coding scheme 1 was 76%, whereas coding scheme 2 was 73%. Since the inter-coder agreement for practice session two was above 70% for each coding scheme, the coding and arbitration process was reasoned reliable for interpreting students' cognitive processes during engineering design according to Schloss and Smith (1999). Furthermore, these agreement rates are notably higher than previously conducted research that advanced due to the limitation of time, though the researchers training methods ended prior to an ideal inter-coder reliability (80%) was reached (Ting, 2014). According to the researcher, Dr. Gero, having trained a number of coders, indicated that a higher inter-coder reliability would be reached by repeating the arbitrating process. Thus, a second training session was conducted.

Table 4

Inter-coder Reliability Percentage Established During Practice Session 2

	Date	Coded	Arbitrated	Agreement*		Agreement**		Agreement***	
				CS # 1	CS #2	CS # 1	CS #2	CS # 1	CS #2
1	10/4/15	1-249	1-100	36%	28%	75%	71%	52%	47%
2	10/11/15	1-249	101-249	52%	47%	76%	73%	76%	73%

Note. * Entering Arbitration – Session, ** Concluding Arbitration-Session, ***Concluding Arbitration-Overall

At the conclusion of the second training session an addendum was made to the coding scheme to provide additional clarity as the researches coded and arbitrated the 20 design sessions of the main study. This addendum did not result in changes to the definitions or descriptions of any codes, but captured agreed upon nuances as a result of the arbitration process (Appendix I). Subsequently, the agreement rates of the main study were much higher than the practice sessions (Appendix J). Overall, the mean agreement rate of all 20 transcripts for coding scheme 1 was 86%, ranging from 71% to 93%, whereas the mean agreement rate coding scheme 2 was 82%, ranging from 71% to 90%. Both the average, and the lowest documented values of agreement rates are above the threshold suggested by numerous researchers and documented as an accepted measure in the social sciences (Howell, 2007; Klenke, 2008; Lammi, 2011; Patton, 2002; Schloss & Smith, 1999; Stemler, 2004).

Lastly, in preparation of the main study, the lead researcher solicited feedback from the coders. They indicated that the segmenting, coding, and arbitrating was a challenging task and consumed a significant portion of their time. Subsequently, the researcher of this study decided to adhere to a detailed schedule for the main study.

Research Question # 1

One of the two main research questions that guided this study was to characterize how 12th grade high school pre-engineering (ENG) and non-pre-engineering (NON) students distribute their cognitive efforts as they dissect the problem domain, as well as reflect on the complexity of the problem throughout an engineering design task. To address research question one, the *Problem Domain-Degree of Abstraction* coding scheme was used to interpret the cognitive issues for each dyad, as well as the means across each group of participants. First, qualitative analysis occurred through coding of students' verbalized utterances and served as the foundation for the quantitative analysis necessary to answer the research questions. For example, the computation of frequency counts were used to calculate percentage occurrences to characterize students' cognitive efforts while in the *Problem Domain-Degree of Abstraction.* Examples of final transcripts for pre-engineering seniors (Appendix K), non-pre-engineering seniors (Appendix L), and master results (Appendix M) are provided in the Appendices of this document. Subsequently, the calculated descriptive statistics are presented in the following section to describe the engineering students, as well as the pre-engineering students' cognitive effort. To begin the presentation of findings for research question one, Tables 5 and 6 capture the descriptive statistics for each dyad of the ENG and NON group for high school seniors, as well as overall means and standard deviations for each group. Additionally, Figures 9 and 10 are included to begin to note emerging relationships between the two groups of students.

Table 5

Problem Domain Descriptive Statistics for ENG

Design Issues	1	2	3	4	5	12	13	14	19	20	MEAN	SD
0-System	16.75	12.10	3.60	18.30	9.10	30.60	7.07	16.91	24.07	17.23	**15.57**	**8.03**
1-Subsystems	33.00	52.30	38.20	41.70	21.00	28.70	36.36	15.44	13.70	21.72	**30.21**	**12.38**
2-Detail	50.25	35.50	58.20	40.00	69.90	40.80	56.57	67.65	62.22	61.05	**54.21**	**12.05**

Note. Teams 1, 2, 3, 4, 5, (Yellow Highlight) were site 1; Teams 12, 13, 14 (Blue Highlight) were site 2; and Teams 19, 20 (Green Highlight) were site 3.

Table 6

Problem Domain Descriptive Statistics for NON

Design Issues	6	7	8	9	10	11	15	16	17	18	MEAN	SD
0-System	24.00	26.80	30.20	25.40	16.70	27.10	22.90	11.30	24.26	34.21	**24.29**	**6.47**
1-Subsystems	19.70	29.30	20.20	32.70	37.30	17.60	28.24	19.57	35.74	25.44	**26.58**	**7.19**
2-Detail	56.30	43.90	49.60	41.90	46.10	55.30	48.85	69.13	40.00	40.35	**49.14**	**9.06**

Note. Teams 6, 7, 8, 9, 16, 17 (Yellow Highlight) were site 1; Teams 10, 11, 15 (Blue Highlight) were site 2; and Team 18 (Green Highlight) were site 3.

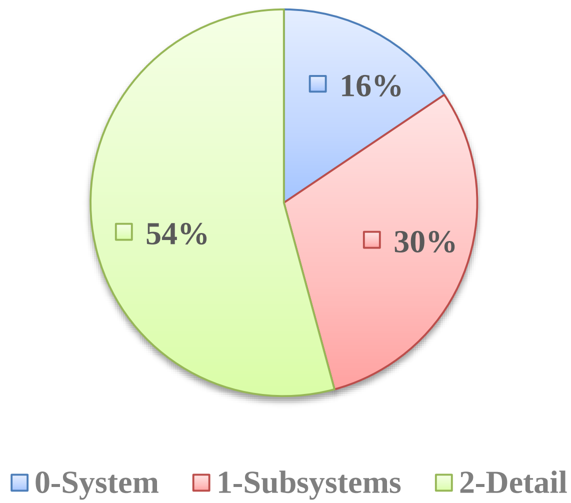

Figure 9. ENG Students CS # 1: Problem Domain - Degree of Abstraction.

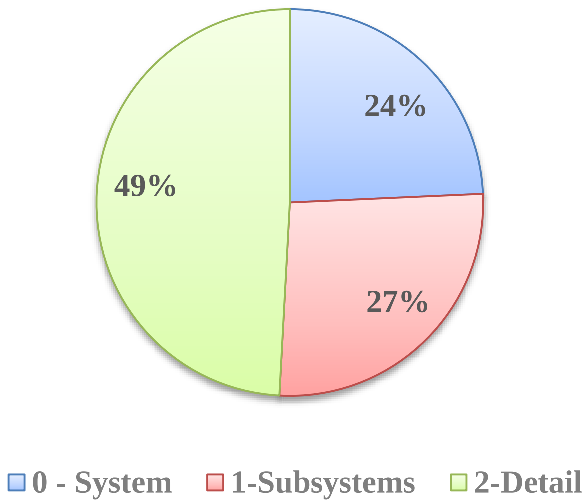

Figure 10. NON Students CS # 1: Problem Domain - Degree of Abstraction.

Pre-Engineering Seniors (ENG)

The percentage occurrences for each pre-engineering (ENG) senior dyad were calculated from the total number of *Problem Domain – Degree of Abstraction* coded segments for each design session. For the ENG group, there was a mean of 245 coded segments across all ten design sessions. Verbalized utterances that were not captured within the *Problem-Domain- Degree of Abstraction* coding scheme were removed from total segmentation. Once the distrubtion of cognitive effort for each dyad was computed, the overall means and standard deviations were calculuated for the individual codes of System (0), Subsystems (1), and Details (2). As Table 5 and Figure 9 illustrate, senior level students of the ENG group exerted the most cognitive effort on Details (2) at 54.21% with the lowest being System (0) at 15.57%. Students spent the remaining 30.21% on the Subsystems (1) of their design.

As illustrated in Table 5, data indicated that the senior year ENG group dyads exerted a broad range of cognitive effort for each design issue. For example, effort spent on System (0) issues ranged from 3.60% to 30.60%, while Subsystems (1) ranged from 13.70% to 52.30%, and 35.50% to 69.60% for Details (2). Within the ENG group, dyad 3 (Site 1) and dyad 13 (Site 2) distributed their cognitive efforts across all three design issues similarly with minimal attention to System (0) issues, but significant consideration towards Detail (2) issues. In comparison, dyad 12 (site 2), dispersed attention to all three issues fairly equally. Whereas, dyad 5 (site 1) and dyad 14 (site 2) exerted the majority of their cognitive efforts towards Detail (2) issues, both approaching nearly 70%. Additionally, dyad 19 (site 3) spent the most attention to System (0) issues among dyads of the ENG group, yet redirected the majority of remaining efforts to Details (2) of the design task. Lastly, dyad 2 (site 1), exerted the most cognitive effort to the Subsystem (1) issues of the design task, yet the least amount of attention to the Details (2). These findings show that students across the ENG group are generally focused in a similar manner in how they attend to issues of the Problem Domain and their degree of abstraction regarding how they dissect the problem.

Non-Pre-Engineering Seniors (NON)

The second component of research question one was characterizing how non-pre-engineering students' (NON) distribute their cognitive efforts as they dissect the problem domain, as well as reflect on the complexity of the problem, throughout the engineering design session. The percentage occurrences were also calculated from the total number of *Problem Domain – Degree of Abstraction* coded segments for each design session. For the NON group, there was a mean of 300 coded segments across all ten design sessions, in comparison of 245 for the ENG group. Verbalized utterances that were not captured within the *Problem-Domain- Degree of Abstraction* coding scheme were removed from total segmentation. Once each dyad's distribution of cogntive effort was computed, the overal means and standard deviations were calculuated for the individual codes of System (0), Subystems (1), and Details (2).

As Figure 10 illustrates, senior students from the NON group exert, on average, 49% of their effort on detail related issues, 27% considering the subsystems of the design, and 24% of their cognitive effort on system related design issues. Thus, a higher mean was apparent for the NON group than the ENG group in regards to System (0) related issues by nearly 10%, while attention to Subsystems (1) and Details (2) were less than the ENG group overall. Whether or not there was a statistically significant difference between design issues for both groups will be discussed in the findings for research question three.

Senior year students from the NON group exerted a broad range of cognitive effort for each design issue. As Table 5 illustrates, effort spent engaged in System (0) oriented issues ranged from 11.30% to 34.21%, while Subsystems (1) ranged from 17.60% to 37.30%, and 40.00% to 69.13% for Details (2). These variations were less dispersed than those of the ENG group. Within the NON group, dyad 16 (site 1), exerted the most cognitive effort towards Details (2) of the design task at almost 70%, while also considering the lowest amount of System (0) issues of the NON group at 11.30%. With lower attention to the Details (2) of the design, the majority of dyads are similarly in that they distribute their remaining cognitive effort among the system and subsystems fairly equally. The exception being dyad 10 (Site 2), that exerted much more effort towards Subsystem (1) issue than System (0) issues of the design task.

Research Question # 2

The second of the two main research questions that guided this study was, how 12th grade high school pre-engineering (ENG) and non-pre-engineering (NON) students distribute their cognitive efforts as they analyze, synthesize, and evaluate during engineering design tasks. To address research question two, the *Cognitive Strategies* coding scheme was used to interpret students' cognitive issues for each group of participants. Additionally, to address this research question, the qualitative analysis used through coding was the foundation for the quantitative analysis. For example, the computed frequency counts for each of the 19 design issues, were used to calculate percentage occurrences to characterize students' cognitive efforts while in the *Cognitive*

Strategies domain*.* Subsequently, the calculated descriptive statistics are presented in the following section to describe the engineering students, as well as the pre-engineering students' cognitive effort. To begin the presentation of findings for research question two, Tables 7 and 8 capture the descriptive statistics for each dyad of the ENG and NON group for high school seniors, as well as overall means and standard deviations for each group. Additionally, Figures 11 and 12 are included to begin to note emerging relationships between the two groups of students, which will be addressed in greater detail for research question three.

Table 7

Percentage Occurrences of Cognitive Strategies for ENG Group

Cognitive Issue	**1**	**2**	**3**	**4**	**5**	**12**	**13**	**14**	**19**	**20**	**MEAN**	**SD**
Ap	0.42	4.00	0.00	2.90	2.10	3.50	0.94	2.60	1.94	0.00	**1.84**	**1.45**
Cp	2.51	5.60	0.70	2.10	6.90	1.50	2.83	2.60	4.65	4.65	**3.40**	**1.96**
Ep	0.42	1.60	2.90	0.70	4.20	3.00	1.89	0.00	0.00	0.00	**1.47**	**1.50**
Pp	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00	0.00	**0.11**	**0.23**
Ps	17.57	17.70	28.10	14.30	18.80	10.60	29.25	14.94	18.99	15.12	**18.54**	**5.90**
Cl	16.32	25.00	16.50	28.60	18.80	13.10	10.38	25.32	17.05	7.75	**17.88**	**6.74**
Re	3.35	1.60	3.60	0.70	2.80	2.50	2.83	0.00	0.78	3.88	**2.20**	**1.35**
Dd	16.32	5.60	3.60	3.60	6.90	3.50	16.98	9.09	5.43	8.91	**7.99**	**4.99**
Co	0.00	0.00	0.70	2.10	0.00	6.00	0.94	1.95	0.39	0.39	**1.25**	**1.84**
Pd	0.42	0.80	1.40	0.00	0.00	3.50	0.94	0.00	0.78	0.39	**0.82**	**1.05**
La	3.35	2.40	2.20	2.10	2.80	2.00	3.77	1.95	2.71	3.10	**2.64**	**0.62**
Lb	0.84	0.80	0.00	0.70	0.70	4.50	1.89	2.60	0.78	1.94	**1.48**	**1.31**
Ju	2.09	6.50	5.80	3.60	4.20	4.50	5.66	5.19	7.75	5.04	**5.03**	**1.57**
An	19.67	15.30	11.50	25.00	15.30	15.10	13.21	11.69	17.83	29.84	**17.44**	**5.93**
Pa	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.14**	**0.44**
Ca	2.09	0.00	1.40	0.00	0.70	0.00	0.00	0.65	0.00	0.39	**0.52**	**0.72**
Ev	2.51	7.30	9.40	2.90	4.90	5.00	4.72	3.90	3.88	2.33	**4.68**	**2.21**
Ka	3.77	0.00	0.00	0.00	2.10	2.50	0.94	4.55	7.75	6.20	**2.78**	**2.74**
Kd	2.51	0.80	2.20	2.90	4.90	6.00	0.94	2.60	7.75	6.59	**3.72**	**2.43**
Ds	5.44	4.80	8.60	7.90	4.20	13.10	1.89	9.74	1.55	3.49	**6.07**	**3.69**
Segment Total	**239**	**124**	**139**	**140**	**144**	**199**	**106**	**154**	**258**	**258**		

Note. Teams 1, 2, 3, 4, 5, (Yellow Highlight) were site 1; Teams 12, 13, 14 (Blue Highlight) were site 2; and Teams 19, 20 (Green Highlight) were site 3. Numbers are percentage occurrences of overall cognitive effort.

Table 8

Percentage Occurrences of Cognitive Strategies for NON Group

Cognitive Issue	6	7	8	9	10	11	15	16	17	18	MEAN	SD
Ap	1.10	3.10	3.80	0.90	0.90	2.80	4.23	1.72	3.31	0.78	**2.26**	**1.33**
Cp	5.80	9.40	8.70	2.00	4.60	6.00	7.04	3.00	1.47	4.69	**5.27**	**2.66**
Ep	2.20	1.00	2.60	0.00	1.90	0.70	0.70	0.86	2.21	0.78	**1.30**	**0.86**
Pp	0.30	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	**0.07**	**0.15**
Ps	13.00	15.60	14.30	12.80	18.50	22.30	14.79	17.60	10.29	9.38	**14.86**	**3.88**
Cl	20.20	13.50	18.10	21.70	24.10	10.60	13.38	8.58	16.54	8.59	**15.53**	**5.48**
Re	1.70	1.00	2.30	2.30	1.90	1.10	0.70	2.58	2.94	1.56	**1.81**	**0.73**
Dd	7.70	6.30	14.00	4.90	10.20	5.30	11.27	9.44	4.78	10.16	**8.41**	**3.11**
Co	0.60	2.10	4.50	0.30	0.00	0.40	0.70	0.00	1.84	13.28	**2.37**	**4.07**
Pd	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	1.84	0.00	**0.21**	**0.58**
La	1.70	1.00	0.80	4.10	1.90	1.40	1.41	6.01	4.04	4.69	**2.71**	**1.83**
Lb	1.10	1.00	0.00	0.90	0.00	1.10	2.11	0.43	0.74	0.00	**0.74**	**0.66**
Ju	3.00	2.10	8.30	2.30	4.60	4.60	4.93	3.00	2.57	7.03	**4.24**	**2.09**
An	19.60	24.00	10.60	29.00	13.90	20.50	11.97	26.61	22.43	18.75	**19.74**	**6.13**
Pa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**0.00**
Ca	3.90	4.20	0.40	0.30	0.90	0.00	0.00	0.43	0.00	0.78	**1.09**	**1.59**
Ev	5.20	8.30	5.30	4.30	0.90	3.90	1.41	3.00	6.25	7.81	**4.64**	**2.46**
Ka	3.60	1.00	1.10	4.10	6.50	8.80	6.34	3.43	2.94	1.56	**3.94**	**2.58**
Kd	4.40	1.00	2.30	4.90	2.80	5.70	6.34	1.72	3.68	7.81	**4.07**	**2.17**
Ds	5.00	5.20	3.00	4.90	6.50	4.60	12.68	11.59	12.13	2.34	**6.79**	**3.87**
Segment Total	**362**	**96**	**265**	**345**	**108**	**283**	**142**	**233**	**272**	**128**		

Note. Teams 6, 7, 8, 9, 16, 17 (Yellow Highlight) were site 1; Teams 10, 11, 15 (Blue Highlight) were site 2; and Team 18 (Green Highlight) were site 3. Numbers are percentage occurrences of overall cognitive effort.

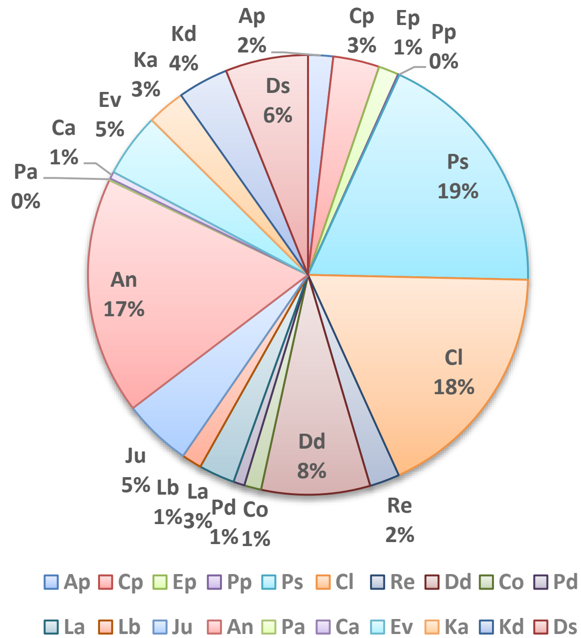

Figure 11. ENG Students CS #2: Strategy Classification.

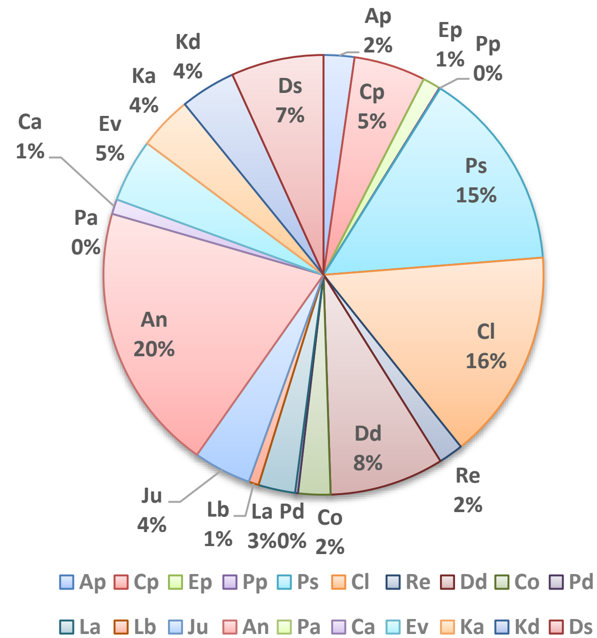

Figure 12. NON Students CS #2: Strategy Classification.

Pre-Engineering Seniors (ENG)

To characterize the *Cognitive Strategies* of high school seniors who took pre-engineering courses (ENG), percentage occurrences were calculated from the total number of coded segments for each design session. Verbalized utterances that were not captured within the *Cognitive Strategies* coding scheme were removed from total segmentation. Computation of these percentage occurrences, revealed in Table 7, illustrates how each senior year dyad of the ENG group distributed their cognitive effort across the various design issues. Once each dyad's cognitive effort was computed, the overall means and standard deviations were calculated for all 19 individual codes. Ranges and groupings among dyads of the ENG group will also be presented to highlight the various cognitive issues that received the least and most attention and to begin to document emerging relationships that may be evident between the ENG and NON groups. These findings will also inform research question three, which was, do differences exist between the ENG and NON seniors.

As Table 7 and Figure 11 illustrate, senior year ENG students exerted the most cognitive effort on three design issues. Those issues were Proposing a Solution (Ps) at 19%, Clarifying a Solution (Cl) at 18%, and Analyzing a Proposed Solution (An) at 17%. Collectively, those three design issues cover 54% of their cognitive effort throughout the engineering design task. Conversely, the least amount of cognitive effort was spent on Postponing the Analysis of the Problem (Pp) at 0.11%, Postponing an Analysis Action (Pa) at 0.14%, and Performing Calculations to Analyze a Proposed Solution (Ca) at 0.52%.

Though no groupings seemed to emerge in the findings for the ENG group in regards to the *Cognitive Strategies* design issues, a few dyads distributed their cognitive effort across design issues differently than other groups. For example, dyad 20 (site 3) and dyad 4 (site 1) exhausted much more effort in Analyzing the Problem (Ap) than other groups, and shared similarity in how they distributed their attention to Proposed Solutions (Ps), yet both dyads did not attend to Clarification of Solutions (Cl) to the same extent. Specifically, for dyad 20, design issues pertaining to Clarifying a Solution consumed only 7.75% of their overall cognitive effort, whereas dyad 4 distributed their attention to these issues at only 28.60%, the highest among all groups. Additionally, dyad 1 (site 1) and dyad 13 (site 2), led the ENG group by distributing their attention to Making Design Decisions (Dd) similarly, both near 16%, though no other parallels exist between the two dyads across additional design issues. Lastly, it should be noted that dyads 19 and 20, both of site 3, engaged in Explicitly Referring to Application Knowledge (Ka) and Explicitly Referring to Domain Knowledge (Kd), more than most other groups.

Despite evidence of groupings between the sites and dyads, there does appear to be one similar trend among dyads of the ENG group. That is, dyads would engage in presenting a proposal for a solution, provide clarification for a solution they have proposed, and analyze a proposed solution. Subsequently, these three design issues are spread across the *Synthesizing Solution* and *Evaluating Solution* domains, and not the *Analysis Problem* and *Explicit Strategies* of the *Cognitive Strategies* coding scheme.

Non-Pre-Engineering Seniors (NON)

The second component of research question two was to characterize how non-pre-engineering (NON) students' distribute their cognitive efforts in regards to the coded segments of the *Cognitive Strategies* design issues. The percentage occurrences were also calculated from the total number of *Cognitive Strategies* coded segments for each dyad. Verbalized utterances that were not captured within the *Cognitive Strategies* coding scheme were removed from total segmentation. Once each dyad's cognitive effort was computed, the overall means and standard deviations were calculuated for all 19 individual codes.

As Table 8 and Figure 11 illustrate, senior NON-pre-engineering students exerted the most cognitive effort on Proposing a Solution (An) at 20%, Clarifying a Solution (Cl) at 16%, and Analyzing a Proposed Solution (Ps) at 15%. What should be noted, is that these three design issues were also the three highest of the ENG group. Conversely, the lowest three cognitive issues that the NON group attended to were Postponing an Analysis Action (Pa) at 0.00%, Postponing the Analysis of the Problem (Pp) at 0.07%, and Postponing a Design Action (Pd) at 0.21%. However, though similar, the ENG group included Performing Calculations to Analyze a Proposed Solution (Ca), but did not include Postponing a Design Action (Pd) as their lowest.

Despite any groupings emerging from the findings for the NON group in regards to the *Cognitive Strategies* design issues, a few dyads distributed their cognitive effort across design issues differently than other groups. For example, dyad 18 (site 3) Consulted External Information for Ideas (Co) than any other dyad. Interestingly, they spent less cognitive effort than others Clarifying Solutions (Cl) as a result. Additionally, dyad 8 (site 1), exerted the highest cognitive effort towards Making Design Decisions (Dd), while also leading the NON group in Justifying a Proposed Solution (Ju). This may also be attributed to their extra attention to issues surrounding Consulting Information about the Problem (Cp). Another finding that arose among the NON group, was dyad 7's distribution of cognition. This dyad lead in Consulting Information about the Problem (Cp), while also attending highly to issues surrounding Evaluating a Proposed Solution (Ev). Yet, dyad 11 (site 2), skewed their attention to Proposing a Solution (Ps), while not redirecting efforts much differently than other dyads across other design issues.

Although there was no evidence of groupings between the sites and dyads, there does appear to be one similar trend among dyads of the NON group that was also evident for the ENG group. That is, dyads attributed a majority of their cognitive effort to Presenting a Proposal for a Solution, Clarifying a Solution, and Analyzing a Proposed Solution. Further research, such as sequential analysis, may reveal a procedural relationship among these three design issues.

Research Question #3

The third and final research question of this study was whether differences in cognitive processes emerge between 12th grade high school students who take pre-engineering courses and those who do not. To address this question, a *t*-test was used to test the difference between the means of the two independent groups of pre-engineering (ENG) and non-pre-engineering seniors (NON). To compute this statistic, the means and standard deviations presented in Tables 5, 6, 7, 8 were used. This research question has two components that will be reported throughout the following two sub-sections. First, the differences between cognitive efforts in the *Problem Domain: Degree of Abstraction*, followed by the differences between *Strategy Classification.*

Problem Domain: Degree of Abstraction

As Figure 13 illustrates, and research question one and two alluded to, differences are apparent across all three design issues of the *Problem Domain: Degree of Abstraction* with the most evident in the System category (0). Findings indicate that the NON group of seniors spent more cognitive effort considering the problem from the point of view of the user than the ENG group. This additional attention resulted in less cognitive effort in the Subsystems and Details design issues than the ENG students.

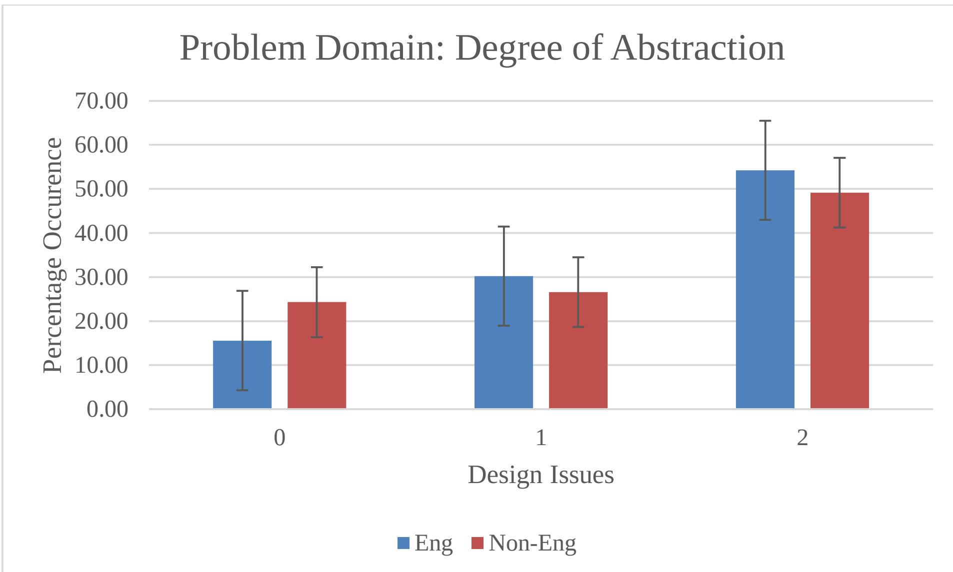

Figure 13. Percent Occurrence of Problem Domain: Degree of Abstraction Design Issues: ENG vs. NON High School Seniors.

Table 9 captures the results of the *t*-test conducted to determine if the differences illustrated in Figure 13 were statically significant. Comparisons of the ENG and NON group data using a *t*-test revealed significant differences were evident among only how the designer considered the problem from the point of view of the user (System – 0). However, analysis revealed no significant differences for the other two cognitive issues of considering the problem in terms of the subsystems (Subsystems - 1) and considering the details of the subsystems (Details – 2). Therefore, findings from data analysis indicate that the ENG group dyads overall exerted less cognitive effort toward the System issues of the design task than did the NON engineering students.

Table 9

Statistical Results of Cognitive Issues: ENG vs. NON High School Seniors

Cognitive Issue	***t* - value (%)**	***p* - value**
0-System	-2.67	0.01
1-Subsystem	0.80	0.22
2-Details	-1.06	0.15

Note. Yellow highlight indicates statistically significant difference between ENG and NON groups

Strategy Classification

As Figure 14 illustrates, differences were also apparent across multiple design issues of the *Strategy Classification* coding scheme. The most obvious design issue differences were Proposing a Solution (Ps), Clarifying a Solution (Cl), Analyzing a Proposed Solution (An), Consulting Information about the Problem (Cp), Postponing a Design Action (Pd), and Looking Back (Lb). Additionally, Figure 14 depicts that there appears to be a clear alignment of three strategies (e.g. Ps, Cl, and An) between the 15 and 20 percentage occurrences, just one alignment between 5 and 10 percentage occurrence for Dd, with all others falling below the 5% mark. Generally, NON-engineering seniors spent more cognitive effort engaged in Cp and An than the pre-engineering seniors.

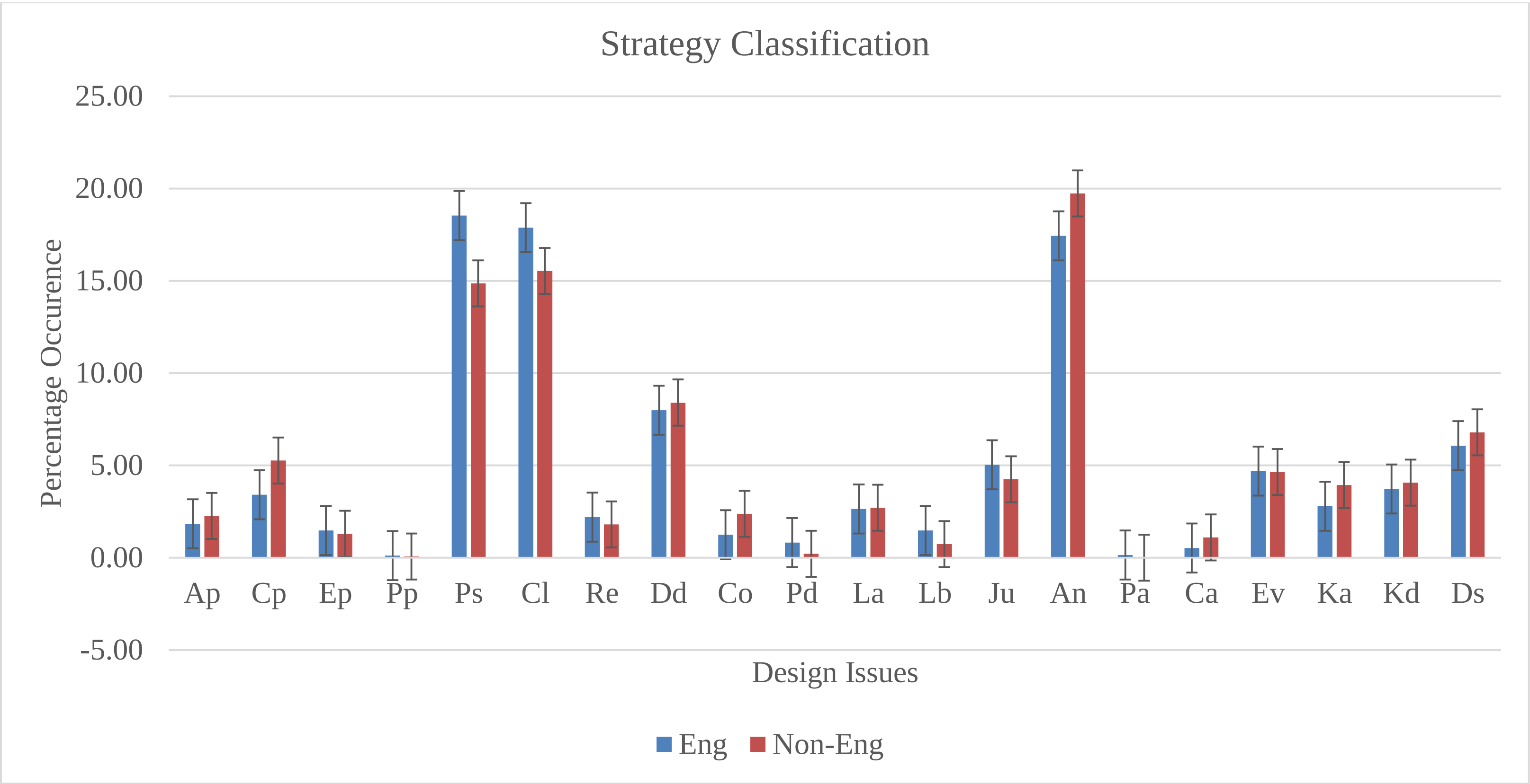

Figure 14. Percent Occurrence of Strategy Classification Design Issues: ENG vs. NON High School Seniors.

Table 10 displays the results of the *t*-test conducted to determine if the differences illustrated in Figure 14 were statistically significant between 12th grade high school students who take pre-engineering courses and those who do not. Comparisons of the pre-engineering (ENG) and non-pre-engineering (NON) group data using a *t*-test revealed significant differences existed only for Consulting Information about the Problem (Cp). Yet, findings indicate that differences existed near the threshold for Proposing a Solution (Ps), Postponing a Design Action (Pd), and Looking Back (Lb). Consequently, the NON group spent statistically significant more cognitive effort Consulting Information about the Problem (Cp) than the ENG, while they exerted considerably less effort Proposing a Solution (Ps), Postponing a Design Action (Pd), and Looking Back (Lb) than the ENG group.

However, the researcher of this study recognizes the low means presented in Table 7 and 8 and the effect they have on the statistical results presented in Table 10. Thus, the low cognitive effort of many of the design issues for coding scheme two (e.g. Pp, Pd, Ca, etc.), coupled with large standard deviation, may be of little substance. In turn, the statistics are not robust enough to be used statistically for comparison. Yet, despite these low numbers, they do warrant further investigation in follow up studies to determine if additional differences exist.

Table 10

Statistical Results of Cognitive Issues: ENG vs. NON High School Seniors

Cognitive Issue	***t* - value (%)**	***p* - value**
Analyzing the Problem (Ap)	-0.68	0.25
Consulting Information about the Problem (Cp)	-1.78	0.05
Evaluating the Problem (Ep)	0.32	0.38
Postponing the Analysis of the Problem (Pp)	0.42	0.34
Proposing a Solution (Ps)	1.65	0.06
Clarifying a Solution (Cl)	0.86	0.20
Retracting a Previous Design Decision (Re)	0.82	0.21
Making a Design Decision (Dd)	-0.22	0.41
Consulting External Information for Ideas (Co)	-0.80	0.22
Postponing a Design Action (Pd)	1.61	0.07
Looking Ahead (La)	-0.11	0.46
Looking Back (Lb)	1.58	0.07
Justifying a Proposed Solution (Ju)	0.96	0.18
Analyzing a Proposed Solution (An)	-0.85	0.20
Postponing an Analysis Action (Pa)	1.00	0.17
Performing Calculations to Analyze a Proposed Solution (Ca)	-1.03	0.16
Evaluating a Proposed Solution (Ev)	0.04	0.48
Explicitly Referring to Application Knowledge (Ka)	-0.97	0.17
Explicitly Referring to Domain Knowledge (Kd)	-0.34	0.37
Explicitly Referring to Design Strategy (Ds)	-0.43	0.34

Note. Yellow highlight indicates statistically significant differences. Green Highlight indicates differences at the threshold. Design issues with low means are not robust enough to statistically compare.

Summary of Findings

The purpose of Chapter 4 was to report findings from the collected and analyzed data for senior level pre- and non-pre-engineering students' cognitive processes when engaged in an engineering design challenge. These findings characterized and described their cognitive processes as they engaged in an engineering design task in regards to the *Problem Domain-Degree of Abstraction* and *Strategy Classification* coding schemes. The researcher also explained how the reliability of the coding schemes were established and how data was examined to compare and contrast students' cognitive processes within the ENG and NON group, as well as compare and contrast between both groups

Through the qualitative and quantitative analysis conducted for this research study, it was evidenced that when engaged in an engineering design task, both groups exert a majority of their cognitive effort towards Detail issues (2), Proposing Solutions (Ps), Clarifying Solutions (Cl), and Analyzing Proposed Solutions (An). Conversely, participants spent less cognitive effort considering the System (0) and Subsystem issues (1) during the *Problem Domain-Degree of Abstraction*, and Performing Calculations to Analyze a Proposed Solution (Ca), Postponing an Analysis Action (Pa), Postponing a Design Action (Pd), Looking Back (Lb), and Postponing the Analysis of the Problem (Pp). However, findings did indicate that the NON group spent statistically significant more cognitive effort considering the problem from the point of view of the user (System) and referencing external information they were provided (Cp). Also, the NON group approached the threshold of statistical difference in a three additional design issues (Ps, Pd, Lb). Conclusions drawn from these findings will be discussed in Chapter 5, along with implications and recommendations.

CHAPTER V: CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

Research Rationale and Purpose

A principal objective of this study was to address the paucity of research surrounding characterization of high school students' cognition during engineering design by developing a deeper and richer understanding of their cognitive issues when solving an authentic challenge. Additionally, an objective of this research study was to determine if high school students' preparation in PLTW pre-engineering courses resulted in dissimilar distribution of cognitive processes during an engineering design challenge than students who did not take pre-engineering courses. Consequently, the fundamental outcome of these research objectives was to raise awareness of students' strengths and weaknesses during engineering design for the support of teaching and learning surrounding Integrative STEM education pedagogical approaches. Therefore, Chapter 5 presents a discussion of the conclusions, implications, and recommendations drawn from the research undertaken in this study. This chapter begins by discussing conclusions inferred from the findings presented in Chapter 4, followed by implications for pedagogical and instructional practice. Lastly, Chapter 5 will present recommendations for researchers, practitioners, and future studies.

Conclusions

Overall, the findings presented in Chapter 4 illustrate that despite high school seniors having been exposed to pre-engineering (ENG) coursework of Project Lead The Way (PLTW) curricula, it was shown that no differences in allocation of cognitive effort emerged for the majority of design issues between the ENG and NON group. The findings from data analyses, regardless of examining students' cognition to a deeper extent, are consistent with previously conducted research (e.g., Wells, et al., 2016). However, the data analysis did reveal that students from both groups shared similar distribution of cognitive effort as they dissected the problem and their use of cognitive strategies through the design process. Additionally, select cases (e.g., Consulting Information about the Problem and System Issues) were statistically different between groups, while three design issues were considerably different (e.g., Proposing a Solution, Postponing a Design Action, and Looking Back). It should be noted that although differences for a majority of design issues were not detected by both coding schemes, it does not necessarily mean that differences do not indeed exist between the ENG and NON group. Rather, differences may have been confounded by other superfluous variables.

Also, the background experience and specific sequence of courses may not be typical of students in other geographic locations. Though, findings do indicate that there are patterns to the distribution of cognitive effort for both groups and for each of the coding schemes employed. In light of these conclusions, the purpose of the following section is to derive meaning from the findings and lead to possible extrapolation about their implications in regards to each of the research questions of this study (McMillan, 2012).

Research Questions 1 and 3

One of the main research questions of this study was, how do 12th grade high school pre- and non-engineering students' distribute their cognitive efforts as they dissect the problem domain during engineering design tasks. This research question is also directly related to research question three, which was do differences in cognitive processes emerge between 12th grade high school students who take pre-engineering courses and those who do not. To answer these questions, both the treatment (ENG) and control group (NON) were characterized using the *Problem Domain- Degree of Abstraction* coding scheme. Within this framework, there were three pre-defined design issues: System (0), Subsystems (1), and Details (2).

Although the findings indicated that the ENG students exerted only slightly more attention to Subsystems (1) and Details (2) issues than the NON students, it is not surprising given Ting (2014) documented similarly that there was not a statistically significant difference between university level freshman and seniors. In turn, findings indicate that pre-engineering educational experiences may not have emphasized sufficiently, the importance of recognizing and understanding Subsystems (1) and Details (2) within a given design task.

However, findings from the present study differ from the aforementioned study in one important way, that is, NON students exerted more attention to System (0) issues than ENG students. Prior research has recognized that novice designers actually spend less cognitive effort than professional engineers considering the problem from the point of view of the user (Ting, 2014). In turn, the author believes that the most plausible reason for why these findings may have occurred appears to be based on the limitation of this study, also recognized by Wells et al., (2016) who conducted similar research, that curricular and pedagogical factors of PLTW may have influenced students' design abilities. For example, inspection of available PLTW program documents suggests that these courses do not explicitly target design cognition as an intentional learning outcome. Furthermore, Wells et al., reflect that,

> A review of the detailed IED curriculum outline indicates that instructional units give attention to teaching the following set of practices and steps in the design process: technical sketching and drawing skills, modeling skills, geometry of design, documentation, and completion of a prescribed design project using Computer Aided Design (CAD) software. Authentic open-ended design challenges are not integral to the learning experience provided students in this entry level pre-engineering course. In light of this, it suggests that the pedagogical preparation provided to educators delivering the earlier courses in PLTW might not be adequate for intentionally incorporating or promoting design thinking as part of the pre-engineering experiences. (2016)

Additionally, even though the NON group attended to Systems (1) issues more than the ENG group, the ENG group may have been better equipped to understand how the System (0) issues functioned, thereby allowing them to progress to the Subsystems (1), and Details (2) issues of the design task. In contrast, students in the NON group may have had to engage in additional cognitive effort in considering the problem from the point of view of the user. Another point to highlight is that the population of both groups is comprised of academically advanced students. This aptitude may have influenced their approach to solving ill-defined problems such as the design task presented to them in this study. Nonetheless, these findings further corroborate the approach uninformed designers take, which provides an implication for curricula designers and educators in the classroom.

Research Questions 2 and 3

The second of the main research questions of this study was to characterize how non-pre-engineering (NON) students' distribute their cognitive efforts in regards to the coded segments of the *Cognitive Strategies* design issues. This research question is also directly related to research question three, which was, do differences in cognitive processes emerge between 12^{th} grade high school students who take pre-engineering courses and those who do not. To answer these questions, both the treatment (ENG) and control group (NON) were characterized using the *Cognitive Strategies* coding scheme. Within this framework, there were 19 pre-defined design issues that illustrated the cognitive processes students employ as they navigate an engineering design task.

The findings presented in Chapter 4 indicated that students across both groups spent a majority of their efforts considering only three design issues (An, Ps, and Cl). The most plausible explanation for why these findings may have occurred to such a degree is in recognizing that students also spent minimal cognitive effort in the *Analysis of the Problem Domain* (Ap, Cp, Ep, and Pp). This is not surprising considering prior research has established that novice designers spend less cognitive effort than experts fully immersed in understanding the problem (Lammi, 2011). Moreover, recent studies report high school students engage in design thinking with minimal understanding of the problem and become engrossed on a lone solution rather than comparing options (Mentzer, Becker, & Sutton, 2015). This would also be supported by the finding that the fourth largest issue students of both groups considered was Making a Design Decision (Dd). At some point in their design process, they would Propose a Solution, Clarify a Solution, Analyze the Proposed Solution, and Make a Design Decision that would be documented or submitted for their final solution.

Consequentially, extrapolating upon those findings that students demonstrated minimal action in the Analysis Problem domain and use of Postponing the Analysis of the Problem (Pp), it can be deduced that students are not metacognitive about their design actions, rather, they follow an uninformed progression through engineering design. This is also apparent in the low attention to design issues such as Retracting a Previous Design

Decision (Re), Justifying Proposed Solutions (Ju), Evaluating Proposed Solutions (Ev), and the *Explicit Strategies* domain (Ka, Kd, and Ds). These cognitive efforts are associated with design issues that would challenge their process of Proposing, Clarifying, and Analyzing solutions to the design task.

Another finding to note was that the design issue of Consulting Information about the Problem (Cp) was found to be statistically different between both groups. Specifically, the NON group attributed significantly more cognitive effort to examination of available information that was provided to them. In turn, this knowledge was at least referenced to further understand the complexity of the problem. Though, reflecting on findings from the first research question, if students were unsure or unfamiliar with the Systems (0) relevant to the design task at hand, then it is understandable that they would in turn exert more cognitive effort to Consulting Information about the Problem (Cp) and referring to the examples provided to them.

Additionally, though not significantly different, was that the treatment group (ENG) spent considerably more cognitive effort than the control group (NON) proposing solutions to the problem (Ps). This finding suggests that the students who took the PLTW program may have had more experiences or background knowledge of viable solutions and were able to generate a series of ideas that they later clarified, which would also point to the higher rate of cognitive effort they exerted than the students who had not taken PLTW courses.

Implications for Instructional Practice

The conclusions drawn from each of the research questions of this study have particular implications for the instruction of technological/engineering design-based teaching and learning and preparation of students equipped to effectively use engineering design to solve authentic problems. Specifically, this research study presented findings indicating minimal differences existed between students who take PLTW curricula and students who do not, which questions the curricula and pedagogy of PLTW pre-engineering programs. However, the findings and implications are limited to the participants that were selected from three high schools in Southwest Virginia. Thus, the implications presented in the following section should be reflected upon the context of each school setting.

Based on the results of this study, a plausible implication is that technology and engineering education should provide students' explicit instruction and strategies on design issues within the *Analysis of the Problem* domain since students from both groups spent minimal effort engaged in these cognitive activities in contrast to experts (Ting, 2014). Merely demonstrating to them how they can make an evaluation related to the problem (Ep) and how or when to postpone analysis of the problem (Pp) may substantially increase their decomposition of what the problem encompasses. Considering this is an effective skillset of expert engineers, intentionally preparing students how to analyze the problem and consult information about the problem, will better equip them in practices of engineering design. In turn, this will afford them the ability to meet the fundamental goal of using engineering design, which is to possess the skillset necessary to solve authentic problems (Mentzer, Becker, & Sutton, 2015).

Findings like those found for the three research questions of this study suggest where teachers' instructional practices and pedagogical approaches may unintentionally guide students towards some cognitive processes and not to others. Considering research suggests “that students who are asked to think learn better (Brookhart, 2014, p. 5), the type of research conducted in this study may aid teachers in recognizing students’ natural cognitive ability as they enter a classroom environment. Furthermore, findings can also assist educators in identifying which cognitive processes students may consider more useful than other when designing and therefore offer insight into which cognitive processes will not be employed. This data could be used in the design of specific learning tasks to evoke particular cognitive competencies.

For example, teachers could employ a pre-assessment or even use the findings from this study as a baseline. This understanding would afford teachers the opportunity to choose strategies and examples of how to attend to other cognitive processes that do not receive adequate attention. For instance, identification of where students generally exert more and less cognitive effort can support educators in guiding students toward improved design cognition.   This recommendation for instructional practice is also in line with Strimel (2014), who recommends that utilization of the most common or least commonly used cognitive processes students employ can serve as “indicators of voids in curricula, instruction, and student learning” (Strimel, 2014, p. 161).

Recommendations for Future Research

Based on the findings and implications of this study, this section presents recommendations for future research regarding the improvement of technological and engineering design-based teaching and learning.

Length of Design Task

The length of the design challenge for this study was limited to 45 minutes. Though this time constraint is comparable to previously conducted design cognition studies (e.g., Lee, Gero, & Williams, 2012; Wells, 2016), other research investigations have allowed students longer periods of time, up to 3 hours (Mentzer, Becker, & Sutton, 2015; Strimel, 2014). Affording students an extended period of time, perhaps even multiple sessions, may probe deeper into how students distribute their cognitive efforts if they are not restricted by time, and may increase their attention to understanding the problem and consideration of design issues that received minimal attention.

Sample Size

For K-12 design cognition studies, the participants in this study (40), is large in comparison to most other research investigations of a similar nature. For example, Lammi (2011) sampled six students, Strimel (2014) investigated eight, while Welch and Lim (2000) researched 10 students. However, a larger sample size employing a similar methodology may be able to find diverse findings as well as generalize to all U.S. high school students.

Participants

A third recommendation is to investigate participants who have been immersed in the entire sequence or have completed a program of study surrounding Project Lead the Way. The students of this study were engaged in at least one PLTW course. Yet, this exposure is minimal compared to other states who have students take up to five PLTW courses in a sequential manner. This additional experience affords students more exposure to PLTW content and opportunities, which may extract differences not evidenced in this study.

Documentation

While this research study broke down categorical issues of design cognition for the FBS Framework, it did not decompose and further characterize students' mental issues during documentation and illustration of their design problem and solution. Future research should investigate components of documentation such as measuring, dimensioning, pictorial process, and development of ideas to determine if differences exist between students who take PLTW and those who do not.

Design Task

Much of the findings of this research are directly related to the design task presented to students. As reported in the literature review of this study, multiple problem types exist, each warranting a more or less constrained approach, that may affect students navigation of solving the design task and result in alternate distribution of cognitive processes. Furthermore, inclusion of criteria and constraints that are related to scientific and mathematical principles may influence students' distribution for coding categories such as Performing Calculations to Analyze a Proposed Solution (Ca). Future studies would benefit from aligning design challenges to students curricula selection and background experiences.

Modeling, Prototyping, and Use of Materials

One area that has not been investigated in this study, due to time and task constraints is the students' cognitive issues surrounding modeling, prototyping, and use of materials. Though this relates directly to the design task recommendations previously discussed, future research should purposefully examine and investigate how students model, prototype and use materials. This recommendation considers findings from

Strimel (2014), who allowed students the opportunity to engage in such experiences. He found that the design solutions students proposed were impacted by the materials they had access to and were familiar with in the classroom. In turn, the mere introduction of these components, which are common in truly authentic design tasks, may affect students' distribution of other cognitive issues.

Information Gathering

Considering the lack of effort students' exert towards analyzing the problem and the broader System (0) view, providing students the resources to gather information should be explored in future research studies. It is unrealistic to restrain students from searching the internet or having readily available resources to search for problem clarification and viable solutions. Since this issue is a primary difference between novice and expert designers (Mentzer, Becker, & Sutton, 2015), understanding and developing students' ability to gather information and prepare them for defining the problem is essential for engineering design experiences.

Vernacular

Lastly, students' vernacular should be examined in future studies to distinguish subtle differences that may not have been discovered from frequency counts and percentage occurrences. For example, the findings that depict where students spend the majority of their cognitive effort would benefit from a content analysis of *how* they are analyzing the problem (Ap), Systems (0), they are discussing, and the Mathematical Calculations (Ca) they are employing. Using this coding scheme, and others, the above design issues would merely be counted, and not analyzed. One group of students therefore may be characterized as Ca from simple addition and subtraction, while another group of students may very well have applied Pythagorean Theorem to solve a design issue. These types of issues could not only further distinguish difference between groups, but also illustrate additional details of how they navigate engineering design.

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APPENDICES

Appendix A

First Year Design Task

Design Challenge: Double-Hung Window Opener

Challenge:

Your design team has been approached by a local nursing home and asked to design a new product that will assist its elderly residents.

Context:

Administrators at the nursing home have noticed that changes in the humidity during the summer months cause the windows of the 65-year old building to "stick," thus requiring significant amounts of force to raise and lower the window panes. The force needed to adjust the windows is often much too large for the nursing home residents, making it very difficult for them to regulate their room temperature.

Criteria:

Your team has been tasked with designing a device that will assist the elderly tenants with raising and lowering the building's windows. The design solution must satisfy the nursing home client and be easy enough to follow that someone could produce the device without questions. Not all windows will be located near an electrical socket, and therefore the newly designed device should not rely on electric power.

The windows in the building are double-hung (as shown in the figure above). The double-hung windows consist of an upper and lower sash that slide vertically in separate grooves in the side jambs. This type of window provides a maximum face opening for ventilation of one-half the total window area. Each sash is provided with springs, balances, or compression weather stripping to hold it in place when raised or lowered to any vertical location.

Resources:

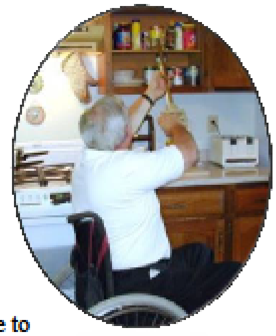
Your team has identified the following websites as potential sources of useful information:

- "Double Hung Window Construction"
  - http://www.oldhouseweb.com/how-to-advice/double-hung-window-construction.shtml
- "Double Hung Windows – Everything You Need to Know" (1 min. 34 sec.):
  - http://www.youtube.com/watch?v=xW7OMHYI4kY
- American Disabilities Act (ADA) information:
  - http://www.ada.gov/
  - http://www.ada.gov/pubs/adastatute08.htm (full act, as amended in 1990)
  - http://en.wikipedia.org/wiki/Americans_with_Disabilities_Act_of_1990
- ADA Accessibility Guidelines for Buildings and Facilities (ADAAG):
  - http://www.access-board.gov/adaag/html/adaag.htm

Appendix B

Second Year Design Task

Design Challenge:
"Reach-n-Grab" Assistive Technology Device



Challenge:

Your design team has been asked to design an assistive technology device that will help a person who is wheelchair bound grab an average size glass food jar off of a cupboard shelf too high for them to reach. The *Reach-n-Grab* device should be designed so that a wheelchair bound person would be able to reach and grab the glass jar when it is about two feet beyond their normal reach.

Context:

Countless products have been designed to make it easier for handicapped people to use them. Yet there are still many everyday tasks that without some sort of assistive technology device handicapped individuals are simply not able to do. For example, the simple task of getting a jar off the top shelf of a cupboard can be a major challenge for someone bound to a wheelchair.

In this activity you are challenged to design an assistive technology device that will help a person in a wheelchair reach and grab glass jars from the upper shelf of a cupboard. Assistive technology devices are mechanical aids which substitute for or enhance the function of a physical or mental ability that is impaired.

Criteria:

The *Reach-n-Grab* assistive technology device you are to design must satisfy the following criteria:

- The device must be designed to operate manually (i.e., by hand with no electronic components).
- The device must be light weight, long enough to reach an item two feet beyond arm's length, and have a clamping mechanism sturdy enough to grip and hold an average size glass food jar.
- The device must have a safety mechanism to ensure the glass jars will not be dropped in the event of device failure.
- The device can be no longer than 24" in any dimension when not being used (i.e., could fold, telescope, etc.) to allow for easy storage.
- The glass food jars being retrieved must not be damaged in any way during the retrieval process.
- Using the assistive technology device must not cause damage to, or leave marks on, the cupboard.

Design Solution:

Using the available white board, create a sketch of your design solution. Include all details needed to explain your solution.

Resources:

Your team is provided the following documentation as potential sources of useful information:

Arcmate: ArcMate\ArcMateProducts.htm

American Disabilities Act (ADA) information:

- http://www.ada.gov/
- http://www.ada.gov/pubs/adastatute08.htm (full act, as amended in 1990)
- http://en.wikipedia.org/wiki/Americans_with_Disabilities_Act_of_1990

jw: High School Design Cognition — Fall 2013 - BHS

Appendix C

Approval Letter to Use Extant Database

VirginiaTech

College of Liberal Arts
and Human Sciences

Integrative STEM Education
Dr. John G. Wells, Program Leader
317 War Memorial Hall (0313)
Blacksburg, Virginia 24061
540/231-8471 Fax: 540/231 9075
http://www.soe.vt.edu/istemed jgwells@vt.edu

MEMORANDUM

To: Virginia Tech IRB

From: John Wells, Principal Investigator
FBS Project, Virginia Tech Award ID EEC - 1160411

Subject: Access/Use Approval – VT Collected FBS Data

Date: 3/16/2015

Mr. Michael E. Grubbs, a doctoral candidate in the Integrative STEM Education graduate program at Virginia Tech (VT), has requested access to and use of transcript data from a current VT NSF project for analysis as part of his dissertation research.

This memo serves as an approval notice for Mr. Grubbs to use select transcript data derived from audio/video recordings captured as part of data collection at Virginia Tech for a longitudinal NSF funded project titled "Collaborative Research: Understanding High School Pre-Engineering Student Design Cognition, Comparisons with Engineering Students," award number EEC-1160411. The transcript data contains text only and does not include information that could in any way be used in identifying project participants.

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Appendix D

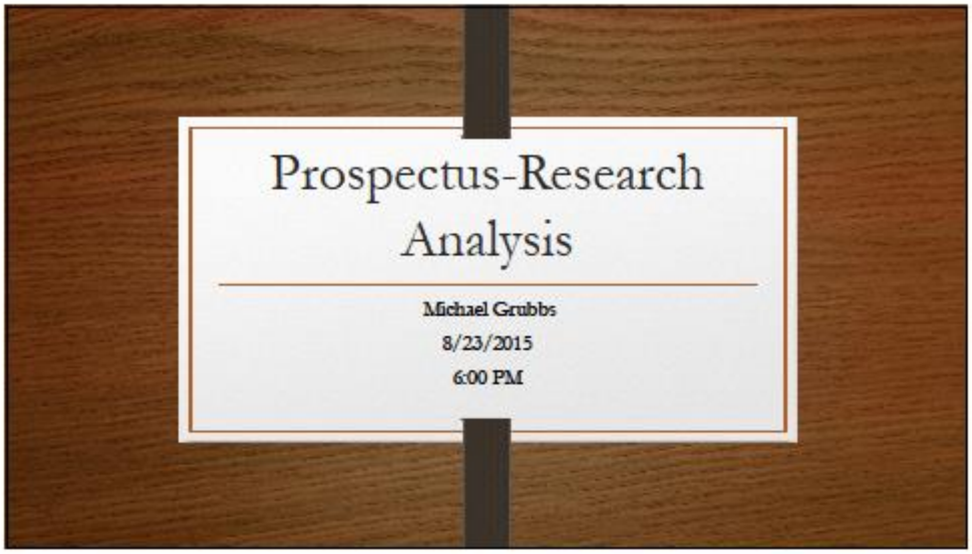
Training Presentation Outline

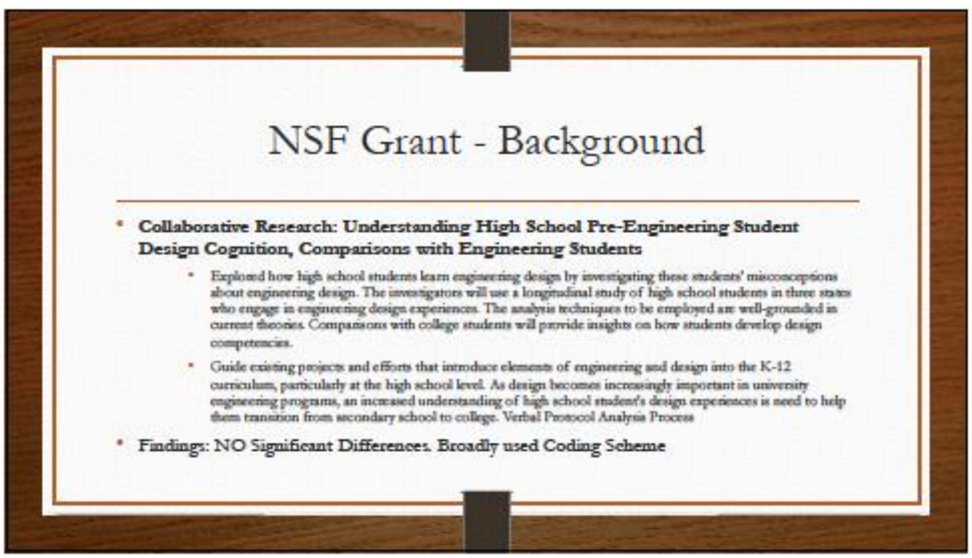
Outline of Presentation: How to Segment, Code, and Arbitrate

Slides	Topic
1)	Background of original NSF Longitudinal Study
2)	Overview of Verbal Protocol Analysis: How Data was Collected
3)	Purpose of Dissertation Research
4)	Description of Coding Scheme 1
	i. Example codes
5)	Description of Coding Scheme 2
	i. Example codes
6)	Overview of Raw Transcript Extant Data
7)	Using Excel to Segment and Code
	i. Attaching meaning to single codes
	ii. How to split individual designers utterances into distinct codes
8)	Merging of Transcripts
9)	Arbitration Process
	i. Reaching Agreement/Final Arbitrator Decision
10)	Practice Session # 1
11)	Practice Sessions: Establishing Inter-Coder Reliability
12)	Actual Coding Sessions

Appendix E

Training Presentation PowerPoint Slides

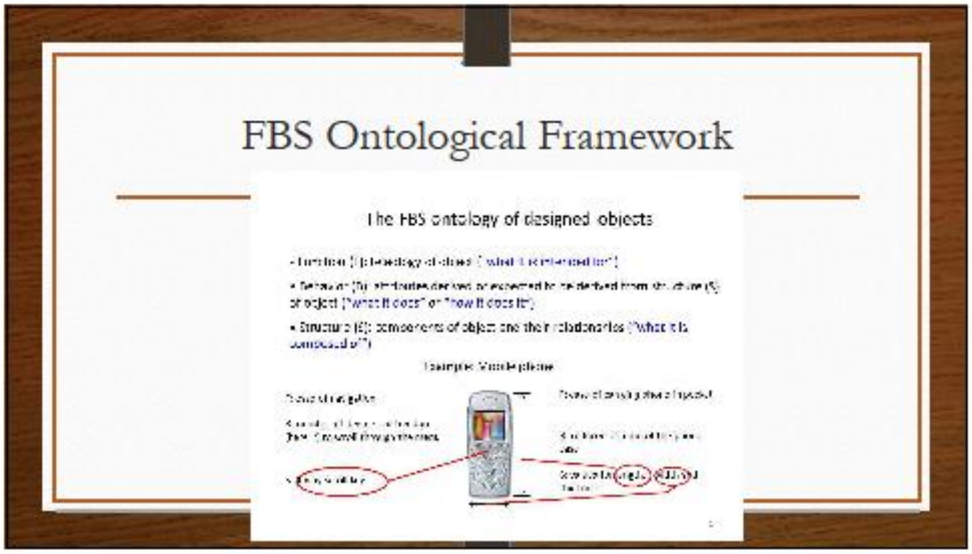

Prospectus-Research Analysis
Michael Grubbs
8/23/2015
6:00 PM

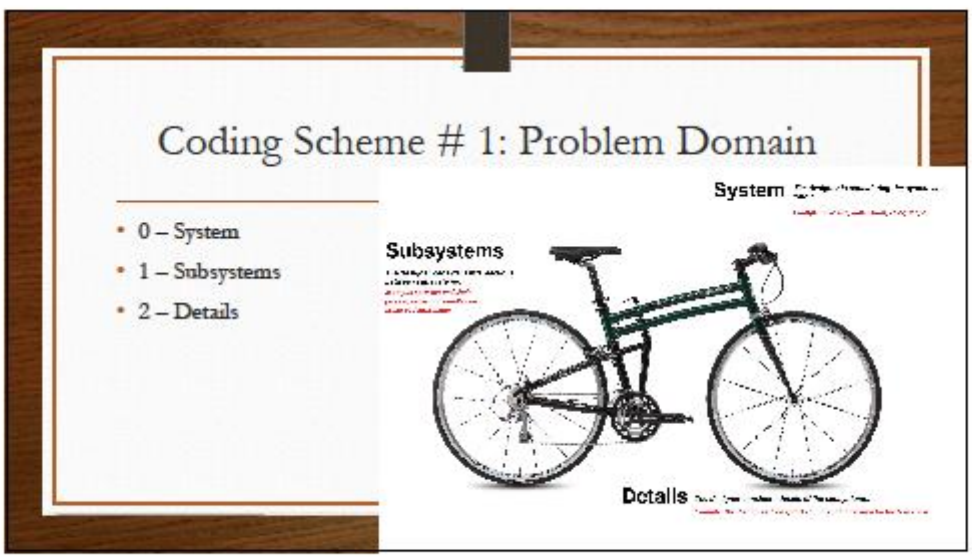

NSF Grant - Background
Collaborative Research: Understanding High School Pre-Engineering Student Design Cognition, Comparisons with Engineering Students
Explored how high school students learn engineering design by investigating these students' misconceptions about engineering design. The investigators will use a longitudinal study of high school students in three states who engage in engineering design experiences. The analysis techniques to be employed are well-grounded in current theories. Comparisons with college students will provide insights on how students develop design competencies.
Guide existing projects and efforts that introduce elements of engineering and design into the K-12 curriculum, particularly at the high school level. As design becomes increasingly important in university engineering programs, an increased understanding of high school student's design experiences is need to help them transition from secondary school to college. Verbal Protocol Analysis Process
Findings: NO Significant Differences. Broadly used Coding Scheme

NSF Grant - Background

My Dissertation

- Purpose
  - Explore K-12 Students Design Cognition at a deeper, more distinct level
  - Determine if differences do indeed exist:
    - 1.) Problem Domain
    - 2.) Analysis, Synthesis, Evaluation
- IRB Procedures
  - Identify coders that were to be used
  - Approval to use data


FBS Ontological Framework
The FBS ontology of designed objects


Coding Scheme # 1: Problem Domain
• 0 – System
• 1 – Subsystems
• 2 – Details
System
Subsystems
Details

Coding Scheme 2

- Analysis: 4 Codes
  - Ap, Cp, Ep, Pp
- Synthesis
  - Ps, Cl, Re, Dd, Co, Pd, La, Lb,
- Evaluation
  - Ju, An, Pa, Ca, Ev
- Explicit Strategies
  - Ka, Kd, Ds

Overview of Raw Transcript Extant Data

[TIME]	NUMBER	SJ	UTTERANCE
	1	A	Begin by watching the video
1:21:00	2	B	Yea and then we can just look at the planel hate these windows though for real
	3	A	Uhmm. yea see if there aren't any rules
	4	B	Who ever designed these windows are an idiot
	5	A	I hate opening these things
3:00:00	6	B	Uhmm scroll down see if theres just like any rules
	7	A	Yea I don't see why
	8	B	that like that like the elderly can't be forced to do anything something like that we might design that's like illegal.. I don't know....perfect entities. accomadtions and commerical facilities.... uhhh yea
	9	A	This means that even facilities that have not been modified or altered in any way after the ADA was passed still have obligations. Removing barriers
	10	B	what what do they what

Using Excel to Segment and Code

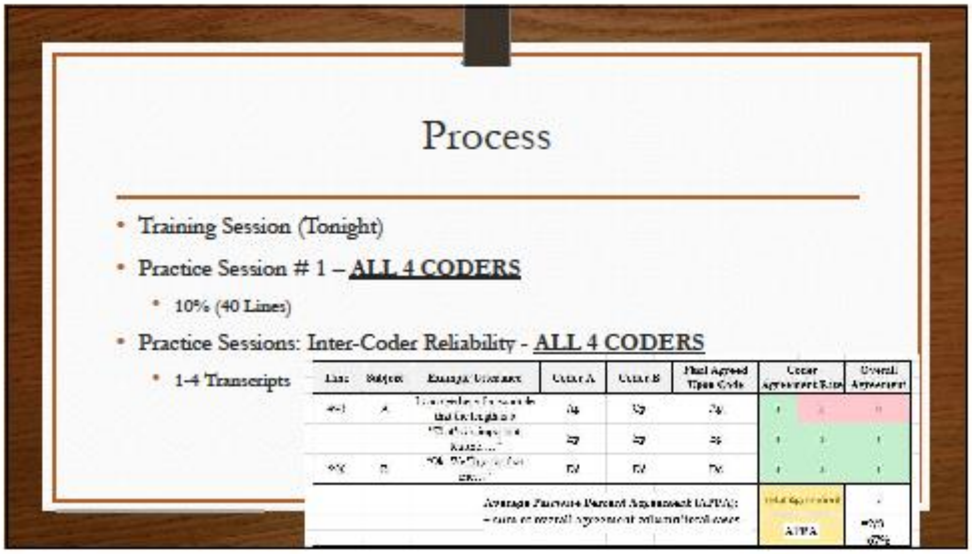
- Attach meaning to single codes
- Split Individual Designers Utterances into Distinct Codes

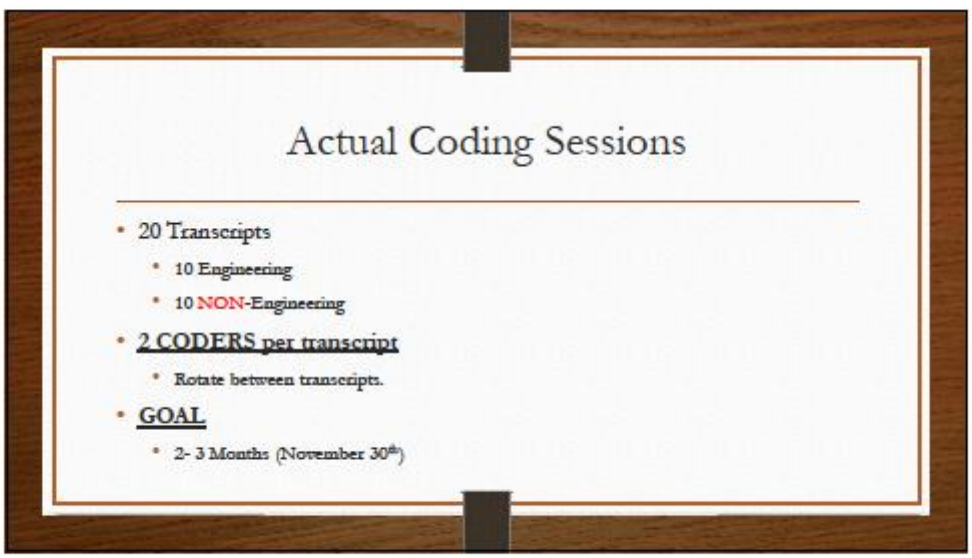
- **Mike will merge transcripts!*

Arbitration Process

Time	Subject	Example Utterance	Coder A		Coder B		Final Code	
			Scheme 1	Scheme 2	Scheme 1	Scheme 2	Scheme 1	Scheme 2
[illegible]	A	I can see here for example that the length is 6	1	Ap	2	Cp	1	Ap
		"That's an important feature…"		Rp		Rp		Rp
[illegible]	B	"Ok. We'll go for that one…"	2	Dd	2	Dd	2	

Figure 6. Concurrent segmentation and coding process. This figure presents an excerpt from an Excel document, detailing how the transcript was concurrently segmented and coded.


Process
Training Session (Tonight)
Practice Session # 1 – ALL 4 CODERS
10% (40 Lines)
Practice Sessions: Inter-Coder Reliability - ALL 4 CODERS
1-4 Transcripts


Actual Coding Sessions
20 Transcripts
10 Engineering
10 NON-Engineering
2 CODERS per transcript
Rotate between transcripts.
GOAL
2- 3 Months (November 30th)

Appendix F

Virginia Tech Institutional Review Board (IRB) Approval Letter

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:	July 30, 2015
TO:	John Wells, Michael Edwin Grubbs
FROM:	Virginia Tech Institutional Review Board (FWA00000572, expires July 29, 2020)
PROTOCOL TITLE:	Further Characterization of High School Pre- and Non-Engineering Students’ Cognitive Activity During Engineering Design
IRB NUMBER:	**15-732**

Effective July 30, 2015, 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**
Protocol Approval Date:	**July 30, 2015**
Protocol Expiration Date:	**July 29, 2016**
Continuing Review Due Date*:	**July 15, 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.

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Appendix G

Calendar and Schedule

October 2015

◄ September 2015 ~ October 2015 ~ Nov 2015 ►

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25 Codes Due 1-5	26 Arbitrate 1-5 Independetly	27	28	29	30	31

November 2015

◄ October 2015 | ~ November 2015 ~ | Dec 2015 ►

Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4 Arbitrate 1-5 Independetly	5	6	7 Codes Due 6-10
8 FINAL ARBI. 1-5	9	10	11 Arbitrate 6-10 Independetly	12	13	14
15	16	17	18 Arbitrate 6-10 Independetly	19	20	21 Codes Due 11-15
22 FINAL ARBI. 6-10	23	24	25 Arbitrate 11-15 Independetly	26	27	28
29	30	**Notes:**				

December 2015

◂ November 2015			~ December 2015 ~			Jan 2016 ▸
Sun	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**
		1	2 Arbitrate 11-15 Independetly	3	4	5 Codes Due 16-20
6 FINAL ARBI. 11-15	7	8	9 Arbitrate 16-20 Independetly	10	11	12
13	14	15	16 Arbitrate 16-20 Independetly	17	18	19
20 FINAL ARBI. 16-20	21	22	23	24	25	26
27	28	29	30	31	**Notes:**	

Appendix H

Training Document

This document was provided to coders to familiarize them with how each coding scheme was conceived and the individual codes that were to be used.

Table 1

Problem Domain: Degree of Abstraction

Category	Code	Definition	Example Utterances
System	0	The designer is considering the problem from the point of view of the user.	"OK let's just see so I've got an idea of what this backpack design looks like"
Subsystems	1	The designer is considering the problem in terms of the subsystems	"side mounted alright"
Detail	2	The designer is considering the details of the subsystems.	"what we're going to do is we're going to run these stays to em to this er this fitting here"

Note. Adopted from: Purcell, Gero, Edwards & McNeil, 1996.

When using Table 1, consider the depth to which the students consider the varying components of their design. As Purcell, Gero, Edward, and McNeil (1996) suggest and compare to a different design session:

"This group of codes is related to the way the designer appears to be dissecting the problem as well as a reflection of the complexity of the problem itself. In the present design episode, the *Systems* level (0) relates to how the finished product would be used and the relation between the bicycle, backpack and backpack carrier as a whole assembly. The bicycle, backpack and backpack carrier could all be considered as subsystems in this design episode. The *Sub-systems* level (1) indicates that the designer is focusing on issues which pertain to only one of these subsystems at that particular time. The *Detail* level (2) indicates that the designer is considering the characteristics of physical components"

When using Table 2, consider the distinguishing features that students spend analyzing, synthesizing, evaluating, and explicit strategies they employ. As Purcell, Gero, Edward, and McNeil (1996) suggest and compare to a different design session:

is classification, "Strategy describes the moment-to-moment activities of the designer during the design episode. The codes used can be dissected into four groups. The first group is concerned with analysis of the problem. The second group is concerned with the proposal of a solution and the third is concerned with analysis of the proposed solution. The fourth group is concerned with time when the designer made explicit reference to what he or she was doing or what he or she knows.

Table 2
Strategy Classification Scheme

Category	Code	Definition	Example Utterance
Analysis Problem			
Analyzing the Problem	Ap	The designer is analyzing the problem.	"what is the system going to need to do…"
Consulting Information about the Problem	Cp	The designer is referencing external information they were provided.	As above but using external information
Evaluating the Problem	Ep	The designer is making an evaluation related to the problem.	"That's an important feature…."
Postponing the Analysis of the Problem	Pp	The designer decides to postpone analysis of the problem.	I can find that out later….."
Synthesizing Solution			
Proposing a Solution	Ps	The designer presents a proposal for solution.	"the way to solve that is"
Clarifying a Solution	Cl	The designer provides clarification for a solution they have proposed.	"I'll do that a bit neater"
Retracting a Previous Design Decision	Re	The designer suggests a previous decision should be retracted.	"That approach is no good what if I…."
Making a Design Decision	Dd	The designer makes a decision between multiple solution proposals.	"Ok. We'll go for that one…"
Consulting External Information for Ideas	Co	The designer consults external information for ideas related to the solution.	"What are my options…."
Postponing a Design Action	Pd	The designer decides to postpone analysis related to a design action.	"I need to do…later"
Looking Ahead	La	The designer anticipates what will need to be completed ahead of time.	"These things will be trivial (difficult) to do"
Looking Back	Lb	The designer reviews past decisions.	"Can I improve this solution?" –"do I need all these features"
Evaluating Solution			
Justifying a Proposed Solution	Ju	The designer decides to justify the problem.	"This is the way to go because…."
Analyzing a Proposed Solution	An	The designer analyzes a proposed solution.	"That will work like this…"
Postponing an Analysis Action	Pa	The designer postpones the analysis of an evaluation.	"I'll need to work that out later"
Performing Calculations to Analyze a Proposed Solution	Ca	The designer performs calculations related to an evaluation of a proposed solution.	"That's seven inches time three"
Evaluating a Proposed Solution	Ev	The designer evaluates a solution.	"This is faster, cheaper etc…"
Explicit Strategies			
Explicitly Referring to Application Knowledge	Ka	The designer references knowledge specifically related to a final design.	"In this environment it will need to be…"
Explicitly Referring to Domain Knowledge	Kd	The designer references domain specific knowledge.	"I know that these components are…"
Explicitly Referring to Design Strategy	Ds	The designer references knowledge related to strategies that they are aware of.	"I'm doing this the hard way…."

Note. Adopted from: Purcell, Gero, Edwards & McNeil, 1996

Appendix I

Addendum Training Document

Training Document Addendum

Code Clarifications

Coding Scheme # 1: Problem Formulation

0 System – General or broad, focused more on final or complete product, not individual parts or how the parts interact.
1 Subsystems- Specific parts or relationships between specific parts.
2 Detail – Focuses more on criteria such as: dimensions, distances, or locations. Is specific in regards to consequences of what the subsystems will do.

Coding Scheme # 2: Strategy Classification

Analysis	
Ap	Developing understanding
Cp	External information to understand and identify the problem, not propose ideas.
Ep	
Pp	
Synthesizing	
Ps	Only the first time an idea is proposed. Later details are captured in Cl,
Cl	Can be drawing or writing if extending previous discussion and proposed ideas.
Re	Should be more concrete and explicit, viewed more as an intentional, expressed strategy.
Dd	Focused on larger context of design session. Decisions that were later changed were double checked.
Co	Use of information for Ps or Cl
Pd	
La	Related to solving the problem not time constraints. (e.g. we will need to solve this later).
Lb	Related to past decisions but not necessarily retracting.
Evaluating Solution	
Ju	Supports why a decision should be made, beyond simply clarifying "how" Ps works.
An	More general than the Ev category and formative in nature.
Pa	
Ca	Beyond basic addition/ subtraction. Consequences of dimensioning can also be inferred.
Ev	More measureable and specific than An, while summative in nature.
Explicit Strategies	
Ka	Knowledge based more on prediction of what will or may occur from general experiences.
Kd	Focused more on past experience than on anticipation.
Ds	Any strategies related to time of design challenge or process that needs to be completed. Examples would be "let's beginning drawing just to get ideas down".

Updates: Practice Session 1: 9/6/15; 9/20/15; 9/23/15. Practice Session 2: 10/4/15; 10/11/15

Appendix J

Overall Agreement

Research Sessions:Data Chart – YEAR 2 - Schedule of Recording Sessions, Transcriptions, Coding, Arbitrations

			Date	Site	ENG/NON	Coders	Complete Arbitration 1					Final Arbi.
							CS 1	CS 2	Deadline	CS 1	CS 2	
Session # 1 **Codes Submitted to Mike:** **10/24/15**	**1**	1	2/20/14	BHS	ENG	MG & SG	65%	57%	Saturday November 7th, 2015	84%	80%	Sunday 11/8/15
		2	2/20/14	BHS	ENG							
	2*	3	2/20/14	BHS	ENG	LM & MK	61%	59%		84%	79%	
		10	2/20/14	BHS	ENG							
	3	5	2/20/14	BHS	ENG	MG & LM	51%	52%		79%	79%	
		6	2/20/14	BHS	ENG							
	4	7	2/20/14	BHS	ENG	SG & MK	64%	63%		86%	83%	
		8	2/20/14	BHS	ENG							
	5	11	2/20/14	BHS	ENG	MG & SG	73%	53%		88%	78%	
		12	2/20/14	BHS	ENG							
Session # 2 **Codes Submitted to Mike:** **11/7/15**	**6***	14	12/18/14	BHS	NONENG	MG & SG	72%	74%	Saturday November 21st, 2015	88%	88%	Sunday 11/22/15
		18	12/18/14	BHS	NONENG							
	7*	13	2/20/14	BHS	NONENG	LM & MK	52%	43%		77%	73%	
		15	2/20/14	BHS	NONENG							
	8*	16	12/18/14	BHS	NONENG	MG & LM	76%	68%		90%	87%	
		17	12/18/14	BHS	NONENG							
	9	19	12/18/14	BHS	NONENG	SG & MK	36%	37%		70%	72%	
		20	12/18/14	BHS	NONENG							
	10	21	2/6/14	LHS	NONENG	MG & SG	77%	70%		90%	85%	
		22	2/6/14	LHS	NONENG							
Session # 3 **Codes Submitted to Mike:** **11/21/15**	**11**	23	2/6/14	LHS	NONENG	MG & SG	80%	59%	Saturday December 5th, 2015	93%	81%	Sunday 12/6/15
		24	2/6/14	LHS	NONENG							
	12	25	2/6/14	LHS	ENG	LM & MK	80%	55%		91%	80%	
		26	2/6/14	LHS	ENG							
	13	27	2/6/14	LHS	ENG	MG & LM	75%	60%		93%	90%	
		28	2/6/14	LHS	ENG							
	14	29	2/6/14	LHS	ENG	SG & MK	54%	41%		80%	71%	
		30	2/6/14	LHS	ENG							
	15	31	2/6/14	LHS	NONENG	MG & SG	85%	80%		93%	90%	
		32	2/6/14	LHS	NONENG							
Session # 4 **Codes Submitted to Mike:** **12/5/15**	**16**	33	12/18/14	BHS	NONENG	MG & SG	76%	66%	Saturday December 19th, 2015	90%	83%	Sunday 12/20/15
		34	12/18/14	BHS	NONENG							
	17	35	2/20/14	BHS	NONENG	LM & MK	63%	56%		83%	78%	
		36	2/20/14	BHS	NONENG							
	18	37	2/27/14	CHS	NONENG	MG & LM	72%	66%		90%	84%	
		38	2/27/14	CHS	NONENG							
	19	39	3/4/14	CHS	ENG	SG & MK	64%	50%		82%	75%	
		40	3/4/14	CHS	ENG							
	20	41	3/4/14	CHS	ENG	MG & SG	83%	72%		92%	87%	
		42	3/4/14	CHS	ENG							

Appendix K

Transcript: PRE-engineering Dyad

[TIME]	#	Sj	UTTERANCE	CS 1		**CODE**				CS 2		**CODE**			
				SG	MG					SG	MG				
2:47	1	A	Where is it	O	O	**O**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	2	B	The device	^	^	**^**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	3		must have a safety mechanism to ensure the glass jars will not be dropped	^	1	**1**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**
	4	A	oh ok I didn't see that	^	^	**^**	**1**	**1**	**100%**	^	Cp	**Cp**	**0**	**1**	**50%**
	5	B	yeah so	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
3:00	6	A	Id say just like a little… platform	O	1	**1**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	7	B	Then it would be	^	2	**2**	**0**	**1**	**50%**	La	An	**La**	**1**	**0**	**50%**
	8		hard to slide under the jar… or something	2	2	**2**	**1**	**1**	**100%**		An	**An**	**0**	**1**	**50%**
	9	A	Oh yeah that's true	^	^	**^**	**1**	**1**	**100%**	^	Re	**^**	**1**	**0**	**50%**
	10	B	grab it, I don't know	^	2	**2**	**0**	**1**	**50%**	^	Ps	**Ps**	**0**	**1**	**50%**
	11	A	Well… or it could work with the…	1	1	**1**	**1**	**1**	**100%**	Ps	An	**An**	**0**	**1**	**50%**
	12		the clamp thing	^	^	**^**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	13		and then it just like as it clamps	2	2	**2**	**1**	**1**	**100%**	Cl	Ps	**Cl**	**1**	**0**	**50%**
	14		and it just slides under	^	2	**2**	**0**	**1**	**50%**	Cl	Ps	**Cl**	**1**	**0**	**50%**
	15	B	Oh I see so you like have the clamp	^	1	**1**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	16		and then itll like fold	^	2	**2**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	17	A	ya ya… so it just like works in one fluid motion	^	2	**2**	**0**	**1**	**50%**	An	An	**An**	**1**	**1**	**100%**
	18	B	and if you let go then the thing comes open	1	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	19	A	that that's true… ummm… let's see	^	^	**^**	**1**	**1**	**100%**	^	La	**^**	**1**	**0**	**50%**
	20	B	So basically we have to design one of these things	O	O	**O**	**1**	**1**	**100%**	Ep	Ep	**Ep**	**1**	**1**	**100%**
	21		with the safety mechanism	^	1	**1**	**0**	**1**	**50%**	^	Cp	**Cp**	**0**	**1**	**50%**
	22	A	ya… alright… okay… well lets see kind of like what we would want to what work with… like start out	O	O	**O**	**1**	**1**	**100%**	^	Ds	**Ds**	**0**	**1**	**50%**
	23	B	Yeah, I've seen probably most that I've seen are like this…	^	O	**O**	**0**	**1**	**50%**	Kd	Kd	**Kd**	**1**	**1**	**100%**
	24	A	yeah yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**

	25	B	cause it has grips around the whole thing	1	1	**1**	1	1	**100%**	Ps	Ps	**Ps**	1	1	**100%**
	26	A	Yeah I think that'd be best… Yeah something like that probably wouldn't be able to	^	2	**2**	**0**	1	**50%**	Ju	Ju	**Ju**	1	1	**100%**
	27	B	yeah	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	28	A	grip onto a jar	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	29	B	but I think this is definitely the best one	^	2	**2**	**0**	1	**50%**	Dd	Dd	**Dd**	1	1	**100%**
	30	A	yeah… lets see… so this is two feet beyond arms length…	2	2	**2**	1	1	**100%**	^	Ka	**Ka**	**0**	1	**50%**
	31		and then it can't be any longer than 24 inches when not being used,	^	2	**O**	**0**	**0**	**0%**	Cp	Cp	**Cp**	1	1	**100%**
	32		so we could… fold it up	^	2	**2**	**0**	1	**50%**	Ps	Ps	**Ps**	1	1	**100%**
	33		or do something like that	^	^	^	1	1	**100%**	^	Pd	**Pd**	**0**	1	**50%**
	34	B	so we need to figure out a safety thing	O	1	**1**	**0**	1	**50%**	Ap	La	**Ap**	1	**0**	**50%**
	35	A	yeah I think that's	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	36	B	and a way to make it smaller	^	2	**O**	**0**	**0**	**0%**	Ap	La	**La**	**0**	1	**50%**
6:00	37	A	yeah I think that's the best that's the thing we should start off with… okay well	^	^	^	1	1	**100%**	^	Ds	**Ds**	**0**	1	**50%**
	38	B	alright well we'll draw the idea you that you had first	^	^	^	1	1	**100%**	^	Dd	**Dd**	**0**	1	**50%**
	39	A	just like a little platform	O	1	**1**	**0**	1	**50%**	Ps	Ps	**Ps**	1	1	**100%**
	40	B	yeah… so we have the little grabbber thing [DRAW]..	1	1	**1**	1	1	**100%**	Cl	Ps	**Cl**	1	**0**	**50%**
	41		and then I guess a platform	^	1	**1**	**0**	1	**50%**	^	Ps	**Ps**	**0**	1	**50%**
	42		underneath it	^	2	**2**	**0**	1	**50%**	^	^	^	1	1	**100%**
	43	A	Yeah I mean it doesn't even need to be.. To be that, that big	^	2	**2**	**0**	1	**50%**	Cl	An	**An**	**0**	1	**50%**
	44	B	yeah but	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	45	A	umm but like you said sliding it under	1	2	**2**	**0**	1	**50%**	Cl	Lb	**Lb**	**0**	1	**50%**
	46	B	would be hard	^	^	^	1	1	**100%**	^	Ev	**Ev**	**0**	1	**50%**
	47	A	yeah	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**

	48	B	but I guess the side view would look like… something like that [DRAW]	^	2	**2**	**0**	**1**	**50%**	An	Cl	**Cl**	**0**	**1**	**50%**
	49	A	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	50	B	Then you have your jar right here [DRAW]	O	O	**O**	**1**	**1**	**100%**	^	Ps	**Cl**	**0**	**0**	**0%**
	51	A	well maybe if… the like clamps	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	52		extended out… when when their like not..	^	2	**2**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**
	53		Um when you don't, when you're not pressing	^	O	**O**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**
	54		like the lever or whatever	^	2	**1**	**0**	**0**	**0%**	^	^	**^**	**1**	**1**	**100%**
	55	B	mhmm	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	56	A	and then it comes back in	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	57		when you press it… like when you press it	O	O	**O**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	58		and it clamps together	2	2	**2**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	59		it kind of like retracts a little bit or something	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	60	B	alright	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	61	A	So then that way itlll pull it onto the	O	2	**2**	**0**	**1**	**50%**	Cl	Ju	**An**	**0**	**0**	**0%**
	62	B	it will force it onto the platform	1	2	**2**	**0**	**1**	**50%**	^	Cl	**An**	**0**	**0**	**0%**
	63	A	Because that second idea that we had probably wouldn't work because	^	2	**2**	**0**	**1**	**50%**	Re	Re	**Re**	**1**	**1**	**100%**
	64	B	yeah but then again say this say you're standing right say the person is like in the chair here they would have to reach up here cause they would have to have it slide in perfectly	O	O	**O**	**1**	**1**	**100%**	Ka	Ka	**Ka**	**1**	**1**	**100%**
	65	A	Yeah that's right that's right	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	66	B	And that would be like seven feet tall	^	2	**2**	**0**	**1**	**50%**	Ka	Ka	**Ka**	**1**	**1**	**100%**
	67	A	haha yeah umm… yeah I don't know how that's going to work… how's that going to work? It seems so simple	^	^	**^**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	68	B	I know	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**

9:00	69	A	Umm… Yeah I don't think I don't think we should use that idea, let's just throw that one out	^	^	**^**	**1**	**1**	**100%**	Re	Re	**Re**	**1**	**1**	**100%**
	70	B	Ok	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	71	A	Or maybe try to like change it up but just a little bit to make it work	^	O	**O**	**0**	**1**	**50%**	Ev	Ps	**Re**	**0**	**0**	**0%**
	72	B	I mean I was thinking like we could extend	1	2	**2**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	73		the arm down here [DRAW],	1	1	**1**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	74		then have the handle or the trigger thing	^	1	**1**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	75	A	Yeah I mean that could work	^	^	**^**	**1**	**1**	**100%**	Ev	Ev	**Ev**	**1**	**1**	**100%**
	76	B	like right here but then again it would be really hard to hold it once you have all the weight right here	O	O	**O**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	77	A	yeah yeah… how would you get it to stay like that too?	O	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	78	B	What do you mean?	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	79	A	Like that	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	80	B	At the ninety degree? I don’t know	1	^	**2**	**0**	**0**	**0%**	^	^	**^**	**1**	**1**	**100%**
	81	A	Because you would have to fold it up because it would be too long	1	2	**2**	**0**	**1**	**50%**	Ev	Ju	**Ev**	**1**	**0**	**50%**
	82	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	83	A	unless you had something going from like here to here	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	84	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	85	A	But then I don't know how you would fold that up either… ok	O	2	**2**	**0**	**1**	**50%**	An	An	**An**	**1**	**1**	**100%**
	86	B	You might be able to have like a locking mechanism on the	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	87	A	on the handle?	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	88	B	Yeah like	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	89	A	that would be good	^	^	**^**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	90	B	you squeeze it	O	O	**O**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**

	91		and it clicks in	^	1	**2**	**0**	**0**	**0%**	^	^	^	**1**	**1**	**100%**
	92	A	or just even like like a safety type thing	O	1	**1**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	93		where you just flip something over	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	94	B	yeah	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	95	A	so like lets say, it can can be, it can be like that simple when you when you pull it	O	O	**O**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	96	B	Oh you know those	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	97	A	then it pushes over and it slides in and locks it	1	1	**1**	**1**	**1**	**100%**	^	Ps	**Ps**	**0**	**1**	**50%**
	98	B	you know those	1	1	**1**	**1**	**1**	**100%**	Kd	Kd	**Kd**	**1**	**1**	**100%**
	99		uh I don't know but they have ridges	2	2	**2**	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	100		and you like pull a rope across it and it tightens up it like notches up, you could do that and it h\as certain notches and you release a button	^	2	**2**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	101	A	yeah yeah	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	102	B	so	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	103	A	yeah well lets see what those two would look like	1	1	**1**	**1**	**1**	**100%**	^	Ds	**Ds**	**0**	**1**	**50%**
	104	B	okay so you have	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	105	A	lets just erase this [ERASE]	^	^	^	**1**	**1**	**100%**	Re	Re	**Re**	**1**	**1**	**100%**
	106	B	yeah	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
12:00	107	A	cause that's not very good… okay let's see	^	^	^	**1**	**1**	**100%**	^	Ev	**An**	**0**	**0**	**0%**
	108	B	Trying to see how I can draw that… so we have… little grabber thing [DRAW]	1	1	**1**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	109	A	mhmm	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	110	B	and then… down… down at the handle thing [DRAW]	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	111		… I don't know how we'd incorporate it in there	^	^	^	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	112	A	or lets say you had the handle [DRAW]	1	1	**1**	**1**	**1**	**100%**	^	Ps	**Ps**	**0**	**1**	**50%**
	113		and then I don't know how it would look something like	^	^	^	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**

			this I guess and then you just like when you when you pull this clamp thingy right her												
	114	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	115	A	there's like a little bar a little bar right here [DRAW]	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	116		and then when you pull it it slides this part slides up	2	2	**2**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	117		and then there is a little hole inside this part of the handle	^	2	**2**	**0**	**1**	**50%**	^	Dd	**Dd**	**0**	**1**	**50%**
	118		and then you just slide the bar over with your finger and it just locks it into place	^	2	**O**	**0**	**0**	**0%**	^	Dd	**Dd**	**0**	**1**	**50%**
	119	B	okay	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	120	A	so like like a safety on like a gun	1	1	**1**	**1**	**1**	**100%**	Kd	Kd	**Kd**	**1**	**1**	**100%**
	121	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	122	A	essentially	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	123	B	okay	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	124	A	so like you know like when on triggers you just push the little thing over and it stops it	2	2	**2**	**1**	**1**	**100%**	Ka	Ka	**Ka**	**1**	**1**	**100%**
	125	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	126	A	but it would be so when you pull it its kind of like backwards so when you pull it you just slide it over and it locks it into place…	2	2	**2**	**1**	**1**	**100%**	^	Cl	**Cl**	**0**	**1**	**50%**
	127	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	128	A	I think… unless you can figure out what to do with that	^	^	**^**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	129	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	130	A	I think I think that's a good idea…	^	2	**2**	**0**	**1**	**50%**	^	An	**An**	**0**	**1**	**50%**
	131		I just need to figure out how to make it look better,	^	^	**^**	**1**	**1**	**100%**	Cl	Ds	**Ds**	**0**	**1**	**50%**
	132		but you understand what Im saying, right?	^	^	**^**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	133	B	Yeah I got you…[DRAW] I was trying, I don't know	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**

15:00	134	A	Or it could even be visible	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	135		and then just like have something like that with a little hole in it	^	1	**1**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	136		and have the little thing right there [DRAW]	^	1	**1**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	137	B	yeah, but then again you don't know how like wide	2	2	**2**	**1**	**1**	**100%**	Pp	Pp	**Pp**	**1**	**1**	**100%**
	138		the jar is, it could have a different size	O	O	**O**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	139	A	Yeah yeah that's true… well then I guess	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	140	B	so	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	141	A	you might be able to have something like… how would you make that work…	1	1	**1**	**1**	**1**	**100%**	Ps	An	**An**	**0**	**1**	**50%**
	142		or it could just be like notches	^	^	**^**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	143	B	yeah that's what I was thinking	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	144	A	yeah just like notches	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	145		instead of just one hole	^	^	**^**	**1**	**1**	**100%**	^	Re	**Re**	**0**	**1**	**50%**
	146		you just have one like little like jagged puzzle piece type thing and then it just you can	^	^	**^**	**1**	**1**	**100%**	^	Ps	**Ps**	**0**	**1**	**50%**
	147	B	you could have	^	^	**^**	**1**	**1**	**100%**	^	Ps	**Ps**	**0**	**1**	**50%**
	148	A	slide it into each one, to either one, or	1	2	**2**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**
	149	B	you could have like an opening right here	1	2	**2**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	150		a metal jagged piece type thing that goes through here	^	1	**2**	**0**	**0**	**0%**	^	Ps	**Ps**	**0**	**1**	**50%**
	151		[DRAW],	^	^	**^**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	152		like when you close it	^	2	**2**	**0**	**1**	**50%**	^	Cl	**Cl**	**0**	**1**	**50%**
	153	A	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	154	B	and then like a release button	1	1	**1**	**1**	**1**	**100%**	Cl	Dd	**Dd**	**0**	**1**	**50%**
	155	A	yeah yeah I see what your saying, so like there's a little	^	1	**1**	**0**	**1**	**50%**	^	Cl	**Cl**	**0**	**1**	**50%**
	156	B	so like you press this,	O	O	**O**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**

	157		there's like a little metal piece	1	1	**1**	**1**	**1**	**100%**	**Dd**	**Dd**	**Dd**	**1**	**1**	**100%**
	158		that sticks out	2	2	**2**	**1**	**1**	**100%**	**Dd**	**Dd**	**Dd**	**1**	**1**	**100%**
	159	A	and then it can move like back and forth	^	2	**2**	**0**	**1**	**50%**	^	Dd	**Ju**	**0**	**0**	**0%**
	160	B	so you'd have the handle here [DRAW]	1	1	**1**	**1**	**1**	**100%**	An	Dd	**Dd**	**0**	**1**	**50%**
	161		and you'd have the little metal piece with the	^	2	**1**	**0**	**0**	**0%**	^	Dd	**Dd**	**0**	**1**	**50%**
	162	A	yeah yeah I see what your saying	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	163	B	and then this part you'd have a little metal piece that sticks out that catches it [DRAW]	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	164	A	yeah yeah I like that idea	^	^	**^**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	165	B	and then when you press	1	O	**O**	**0**	**1**	**50%**	Ev	Dd	**Dd**	**0**	**1**	**50%**
	166		the button over here [DRAW]	1	1	**1**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	167		this goes that way	2	2	**2**	**1**	**1**	**100%**	^	Dd	**An**	**0**	**0**	**0%**
	168	A	I like that, I think that's a good idea… I think that's the best one	^	^	**^**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	169	B	Yeah, ok… I guess the metal piece would be like that [DRAW]	1	1	**1**	**1**	**1**	**100%**	Cl	Dd	**Dd**	**0**	**1**	**50%**
	170	A	yeah yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	171	B	okay	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	172	A	that way you don't have a bunch of… I mean you still have some moving parts but it's not	1	1	**1**	**1**	**1**	**100%**	Ev	Ju	**Ju**	**0**	**1**	**50%**
	173	B	And you have the full handle thing [DRAW]	1	1	**1**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	174	A	I think that's a good idea… so you just want to go on that	^	^	**^**	**1**	**1**	**100%**	^	Ev	**An**	**0**	**0**	**0%**
	175	B	yeah, so that's the safety mechanism,	1	2	**1**	**1**	**0**	**50%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	176		so we need to find a way to fold it up	^	2	**2**	**0**	**1**	**50%**	La	La	**La**	**1**	**1**	**100%**
	177	A	okay, so… I'm guessing, like with the handle, like oh gosh how do I want to say this, like the handle is going to be like this	2	2	**2**	**1**	**1**	**100%**	Ps	Dd	**Ps**	**1**	**0**	**50%**

	178		and then no the handle is going to be like this	^	^	**^**	**1**	**1**	**100%**	^	Re	**Re**	**0**	**1**	**50%**
	179		the grabber is going to be like this,	^	^	**^**	**1**	**1**	**100%**	^	Dd	**Ps**	**0**	**0**	**0%**
	180		so the grabber is going to be like parallel to the ground	^	^	**^**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	181	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	182	A	and then the handle is going to be like this	^	2	**2**	**0**	**1**	**50%**	Cl	Dd	**Dd**	**0**	**1**	**50%**
	183	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	184	A	so then you could just press the button like that	^	O	**O**	**0**	**1**	**50%**	Cl	Dd	**Dd**	**0**	**1**	**50%**
	185	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	186	A	ok well then how are you going to get the grabber to get stuff at like angles	1	2	**2**	**0**	**1**	**50%**	La	La	**La**	**1**	**1**	**100%**
	187	B	well it doesn't matter cause I mean you reach up, you can I don't know	O	O	**O**	**1**	**1**	**100%**	Ka	Ju	**Ka**	**1**	**0**	**50%**
18:00	188	A	you know I mean it might still work	^	^	**^**	**1**	**1**	**100%**	^	An	**An**	**0**	**1**	**50%**
	189	B	Cause I mean they still use those grabbers to reach up in cabinets	O	O	**O**	**1**	**1**	**100%**	Kd	Kd	**Kd**	**1**	**1**	**100%**
	190	A	Yeah yeah that's true	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	191	B	So they can still get stuff down it was just a safety mechanism	1	1	**1**	**1**	**1**	**100%**	Ev	Ju	**Ju**	**0**	**1**	**50%**
	192	A	Okay	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	193	B	but I think we drew this wrong, we forgot… [DRAW]	1	1	**1**	**1**	**1**	**100%**	Kd	Lb	**Lb**	**0**	**1**	**50%**
	194		to cause you have this, most grabbers have like uh ….a stationary handle	^	^	**^**	**1**	**1**	**100%**	Kd	Re	**Kd**	**1**	**0**	**50%**
	195		and then they have the thing that comes out here [DRAW]	2	2	**2**	**1**	**1**	**100%**	^	Cl	**Cl**	**0**	**1**	**50%**
	196	A	yeah yeah yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	197	B	so we need a way to figure out how to do this without getting in the way of your hand	O	O	**O**	**1**	**1**	**100%**	Ev	La	**La**	**0**	**1**	**50%**
	198	A	okay, maybe if you had something	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**

			through the handle this way											
	199		coming out of here instead of coming out of here and then it goes in in it's pretty much the same thing except it locks into this pieceinstead of that piece… so instead of like something coming out of here [DRAW] and then going	2	2	**2**	**1**	**1**	**100%**	^	Ps	**Ps**	**0**	**1**	**50%**
	200	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	201	A	you would have something going this way	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	202	B	so youd have be stationary here, there would be a hole right here [DRAW]	1	1	**1**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	203	A	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	204	B	with a little	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	205	A	the the notches	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	206	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	207	A	the bar with the notches on it, so it's basically the same thing but just backwards	2	1	**2**	**1**	**0**	**50%**	An	Cl	**An**	**1**	**0**	**50%**
	208	B	the nothces, yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	209	A	and then you can still have enough room for your hand in there	O	O	**O**	**1**	**1**	**100%**	Ka	Ka	**Ka**	**1**	**1**	**100%**
	210	B	yeah you could just extend this down	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	211		[DRAW]	^	^	**^**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	212	A	yeah, I think that's a good idea and then have the release thing	1	1	**1**	**1**	**1**	**100%**	Cl	An	**An**	**0**	**1**	**50%**
	213		somewhere up in here I guess, or no maybe it would have to be on there	^	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	214	B	Like just the little button thing	^	^	**^**	**1**	**1**	**100%**	^	Ps	**Cl**	**0**	**0**	**0%**
	215	A	okay, I think that's good, I think that's good	^	^	**^**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	216	B	and the retractable thing	2	1	**1**	**0**	**1**	**50%**	Ka	Dd	**Dd**	**0**	**1**	**50%**

	217		cause the way these things work is they have a little metal bar going through here [DRAW]	^	1	2	0	0	0%	Ka	Ka	Ka	1	1	100%
	218		so when you pull this it kind of this is bulled back and then everything collapses	^	2	2	0	1	50%	^	Dd	An	0	0	0%
	219	A	everything goes together	^	2	2	0	1	50%	^	Dd	An	0	0	0%
	220	B	cause the thing spreads out here	^	2	2	0	1	50%	^	Dd	An	0	0	0%
	221	A	mhmm	^	^	^	1	1	100%	^	^	^	1	1	100%
	222	B	so we need a way to figure out how to fold it up without doing anything to that metal piece	1	2	2	0	1	50%	Ap	La	La	0	1	50%
	223	A	yeah… okay… well let's see	^	^	^	1	1	100%	^	^	^	1	1	100%
	224	B	like a telescope would be	1	2	1	1	0	50%	Ps	Ps	Ps	1	1	100%
	225	A	that might work or like tent poles,	1	1	1	1	1	100%	Kd	Kd	Kd	1	1	100%
	226		how you like pull them out	^	2	2	0	1	50%	^	^	^	1	1	100%
	227		it has a string in the middle	^	1	1	0	1	50%	^	^	^	1	1	100%
	228	B	yeah	^	^	^	1	1	100%	^	^	^	1	1	100%
	229	A	I don't know its just an idea, it might work, it might not	^	^	^	1	1	100%	^	An	An	0	1	50%
21:00	230	B	yeah	^	^	^	1	1	100%	^	^	^	1	1	100%
	231	A	I don't know show me what show me what you were thinking	^	^	^	1	1	100%	Cl	Cl	Cl	1	1	100%
	232	B	I mean you just have like cause once this is pulled out all the way it'll still be able to be used so you would just have bigger pieces going into [DRAW]	1	1	1	1	1	100%	Ev	Cl	An	0	0	0%
	233	A	smaller pieces, yeah	^	1	1	0	1	50%	^	^	^	1	1	100%
	234	B	and you can just fold it together	O	O	O	1	1	100%	^	Cl	Ps	0	0	0%
	235	A	Uh yeah that might	^	^	^	1	1	100%	An	An	An	1	1	100%
	236	B	and each of these pieces could be a foot	1	2	2	0	1	50%	Ps	Ps	Ps	1	1	100%
	237	A	yeah that might be, that's a better idea	^	^	^	1	1	100%	^	An	An	0	1	50%

	238	B	and then you can extend it to like four feet [DRAW]	2	2	**2**	**1**	**1**	**100%**	An	Ps	**Cl**	**0**	**0**	**0%**
	239	A	you just need to make sure it doesn't get too small	^	2	**2**	**0**	**1**	**50%**	La	La	**La**	**1**	**1**	**100%**
	240	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	241	A	so like it wouldn't be able to take the weight, but that that's easy	O	O	**O**	**1**	**1**	**100%**	^	Ju	**Ju**	**0**	**1**	**50%**
	242	B	Cause you can just collapse it, you have lets say each one of these is one foot and you have the little grabber thing which is mega light [DRAW]	2	2	**2**	**1**	**1**	**100%**	Ev	Ev	**Ev**	**1**	**1**	**100%**
	243	A	So essentially it could be like as long as you	^	2	**2**	**0**	**1**	**50%**	Cl	An	**An**	**0**	**1**	**50%**
	244	B	so it could be like a foot	^	2	**2**	**0**	**1**	**50%**	^	Ps	**Ps**	**0**	**1**	**50%**
	245	A	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	246	B	when you collaspe it all together	^	O	**O**	**0**	**1**	**50%**	^	Cl	**Cl**	**0**	**1**	**50%**
	247	A	yeah yeah, I think that's a good idea…	^	2	**2**	**0**	**1**	**50%**	Dd	An	**An**	**0**	**1**	**50%**
	248		a foot plus this [DRAW]	^	^	**^**	**1**	**1**	**100%**	Ca	Ca	**Ca**	**1**	**1**	**100%**
	249	B	yeah which that's going be	^	^	**^**	**1**	**1**	**100%**	^	Ca	**Ca**	**0**	**1**	**50%**
	250	A	maybe like six inches	^	2	**2**	**0**	**1**	**50%**	Ev	Ps	**Ca**	**0**	**0**	**0%**
	251	B	yeah that can't even be a foot	1	2	**2**	**0**	**1**	**50%**	Ka	Ka	**Ka**	**1**	**1**	**100%**
	252		and then you have your handle, [DRAW] ok	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	253	A	I think that's good lets lets try to get a bigger	O	O	**O**	**1**	**1**	**100%**	^	An	**An**	**0**	**1**	**50%**
	254	B	picture	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	255	A	bigger picture, we'll just keep that	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	256	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	257	A	so we'll have something to go by	^	^	**^**	**1**	**1**	**100%**	^	Ds	**Ds**	**0**	**1**	**50%**
	258	B	alright [DRAW]	^	^	**^**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	259	A	alright, lets see	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	260	B	so we've got our big pieces with our stationary handle	1	1	**1**	**1**	**1**	**100%**	Ev	Dd	**Dd**	**0**	**1**	**50%**
	261	A	and then that's going to be a foot long	^	2	**2**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**

	262	B	this thing?	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	263	A	this this part	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	264	B	oh yeah [DRAW]	^	^	**^**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	265	A	that's like… how big is like the average hand, it's over three inches from here to here	O	O	**O**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	266	B	I mean we could give six inches just for	^	2	**2**	**0**	**1**	**50%**	^	Ps	**Ps**	**0**	**1**	**50%**
	267	A	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	268	B	but and then you have the little handle, [DRAW]	1	1	**1**	**1**	**1**	**100%**	Cl	Dd	**Cl**	**1**	**0**	**50%**
	269		did I get that right?	^	^	**^**	**1**	**1**	**100%**	^	An	**An**	**0**	**1**	**50%**
	270	A	yeah yeah that's right	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	271	B	yeah like that, okay, okay and then the telescoping pieces, [DRAW]	2	2	**2**	**1**	**1**	**100%**	Cl	Dd	**Dd**	**0**	**1**	**50%**
	272		each of these are a foot	^	^	**^**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	273	A	so it could be three foot	^	2	**2**	**0**	**1**	**50%**	^	Ca	**Ca**	**0**	**1**	**50%**
	274	B	So it could go three to four feet	^	2	**2**	**0**	**1**	**50%**	^	An	**An**	**0**	**1**	**50%**
	275	A	I'm going to see if there's it says I think it says two feet away or something like that	O	2	**2**	**0**	**1**	**50%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
24:00:00	276	B	yeah [DRAW]	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	277	A	yeah, so it really doesn't even need to be that long but	O	2	**2**	**0**	**1**	**50%**	^	An	**An**	**0**	**1**	**50%**
	278	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	279	A	it can be, so you would still have the one, the one bar in the middle	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	280	B	yeah it yeah it can just collapse with it, it'll do the same thing, it'll just be inside of here	1	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	281	A	Alright so it's basically just the same thing, but inside, on a smaller scale	^	2	**2**	**0**	**1**	**50%**	An	An	**An**	**1**	**1**	**100%**
	282	B	yeah, this just collapses and then it like connects to here [DRAW]	^	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**

	283	A	okay	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	284	B	just like on the inside	2	2	**2**	**1**	**1**	**100%**	^	Cl	**Cl**	**0**	**1**	**50%**
	285	A	then then	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	286	B	then this goes out [DRAW]	^	2	**2**	**0**	**1**	**50%**	^	Dd	**Dd**	**0**	**1**	**50%**
	287	A	This is going to be the hard part to draw	^	^	**^**	**1**	**1**	**100%**	^	La	**La**	**0**	**1**	**50%**
	288	B	this is like 8 inches [DRAW]	O	2	**2**	**0**	**1**	**50%**	Cl	Dd	**Dd**	**0**	**1**	**50%**
	289	A	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	290	B	so when it's like.. We'll draw it collapsed or something [DRAW]	O	O	**O**	**1**	**1**	**100%**	^	Ds	**Ds**	**0**	**1**	**50%**
	291	A	Yeah collapsed it would just have a little coming out and then	^	^	**^**	**1**	**1**	**100%**	^	Cl	**Cl**	**0**	**1**	**50%**
	292	B	we have this… and [DRAW]	^	^	**^**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	293	A	so it would still work if it was that short, right?	O	O	**O**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	294	B	1 feet 8 inches…	O	2	**2**	**0**	**1**	**50%**	^	Dd	**Dd**	**0**	**1**	**50%**
	295		Yeah it could work either way [DRAW]	^	^	**^**	**1**	**1**	**100%**	^	An	**An**	**0**	**1**	**50%**
	296	A	okay well this is going to be the uh hard part to uh actually draw	^	^	**^**	**1**	**1**	**100%**	^	An	**Ds**	**0**	**0**	**0%**
	297	B	yeah, so we could	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	298	A	you're going to need, you want to have it far enough up here but not too far so you can't	O	O	**O**	**1**	**1**	**100%**	Ka	Ka	**Ka**	**1**	**1**	**100%**
	299	B	like extend your hand	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	300	A	because I mean	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	301	B	I mean we can make the notches pretty small	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	302	A	Yeah yeah you'll need to just so you can have like a wide	O	O	**O**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	303	B	So do like… [DRAW] It's going to be so hard… so we have this handle and then the arm and we have the little jagged piece coming from here	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
27:00:00	304	A	yeah coming from there	^	^	**^**	**1**	**1**	**100%**	^	Cl	**Cl**	**0**	**1**	**50%**

	305	B	and uh….	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	306	A	well I mean is this fully, is this like not being pulled in at all	O	O	**O**	**1**	**1**	**100%**	Ev	An	**An**	**0**	**1**	**50%**
	307	B	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	308	A	so you don't need to have it coming out that far	O	O	**O**	**1**	**1**	**100%**	Re	Re	**Re**	**1**	**1**	**100%**
	309	B	TRUE	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	310	A	you can have it just coming out just like a couple centimeters	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	311	B	this part needs to be jagged… [DRAW] yeah that needs to be whatever… yeah and this… and this is going to be so hard to draw	1	2	**2**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	312	A	wait the jagg the jagged edge needs to be going the other way	1	2	**1**	**1**	**0**	**50%**	Re	Re	**Re**	**1**	**1**	**100%**
	313	B	yeah that's what I was saying	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	314	A	okay that's good	^	^	**^**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	315	B	So that's going to there,	2	1	**2**	**1**	**0**	**50%**	Cl	Dd	**Dd**	**0**	**1**	**50%**
	316		there's a little release button [DRAW] for the I don't know the little metal piece that stops it	1	1	**1**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	317	A	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	318	B	so that would I guess that we could show it [DRAW]	^	^	**^**	**1**	**1**	**100%**	^	Ds	**Ds**	**0**	**1**	**50%**
	319	A	hitting that	^	^	**^**	**1**	**1**	**100%**	^	Dd	**Dd**	**0**	**1**	**50%**
	320	B	that's like	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	321	A	okay	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	322	B	yeah okay… okay… so is that it or	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	323	A	I guess so	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	324	B	I guess we have to label all these parts	^	2	**2**	**0**	**1**	**50%**	^	Ds	**Ds**	**0**	**1**	**50%**
	325	A	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
30:00:00	326	B	ummm… well what did we say this was? Like a foot [DRAW]	^	2	**2**	**0**	**1**	**50%**	Cl	Dd	**Cl**	**1**	**0**	**50%**
	327	A	yeah I guess so, I mean I don't know how long this really	1	2	**2**	**0**	**1**	**50%**	Ev	Ev	**Ev**	**1**	**1**	**100%**

			needs to be cause you're going to have to show how far this is up the handle												
	328	B	okay show how far this is?	^	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	329	A	up the handle,	1	1	**2**	**0**	**0**	**0%**	An	An	**An**	**1**	**1**	**100%**
	330		yeah, to show how much room there is down there	2	2	**2**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	331	B	You said six inches, so this would be like four inches down [DRAW]	^	2	**2**	**0**	**1**	**50%**	Ca	Ca	**Ca**	**1**	**1**	**100%**
	332	A	yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	333	B	that should be fine and so you need us to write out like a sequence of operations or… okay, sounds good	^	2	**2**	**0**	**1**	**50%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	334	A	How far away are these edges going to be	^	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	335	B	I don't know… It doesn't need to be that much	^	^	**^**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	336	A	I don't know the idea for jar sizes… IS there going to be like a rubber piece inside of this	1	2	**2**	**0**	**1**	**50%**	Ev	Ev	**Ev**	**1**	**1**	**100%**
	337	B	oh yeah this will be rubber [DRAW]	1	2	**1**	**1**	**0**	**50%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	338	A	and also im guessing this is going to be circular	1	2	**2**	**0**	**1**	**50%**	Cl	Dd	**Dd**	**0**	**1**	**50%**
	339	B	yeah….tube… okay [DRAW]	^	1	**1**	**0**	**1**	**50%**	^	Dd	**Dd**	**0**	**1**	**50%**
	340	A	okay	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	341	B	okay… alright so	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	342	A	well really this is the wrong view cause this is not going to be like that	^	^	**^**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	343	B	well yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	344	A	but that's alright	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	345	B	I mean we had to show it anyway	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	346	A	yeah, how coulud you show it grabbing something?	2	2	**2**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	347	B	okay I mean I can do it right here	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
33:00:00	348	A	We can erase this stuff, we don't need	^	^	**^**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**

			that anymore [ERASE]												
	349	B	I mean I can just do it right here going across umm… [DRAW] so we have a little grabber arm with a jar..	2	2	**2**	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	350		Okay and the handle [DRAW]	1	1	**1**	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	351	A	then I guess you can just show that locked and in position like this locking part… over here you have that on top	2	2	**2**	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	352	B	hmm	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	353	A	you have that on top, that jagged part on top	^	2	**2**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	354	B	okay… the little button… I guess that's it [DRAW]	^	1	**1**	**0**	**1**	**50%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	355	A	looks good	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	356	B	yeah… I think we're done	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
									84%						80%
				Calculations											
				Coding Scheme 1			**Coding Scheme 2**								
				0	34	16.75%	**Ap**	1	0.42%						
				1	67	33.00%	**Cp**	6	2.51%	**3.77%**					
				2	102	50.25%	**Ep**	1	0.42%						
				^	153		**Pp**	1	0.42%						
							Ps	42	17.57%						
							Cl	39	16.32%						
							Re	8	3.35%						
							Dd	39	16.32%	**58.16%**					
							Co	0	0.00%						
							Pd	1	0.42%						
							La	8	3.35%						
							Lb	2	0.84%						
							Ju	5	2.09%						
							An	47	19.67%	**26.36%**					
							Pa	0	0.00%						

							Ca	5	2.09%						
							Ev	6	2.51%						
							Ka	9	3.77%						
							Kd	6	2.51%	**11.72%**					
							Ds	13	5.44%						
							^	117							

Appendix L

Transcript: NON-pre-engineering Dyad

[TIME]	#	Sj	UTTERANCE	CS 1						CS 2					
				SG	MG					SG	MG				
	1	A	There it is. What is that?	1	O	**O**	**0**	**1**	**50%**	Cp	Co	**Cp**	**1**	**0**	**50%**
	2	B	Grabbers.	1	^	**^**	**0**	**1**	**50%**	Cl	Cp	**Cp**	**0**	**1**	**50%**
	3	A	Grabbers. Very nice.	1	^	**^**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**
	4	B	Do we start?	O	^	**^**	**0**	**1**	**50%**	Ap	Ds	**Ds**	**0**	**1**	**50%**
	5	A	How much time do we have?	O	^	**^**	**0**	**1**	**50%**	Cp	La	**La**	**0**	**1**	**50%**
	6	B	Forty five minutes.	^	^	**^**	**1**	**1**	**100%**	Cp	La	**La**	**0**	**1**	**50%**
2:42	7	A	Awesome. (Reading the design challenge verbatim.)	^	^	**^**	**1**	**1**	**100%**	Cp	Co	**Cp**	**1**	**0**	**50%**
	8	B	Simple task	O	O	**O**	**1**	**1**	**100%**	Ap	Ep	**Ep**	**0**	**1**	**50%**
	9		of getting a jar off the top shelf. Ok.	^	^	**^**	**1**	**1**	**100%**	Ap	Ap	**Ap**	**1**	**1**	**100%**
	10	A	Has to be designed to operate manually.	O	O	**O**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	11	B	Do want to underline any of the....	O	^	**^**	**0**	**1**	**50%**	Ap	Ds	**Ds**	**0**	**1**	**50%**
	12	A	It looks average size.	2	O	**2**	**1**	**0**	**50%**	Ep	Cp	**Ep**	**1**	**0**	**50%**
	13	B	Yeah probably. It shouldn't be anything much bigger than that.	O	O	**O**	**1**	**1**	**100%**	Ap	Ep	**Ep**	**0**	**1**	**50%**
	14		So last time it was like trying to do a window, this time you're just trying to get something that will grab.	^	^	**^**	**1**	**1**	**100%**	^	Ep	**Ep**	**0**	**1**	**50%**
	15	A	Ok I have an idea.	O	^	**O**	**1**	**0**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	16	B	Nana has one of those.	O	O	**O**	**1**	**1**	**100%**	Kd	Kd	**Kd**	**1**	**1**	**100%**
	17	A	I was just thinking it should have like, you know how what is it, not pliers, but not a wrench.	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	18		You know that thing that has like the little eight shifts.	1	^	**1**	**1**	**0**	**50%**	Kd	Kd	**Kd**	**1**	**1**	**100%**
	19	B	It's pliers.	1	1	**1**	**1**	**1**	**100%**	Cl	Kd	**Kd**	**0**	**1**	**50%**
	20	A	It looks like this you know	^	^	**^**	**1**	**1**	**100%**	Cl	Dd	**Cl**	**1**	**0**	**50%**
	21		and either they're rounded can go in here or in here.	2	2	**2**	**1**	**1**	**100%**	Kd	Ps	**Kd**	**1**	**0**	**50%**
	22		They can get stuck.	^	2	**2**	**0**	**1**	**50%**	^	An	**An**	**0**	**1**	**50%**
	23	B	Yeah, and those are pliers. I'm pretty sure.	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	24	A	So I feel like the thing should have that.	O	1	**O**	**1**	**0**	**50%**	Ap	Dd	**Dd**	**0**	**1**	**50%**
	25	B	There's two sides,	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	26		maybe like the bigger one and a smaller one.	^	2	**2**	**0**	**1**	**50%**	^	Ps	**Ps**	**0**	**1**	**50%**
	27	A	Maybe it's too much effort for them to like squeeze it you know.	O	O	**O**	**1**	**1**	**100%**	Ka	Ka	**Ka**	**1**	**1**	**100%**

	28	B	Yeah.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	29	A	Cause of like arthritis they shouldn't have to squeeze it so it could adjust.	O	O	**O**	**1**	**1**	**100%**	La	La	**La**	**1**	**1**	**100%**
	30		You know how a wrench.	^	^	**^**	**1**	**1**	**100%**	Kd	Kd	**Kd**	**1**	**1**	**100%**
	31	B	Cause you have to squeeze a wrench together.	O	O	**O**	**1**	**1**	**100%**	Kd	An	**Kd**	**1**	**0**	**50%**
	32	A	You could put it on that setting that you don't have to	O	1	**1**	**0**	**1**	**50%**	Ps	Ka	**Ka**	**0**	**1**	**50%**
	33	B	What do you mean?	^	^	**^**	**1**	**1**	**100%**	^	Cl	**Cl**	**0**	**1**	**50%**
	34	A	Where it just grabs them.	O	1	**O**	**1**	**0**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	35	B	You know how on that thing	1	1	**1**	**1**	**1**	**100%**	An	Cl	**Cl**	**0**	**1**	**50%**
	36		where theres two holes	^	2	**2**	**0**	**1**	**50%**	^	Cl	**Cl**	**0**	**1**	**50%**
	37		and sometimes you can move it to the outside hole	2	2	**2**	**1**	**1**	**100%**	^	An	**An**	**0**	**1**	**50%**
	38		so you can't bend it	2	O	**2**	**1**	**0**	**50%**	Ev	An	**Ev**	**1**	**0**	**50%**
	39		like you can't squeeze it in.	O	O	**O**	**1**	**1**	**100%**	Ka	^	**Ka**	**1**	**0**	**50%**
	40	A	Right right.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	41	B	And it just stays open.	O	2	**2**	**0**	**1**	**50%**	An	Cl	**An**	**1**	**0**	**50%**
4:57	42	A	Right.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	43	B	I was saying we could have that so you just put it in.	O	O	**O**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	44	A	Ok. So draw that part, what the head of it would look like.	1	1	**1**	**1**	**1**	**100%**	Cl	Ds	**Ds**	**0**	**1**	**50%**
	45	B	I think that because of the it will do it because it said sturdy enough to grip and hold glass jars.	2	2	**2**	**1**	**1**	**100%**	An	Cl	**Cl**	**0**	**1**	**50%**
	46	A	Put away for storage.	2	O	**O**	**0**	**1**	**50%**	An	Ju	**Ju**	**0**	**1**	**50%**
	47		So maybe it should have rubber on it.	^	2	**2**	**0**	**1**	**50%**	^	Cp	**Cp**	**0**	**1**	**50%**
	48		Not felt	2	2	**2**	**1**	**1**	**100%**	Dd	Ps	**Ps**	**0**	**1**	**50%**
	49		cause that would slip unlike rubber.	^	^	**^**	**1**	**1**	**100%**	Ju	Dd	**Dd**	**0**	**1**	**50%**
	50	B	Oh yeah yeah so it'll grip like a rubber grip. Ok so we'll write that.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	51	A	So rubber grip.	2	2	**2**	**1**	**1**	**100%**	Dd	An	**Dd**	**1**	**0**	**50%**
	52	B	I think that because so they don't have to clench it	O	O	**O**	**1**	**1**	**100%**	Ka	Dd	**Dd**	**0**	**1**	**50%**
	53		I think there should be some sort of button	1	1	**1**	**1**	**1**	**100%**	Ps	La	**La**	**0**	**1**	**50%**
	54		you press	O	O	**O**	**1**	**1**	**100%**	^	Ps	**Ps**	**0**	**1**	**50%**
	55		that closes on that.	2	2	**2**	**1**	**1**	**100%**	An	Ps	**Ps**	**0**	**1**	**50%**

	56	A	Can't be automatic.	O	2	**O**	1	**0**	**50%**	Cp	^	**Cp**	1	**0**	**50%**
	57	B	Can't be automatic. Where does it say that.	^	^	^	1	1	**100%**	Cp	Cp	**Cp**	1	1	**100%**
	58	A	It says manual.	O	O	**O**	1	1	**100%**	Cp	^	**Cp**	1	**0**	**50%**
	59	B	Oh operate manually. Dang it. That would be so great.	O	O	**O**	1	1	**100%**	Cp	Cp	**Cp**	1	1	**100%**
	60		We could have the stick twenty four inches.	2	^	**2**	1	**0**	**50%**	Ps	Cp	**Ps**	1	**0**	**50%**
	61	A	Ew ew ew ew ok so it could be like this	2	2	**2**	1	1	**100%**	An	Ps	**Ps**	**0**	1	**50%**
	62		to free it to be able to go adjust to sides	^	^	^	1	1	**100%**	^	Ju	**Ju**	**0**	1	**50%**
	63		like on really old CD players that have the antenna.	^	^	^	1	1	**100%**	Kd	Kd	**Kd**	1	1	**100%**
	64	B	Yeah and it just goes down.	^	2	**2**	**0**	1	**50%**	An	Ps	**Ps**	**0**	1	**50%**
	65	A	It would fold in into little layers.	2	2	**2**	1	1	**100%**	Ps	Ps	**Ps**	1	1	**100%**
	66	B	Yeah like on cars. Actually some cars don't have it.	O	O	**O**	1	1	**100%**	Kd	Kd	**Kd**	1	1	**100%**
	67	A	It's like this kind of.	O	^	**O**	1	**0**	**50%**	Cl	Cl	**Cl**	1	1	**100%**
	68	B	It's like a tube.	1	1	**1**	1	1	**100%**	^	^	**Cl**	**0**	**0**	**0%**
	69	A	It's like this but a little smaller.	^	2	**2**	**0**	1	**50%**	Ev	^	**Ev**	1	**0**	**50%**
	70	B	It looked like one of those light sabers the light sabers like the Star Wars ones.	O	O	**O**	1	1	**100%**	Kd	Kd	**Kd**	1	1	**100%**
	71	A	Yeah yeah!	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	72	B	Yeah.	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	73	A	And then it has a little clinger grip	2	1	**2**	1	**0**	**50%**	Ps	Ps	**Ps**	1	1	**100%**
	74		at the end.	^	2	**2**	**0**	1	**50%**	^	Ps	**Ps**	**0**	1	**50%**
	75	B	The only thing is that like flexible to bend	2	2	**2**	1	1	**100%**	An	An	**An**	1	1	**100%**
	76		like cause if it's a straight one	O	2	**2**	**0**	1	**50%**	Ka	Ka	**Ka**	1	1	**100%**
	77		then its sit her down.	O	O	**O**	1	1	**100%**	^	Ju	**Ju**	**0**	1	**50%**
	78		It would bend like the top one maybe.	2	2	**2**	1	1	**100%**	An	An	**An**	1	1	**100%**
	79		I guess you can't go like this you know what I mean?	^	^	^	1	1	**100%**	Cl	An	**An**	**0**	1	**50%**
	80	A	Oh you're right.	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	81	B	The top should be able to bend	2	2	**2**	1	1	**100%**	An	An	**An**	1	1	**100%**
	82	A	So like bend so it closes closes closes.	2	2	**2**	1	1	**100%**	An	An	**An**	1	1	**100%**
	83	B	Yeah you can do that, it can like pull up and out.	2	2	**2**	1	1	**100%**	An	Ju	**Ju**	**0**	1	**50%**

	84	A	Yeah up and out. And how bout just two, this goes up and out.	2	2	**2**	1	1	**100%**	An	Ps	**Ps**	**0**	1	**50%**
7:25	85	B	Like, do you want to go like that, to be a clinger piece?	2	2	**2**	1	1	**100%**	Cl	Ps	**Ps**	**0**	1	**50%**
	86	A	Yeah it will have two of those.	1	2	**2**	**0**	1	**50%**	Ps	Cl	**Ps**	1	**0**	**50%**
	87	B	Like it kind of this piece goes into this little piece. If that makes sense.	2	2	**2**	1	1	**100%**	Cl	Cl	**Cl**	1	1	**100%**
	88	A	Yeah.	^	^	**^**	1	1	**100%**	^	^	**^**	1	1	**100%**
	89	B	That make sense?	^	^	**^**	1	1	**100%**	^	^	**^**	1	1	**100%**
	90	A	And then draw like two more of those	1	2	**2**	**0**	1	**50%**	Cl	Dd	**Cl**	1	**0**	**50%**
	91		so you can like have it any length you know what I mean.	2	2	**2**	1	1	**100%**	Ev	Ev	**Ev**	1	1	**100%**
	92	B	Yeah it's going to be, has to be twenty four inches no longer than twenty four inches.	O	2	**O**	1	**0**	**50%**	Cp	Cp	**Cp**	1	1	**100%**
	93	A	What's twenty four dived by four.	2	2	**2**	1	1	**100%**	Ca	Ca	**Ca**	1	1	**100%**
	94	B	It's six.	^	^	**^**	1	1	**100%**	Ca	Ca	**Ca**	1	1	**100%**
	95	A	We could have six of them four inches long,	2	2	**2**	1	1	**100%**	Ps	Ps	**Ps**	1	1	**100%**
	96		that's stupid.	^	^	**^**	1	1	**100%**	Re	Ev	**Ev**	**0**	1	**50%**
	97	B	Or we could do like this one would have to be longer	2	2	**2**	1	1	**100%**	Ps	Ps	**Ps**	1	1	**100%**
	98	A	No ithas to be twenty four when it's closed.	O	O	**O**	1	1	**100%**	Re	Cp	**Cp**	**0**	1	**50%**
	99	B	The device can be no longer than twenty when not being used. Ok so it can be any length.	O	O	**O**	1	1	**100%**	Cp	Cp	**Cp**	1	1	**100%**
	100	A	Has to be able to grab two feet from an arms length, so twenty four inches.	2	2	**2**	1	1	**100%**	Ca	Ca	**Ca**	1	1	**100%**
	101	B	Right, that makes sense. Oh boy this is like really not engineering classes.	^	^	**^**	1	1	**100%**	^	An	**An**	**0**	1	**50%**
	102	A	It's beyond that though. So it can be any length basically.	O	O	**O**	1	1	**100%**	Ep	Ep	**Ep**	1	1	**100%**
	103	B	Ok well we should come up with a length for it. It's a cool looking tool.	O	O	**O**	1	1	**100%**	Ep	Ep	**Ep**	1	1	**100%**
	104	A	I'm thinking like that long.	O	2	**O**	1	**0**	**50%**	Ps	Ps	**Ps**	1	1	**100%**
	105	B	It looks so funny. It's like a little crab leg. We can call it crab grabber.	O	O	**O**	1	1	**100%**	Kd	Kd	**Kd**	1	1	**100%**
	106	A	How about this middle piece	2	1	**1**	**0**	1	**50%**	Ps	Ps	**Ps**	1	1	**100%**
	107		is flexible.	2	2	**2**	1	1	**100%**	^	Ps	**Ps**	**0**	1	**50%**

	108		But like stiff. But it's not like a, but like really strong so they just have to…	^	2	**2**	**0**	**1**	**50%**	^	Ps	**Ps**	**0**	**1**	**50%**
	109	B	Yeah	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	110	A	So that's the flexible piece.	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	111		So you can bend it this way or this way.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	112		This is how these things should be shaped like this.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	113	B	Yeah can you draw that part.	^	1	**1**	**0**	**1**	**50%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	114	A	Like that.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	115	B	Ok should it be like, yeah rubber lining the inside.	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	116		Like a rubber but the rubber has the little like marks on it you know what I mean	2	2	**2**	**1**	**1**	**100%**	An	Cl	**Cl**	**0**	**1**	**50%**
	117		like they're rigid kind of a gripper.	2	2	**2**	**1**	**1**	**100%**	Ev	Cl	**Cl**	**0**	**1**	**50%**
	118	A	Yeah. Maybe take out this piece	2	1	**1**	**0**	**1**	**50%**	Re	Re	**Re**	**1**	**1**	**100%**
	119		and change the angle that they can use.	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	120	B	Yeah.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
10:12	121	A	But the rubber helps it	1	1	**1**	**1**	**1**	**100%**	An	Ju	**Ju**	**0**	**1**	**50%**
	122		so they don't have to squeeze so hard	O	O	**O**	**1**	**1**	**100%**	La	Ka	**Ka**	**0**	**1**	**50%**
	123		cause it gets a good grip on it with the rubber.	2	2	**2**	**1**	**1**	**100%**	An	Ju	**Ju**	**0**	**1**	**50%**
	124		The safety mechanism	1	1	**1**	**1**	**1**	**100%**	Ap	Ap	**Ap**	**1**	**1**	**100%**
	125		to make sure the jars won't be dropped is the rubber.	^	2	**2**	**0**	**1**	**50%**	^	Ju	**Ju**	**0**	**1**	**50%**
	126	B	Yes.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	127	A	And the glass jar is being retrieved and must not be damaged any way.	O	O	**O**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	128		They won't because I mean. It can't leave marks on the cupboard, so maybe	^	^	^	**1**	**1**	**100%**	Ju	Ju	**Ju**	**1**	**1**	**100%**
	129	B	Leave marks on the cupboard what do you mean?	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	130	A	I guess like maybe the whole thing should be rubber.	1	2	**2**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	131	B	What do you mean?	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	132	A	The whole hand.	1	O	**O**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	133	B	The whole head of it?	^	^	^	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	134	A	Yes.	^	^	^	**1**	**1**	**100%**	^	Dd	^	**1**	**0**	**50%**

	135	B	Like those.	^	^	^	1	1	100%	Cl	Cl	**Cl**	1	1	100%
	136	A	Like if you accidentally hit the cupboard it won't	O	O	**O**	1	1	100%	An	An	**An**	1	1	100%
	137	B	I don't think it would make a mark though.	^	^	^	1	1	100%	^	An	^	1	0	50%
	138	A	What other materials should it be? This is obviously metal. That should be plastic I guess.	2	2	**2**	1	1	100%	Ps	Dd	**Ps**	1	0	50%
	139	B	Yeah, with like a rubber finger grips.	2	1	**2**	1	0	50%	Ps	Dd	**Ps**	1	0	50%
	140	A	And then there's rubber on the inside of that.	2	2	**2**	1	1	100%	Ps	Dd	**Ps**	1	0	50%
	141	B	They have thin grips.	2	2	**2**	1	1	100%	Cl	Cl	**Cl**	1	1	100%
	142		Ok so this part	1	1	**1**	1	1	100%	An	An	**An**	1	1	100%
	143		won't collapse right?	2	2	**2**	1	1	100%	^	^	^	1	1	100%
	144		So it folded up would be	2	O	**2**	1	0	50%	Cl	Cl	**Cl**	1	1	100%
	145	A	Actually this part	2	1	**1**	0	1	50%	Lb	Lb	**Lb**	1	1	100%
	146		having this flexible could be a bad idea.	2	2	**2**	1	1	100%	^	Ev	**Ev**	0	1	50%
	147	B	Why?	^	^	^	1	1	100%	^	^	^	1	1	100%
	148	A	Because if the jar is heavy and not flexible this could make it drop.	O	O	**O**	1	1	100%	Ju	Ju	**Ju**	1	1	100%
	149	B	Yeah if it's flexible.	1	2	**2**	0	1	50%	An	An	**An**	1	1	100%
	150	A	It'd be like if it were really strong flexible.	1	2	**2**	0	1	50%	Ps	Ps	**Ps**	1	1	100%
	151	B	Cause they're gonna have to bend it back and put it in.	O	O	**O**	1	1	100%	An	An	**An**	1	1	100%
	152		I think once it's pulled out, it can't move,	2	2	**2**	1	1	100%	An	An	**An**	1	1	100%
	153		so you just like take it, bring down and get the jar.	O	O	**O**	1	1	100%	Ka	Ka	**Ka**	1	1	100%
	154	A	I wonder if you could put a lock	1	1	**1**	1	1	100%	Ps	Ps	**Ps**	1	1	100%
	155		you know how certain things have the little button that comes out.	1	1	**1**	1	1	100%	^	Kd	**Kd**	0	1	50%
	156	B	Let's get rid of this little piece.	1	1	**1**	1	1	100%	Re	Re	**Re**	1	1	100%
	157	A	Why?	^	^	^	1	1	100%	^	^	^	1	1	100%
	158	B	Becuase like if you're	^	^	^	1	1	100%	Ju	Ju	**Ju**	1	1	100%
	159	A	Hold on, don't get rid of it yet.	1	1	**1**	1	1	100%	Pp	Pp	**Pp**	1	1	100%
	160		You know how like on our desks and stuff, like on tents you have to put up how it has the square and you have the holes,	2	2	**2**	1	1	100%	Kd	Kd	**Kd**	1	1	100%
	161		and you have to lift the rod up	O	^	**O**	1	0	50%	Ka	Ka	**Ka**	1	1	100%
	162		and theres a little button that sticks out and	1	1	**1**	1	1	100%	Kd	Kd	**Kd**	1	1	100%

	163		you have to push the button in and lift it until the button hits a hole until it locks it.	O	O	O	1	1	100%	^	Kd	Kd	0	1	50%
	164	B	Oh yeah.	^	^	^	1	1	100%	^	^	^	1	1	100%
12:59	165	A	You could just have one of those like to lock it so that,	1	1	1	1	1	100%	Ps	Ps	Ps	1	1	100%
	166		that wouldn't make sense. Why did that come into my head.	^	^	^	1	1	100%	Re	Ev	Re	1	0	50%
	167	B	What this is what I'm thinking of for the whole piece.	O	1	O	1	0	50%	Ev	Ev	Ev	1	1	100%
	168		Even if it's really strong.	^	2	2	0	1	50%	^	Ev	Ev	0	1	50%
	169	A	Well this would also be really strong.	O	^	2	0	0	0%	Ev	Ev	Ev	1	1	100%
	170	B	I'm just thinking if it's that big if you pull it up and then bend it and then you take a jar and grab with the jar,	O	2	O	1	0	50%	Ka	Ka	Ka	1	1	100%
	171		it's going to bend	^	2	2	0	1	50%	La	La	La	1	1	100%
	172	A	Bend down.	^	^	^	1	1	100%	^	^	^	1	1	100%
	173	B	You know what I mean?	^	^	^	1	1	100%	Cl	Cl	Cl	1	1	100%
	174	A	It's not going to be sturdy.	O	O	O	1	1	100%	An	An	An	1	1	100%
	175		When you grab something with it it's not going to stay like this kinda.	^	^	^	1	1	100%	^	Ka	Ka	0	1	50%
	176	B	No I got you, like it could drop.	O	O	O	1	1	100%	An	An	An	1	1	100%
	177	A	We have websites.	O	O	O	1	1	100%	Co	Co	Co	1	1	100%
	178	B	Ohhhhhhhh. Those are the grippers.	2	1	1	0	1	50%	Cl	Cl	Cl	1	1	100%
	179		So the little rubber piece.	2	2	2	1	1	100%	^	An	An	0	1	50%
	180	A	Yeah. I like this idea how it can go like that.	O	O	O	1	1	100%	Co	Co	Co	1	1	100%
	181	B	Yeah, go up. Let's see.	^	^	^	1	1	100%	^	^	^	1	1	100%
	182	A	See those look really week. The one at the bottom looked really strong.	O	O	O	1	1	100%	Ap	Ev	Ev	0	1	50%
	183		They need to have this going all the way around.	^	2	2	0	1	50%	^	Ps	Ps	0	1	50%
	184		Especially to the grabber.	1	1	1	1	1	100%	^	^	^	1	1	100%
	185	B	The way we have it and the rubber is really good. Well it's probably good to reference it, but all the way around.	2	1	2	1	0	50%	Dd	Ev	Ev	0	1	50%
14:58	186	A	Um. What's up? Are you thinking about the flexible piece still?	1	1	1	1	1	100%	An	Lb	Lb	0	1	50%

	187	B	I don't think we should have that. I'm just thinking what we should have instead.	1	1	**1**	**1**	**1**	**100%**	Re	Re	**Re**	**1**	**1**	**100%**
	188	A	I know that's what I'm trying to figure out too.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	189	B	Cause I was thinking about a really heavy jar like jelly or something, but they would put the jelly on a lower cabinet.	O	O	**O**	**1**	**1**	**100%**	La	Ka	**La**	**1**	**0**	**50%**
	190	A	Ok.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	191	B	What if you did this part.	1	1	**1**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	192		That part folds up	O	2	**2**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**
	193		but if you really needed it for lighter objects you could pull it out for heavier object	O	O	**O**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	194		you just have this that can go like it would be, it's hard to draw that dang it.	1	1	**1**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	195		Like this would be the back of it and it would go like this way.	O	O	**O**	**1**	**1**	**100%**	An	Ps	**Ps**	**0**	**1**	**50%**
	196		So if you had something really heavy it would just barely pop up	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	197		and this piece could go like this.	^	1	**2**	**0**	**0**	**0%**	^	An	**Ps**	**0**	**0**	**0%**
	198	A	I have an idea. This doesn't bend.	1	2	**2**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	199		It just goes straight up,	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	200		and then this end bends.	^	2	**2**	**0**	**1**	**50%**	^	Ps	**Ps**	**0**	**1**	**50%**
	201		That's what I'm saying. So it'll be smaller and that just bends it.	2	2	**2**	**1**	**1**	**100%**	Ev	Ev	**Ev**	**1**	**1**	**100%**
	202	B	Yeah, so you can move it	1	O	**1**	**1**	**0**	**50%**	An	An	**An**	**1**	**1**	**100%**
	203		this way you can make that long,	^	2	**2**	**0**	**1**	**50%**	^	Ps	**Ps**	**0**	**1**	**50%**
	204		and then you have the whole strong piece so you can make this one long,	O	2	**2**	**0**	**1**	**50%**	Ev	Ev	**Ev**	**1**	**1**	**100%**
	205		like you can make it to where if it's far away from you	O	O	**O**	**1**	**1**	**100%**	Ev	Ev	**Ev**	**1**	**1**	**100%**
	206		the piece	1	2	**1**	**1**	**0**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	207		that's flexible	^	2	**2**	**0**	**1**	**50%**	^	Ps	**Cl**	**0**	**0**	**0%**
	208		like you can make the whole head	2	1	**1**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	209		come out like that and then go like that.	2	2	**2**	**1**	**1**	**100%**	^	Ps	**Ps**	**0**	**1**	**50%**
	210	A	I'm just saying we have this thing that extends.	1	1	**1**	**1**	**1**	**100%**	Cl	Dd	**Dd**	**0**	**1**	**50%**

	211	B	Right, so this is the thing that extends and gets smaller right here.	2	1	**2**	1	**0**	**50%**	Cl	Cl	**Cl**	1	1	**100%**
	212		And then the head can go up this way or that way.	2	2	**2**	1	1	**100%**	An	An	**An**	1	1	**100%**
	213	A	So we should draw this on the board. DRAW We can draw an arrow and it can go either way.	O	O	**O**	1	1	**100%**	Ds	Ds	**Ds**	1	1	**100%**
	214	B	It can go flat or it can go like this. So it can go flat all the way around. It wouldn't look like this.	2	2	**2**	1	1	**100%**	An	An	**An**	1	1	**100%**
	215	A	And this can go up or down which is how that adjusts.	2	2	**2**	1	1	**100%**	Cl	Ju	**Ju**	**0**	1	**50%**
17:31	216	B	We might have to draw this.	O	O	**O**	1	1	**100%**	Ds	Ds	**Ds**	1	1	**100%**
	217	A	Ok your idea with the tent thing, that can be this part.	1	1	**1**	1	1	**100%**	Cl	Dd	**Dd**	**0**	1	**50%**
	218	B	Yeah.	^	^	**^**	1	1	**100%**	^	^	**^**	1	1	**100%**
	219	A	With the holes.	1	2	**2**	**0**	1	**50%**	^	^	**^**	1	1	**100%**
	220	B	It locks. So then it stays. We can do that,	2	2	**2**	1	1	**100%**	An	Dd	**Dd**	**0**	1	**50%**
	221		but this part will have to like get the jar like this technically. Cause it's going to be flat. See how it works.	^	^	**^**	1	1	**100%**	An	An	**An**	1	1	**100%**
	222	A	Yeah.	^	^	**^**	1	1	**100%**	^	^	**^**	1	1	**100%**
	223	B	So like it actually go this way or flop, or it can go around technically.	1	2	**2**	**0**	1	**50%**	An	An	**An**	1	1	**100%**
	224	A	I got you.	^	^	**^**	1	1	**100%**	^	^	**^**	1	1	**100%**
	225	B	Yeah and then, so the lock buttons.	1	1	**1**	1	1	**100%**	Cl	Cl	**Cl**	1	1	**100%**
	226		The squeezer what is that going to be?	1	1	**1**	1	1	**100%**	Cl	Cl	**Cl**	1	1	**100%**
	227	A	It's right here. Just the handle.	1	2	**2**	**0**	1	**50%**	Cl	Dd	**Dd**	**0**	1	**50%**
	228	B	So it's going to be like this?	^	^	**^**	1	1	**100%**	Cl	Dd	**Cl**	1	**0**	**50%**
	229	A	Like that, it goes into the bottom. Yeah like that.	2	2	**2**	1	1	**100%**	An	Cl	**Dd**	**0**	**0**	**0%**
	230	B	Ok.	^	^	**^**	1	1	**100%**	^	^	**^**	1	1	**100%**
	231	A	Make sure you draw the little hole. Like this.	1	2	**2**	**0**	1	**50%**	Cl	Ds	**Ds**	**0**	1	**50%**
	232	B	So would it be like a hole here?	^	2	**2**	**0**	1	**50%**	An	An	**An**	1	1	**100%**
	233	A	I think we'll just have three pieces	2	2	**2**	1	1	**100%**	An	Dd	**Dd**	**0**	1	**50%**
	234		and so there's like one two three four holes here. And like the actually things that go in. So then there can be all the way down.	^	2	**2**	**0**	1	**50%**	^	Dd	**Dd**	**0**	1	**50%**

	235	B	Well you wouldn't want the holes.	1	2	**2**	**0**	**1**	**50%**	Re	Re	**Re**	**1**	**1**	**100%**
	236	A	We really want one hole.	1	2	**2**	**0**	**1**	**50%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	237	B	Well and you wouldn't want these showing cause you want them locking it. If it's up. So like you would do.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	238	A	I wouldn't even want a hole.	1	2	**2**	**0**	**1**	**50%**	Re	Re	**Re**	**1**	**1**	**100%**
	239	B	Like thats the hole that's filled in.	1	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	240	A	That's perfect.	^	^	^	**1**	**1**	**100%**	^	Ev	**Ev**	**0**	**1**	**50%**
	241	B	And really I think you'd only need one in the middle section. Right?	2	2	**2**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	242	A	Yeah that's what I'm saying. You only need holes here.	2	2	**2**	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	243	B	Right.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	244	A	And you have the one hole on this one so you can move it.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	245	B	Oh the problem, the actual bubble its called the bubble. The bubble and the hole.	1	1	**1**	**1**	**1**	**100%**	Cl	La	**Cl**	**1**	**0**	**50%**
	246	A	We have to measure how long it is, if it's all the way out ok lets say if it's all the way down here it has to be twenty four inches, so each.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	247	B	Like all of the holes?	1	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	248	A	Two inches yeah. So two inches two inches two inches so that in total they'll be twenty nope thirty inches long.	2	2	**2**	**1**	**1**	**100%**	Ca	Ca	**Ca**	**1**	**1**	**100%**
	249		That's over two feet which is good right? But then when you close it it's twenty four	^	O	**2**	**0**	**0**	**0%**	An	An	**An**	**1**	**1**	**100%**
19:57	250	B	Are you calculating that added?	2	2	**2**	**1**	**1**	**100%**	Ca	Ca	**Ca**	**1**	**1**	**100%**
	251	A	No.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	252	B	So yeah the measurements we're probably going to have to start from the bottom and just pick a measurement for like this is going to be twenty four inches.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	253	A	The whole thing with that has to be twenty four.	2	2	**2**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	254	B	So this will probably be what, that big?	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**

	255	A	This could stick up or stay bent doesn't it?	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	256	B	It could be five inches. Right so this	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	257	A	Here to here has to be twenty four.	2	2	**2**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	258	B	Wait, I thought it was bent up has to be twenty four.	2	2	**2**	**1**	**1**	**100%**	Ap	Ap	**Ap**	**1**	**1**	**100%**
	259	A	Is that going to be bent up?	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	260	B	No I mean like folded up.	O	O	**O**	**1**	**1**	**100%**	Ap	Ap	**Ap**	**1**	**1**	**100%**
	261	A	Yeah that's what I'm saying so folded up.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	262	B	Folded up so like it's sitting on the ground like this.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	263	A	Yeah.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	264	B	Like that? This is what it would looke like sitting down. DRAW All the way compressed.	O	O	**O**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	265	A	This part is going to be here. The second part is going to be here.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	266	B	Wait but you want to fold it all up and it's like cane.	O	O	**O**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	267	A	But what's gonna be holdig this up	1	2	**1**	**1**	**0**	**50%**	An	An	**An**	**1**	**1**	**100%**
	268		if we're using the buttons to do this part what's holding this from this part?	1	1	**1**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	269	B	This is holding	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	270		something has to hold this part because if that's holding that part, you just need something to hold that part.	^	1	**1**	**0**	**1**	**50%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	271	A	I was just going to say we don't, this is just the base	2	1	**1**	**0**	**1**	**50%**	An	An	**An**	**1**	**1**	**100%**
	272		and this is the only thing that moves so that this can go all the way down into this part.	^	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	273	B	Ok.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	274	A	So that should be twenty four plus that.	2	2	**2**	**1**	**1**	**100%**	Ca	Ca	**Ca**	**1**	**1**	**100%**
	275	B	Ok. Plus the little bit of everything ok. So this is	O	O	**O**	**1**	**1**	**100%**	Ca	^	**Ca**	**1**	**0**	**50%**
	276	A	This is just the hand.	1	O	**O**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	277	B	So this has to be, so this would be taller. Right cause	1	1	**1**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	278	A	When it's completely closed it'll look like this.	O	O	**O**	**1**	**1**	**100%**	Ev	Ev	**Ev**	**1**	**1**	**100%**

	279	B	But the four dots move on. Like that.	1	1	**1**	1	1	**100%**	An	An	**An**	1	1	**100%**
	280	A	So the only part that moves really is this part.	2	1	**2**	1	**0**	**50%**	An	An	**An**	1	1	**100%**
	281	B	Yeah.	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	282	A	Ok so then yeah that's twenty four, so then each hole is two.	2	2	**2**	1	1	**100%**	Ca	Ca	**Ca**	1	1	**100%**
	283	B	My eyes hurt so hard.	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	284	A	So what will the total be	2	2	**2**	1	1	**100%**	Cl	Cl	**Cl**	1	1	**100%**
22:45	285	B	Because how long	1	2	**2**	**0**	1	**50%**	Cl	An	**Cl**	1	**0**	**50%**
	286		will this piece be though?	2	1	**1**	**0**	1	**50%**	^	^	^	1	1	**100%**
	287		Would it be the whole thing	O	O	**O**	1	1	**100%**	^	^	^	1	1	**100%**
	288		or this little tiny piece	1	1	**1**	1	1	**100%**	^	^	^	1	1	**100%**
	289		because how are you going to pull it out of this if it's a little tiny piece or would it stack?	2	2	**2**	1	1	**100%**	An	An	**An**	1	1	**100%**
	290		Like when it's dropped down how big is just this piece?	2	2	**2**	1	1	**100%**	An	An	**An**	1	1	**100%**
	291		If we had to separate this into this piece, this piece and this piece, how big is each piece?	2	2	**2**	1	1	**100%**	An	An	**An**	1	1	**100%**
	292	A	So it's twenty four inches, one, six, and seventeen.	2	2	**2**	1	1	**100%**	Ca	Ca	**Ca**	1	1	**100%**
	293	B	Yeah.	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	294	A	Ok.	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	295	B	And then all together when it's fully extended	2	O	**O**	**0**	1	**50%**	An	An	**An**	1	1	**100%**
	296		it can go to twenty four, I mean thirty inches.	2	2	**2**	1	1	**100%**	^	^	^	1	1	**100%**
	297	A	Oh. Full extension ok.	O	O	**O**	1	1	**100%**	^	^	^	1	1	**100%**
	298	B	Um hmm.	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	299	A	Blah. I want to like just draw the measurements out.	O	O	**O**	1	1	**100%**	Ds	Ds	**Ds**	1	1	**100%**
	300	B	We'll draw that.	^	^	^	1	1	**100%**	^	^	^	1	1	**100%**
	301	A	Is this the folded up one? I'll do that because I want it to be big cause of the dots and everything. Um.. So this part	O	O	**O**	1	1	**100%**	Ds	Ds	**Ds**	1	1	**100%**
	302	B	This is the big part. Just the handle?	1	1	**1**	1	1	**100%**	Cl	Cl	**Cl**	1	1	**100%**
	303		Is this just plastic?	^	2	**2**	**0**	1	**50%**	^	Cl	**Dd**	**0**	**0**	**0%**
	304	A	It could be like the rubber grips.	2	2	**2**	1	1	**100%**	Cl	Ps	**Dd**	**0**	**0**	**0%**

	305	B	Plastic with the rubber grips, the whole thing plastic.	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	306	A	The whole thing	2	O	**O**	**0**	**1**	**50%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	307		is probably going to be metal.	2	2	**2**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	308		Not like heavy metal but like light weight metal like that.	^	2	**2**	**0**	**1**	**50%**	^	Cl	**Cl**	**0**	**1**	**50%**
	309	B	Yeah. What is that stuff?	^	^	**^**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	310	A	Look in the other resources we're allowed to and see if it like says anything on there exactly what it's called.	^	^	**^**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	311	B	This shows old people problems.	O	O	**O**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	312	A	Wow! They have a lot. This is a disability.	O	O	**O**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	313	B	It's ok we'll just I mean like	^	^	**^**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	314	A	Like a light weight metal.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	315	B	We'll just say like metal.	2	2	**2**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
28:02	316	A	So this is seventeen inches.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	317		Then you have the six inches right here. With four holes.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	318		And then the one inch sticking up right here but that is like. Ok.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	319		Let's figure it out and make sure everything is added up right. And this you want it. And then oh.	O	O	**O**	**1**	**1**	**100%**	Ca	Ca	**Ca**	**1**	**1**	**100%**
	320	B	Oh, no we didn't.	^	^	**^**	**1**	**1**	**100%**	Lb	Lb	**Lb**	**1**	**1**	**100%**
	321	A	What?	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	322	B	Wait is this hole thing an inch?	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	323	A	I don't know see I was going to see this right where it meets it, that will be an inch.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	324		This part is sinking.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	325	B	That whole thing's an inch.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	326	A	Yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	327	B	Ok just wanted to make sure.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	328	A	So then um, lets two inches right there in between each hole there. .	2	2	**2**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	329		So when it's closed the dot's there.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	330		What pole is the button on? Which part?	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**

	331		Which part has the button and which part has the holes? Cause it cant be the same part	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	332	B	I know its the third part has the whole you put the button.	2	2	**2**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	333	A	Oh ok. So this part separately from the top part	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	334		is how many inches long when it's out.	^	2	**2**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**
	335		And it has the button on it.	^	1	**1**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**
	336	B	It can extend to nine inches. If it's on the last hole it's at nine inches.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	337	A	And then I'll draw it with the extended version over here	2	2	**2**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	338		but ok so then another two inches	^	2	**2**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	339		this whole thing	O	O	**O**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	340		is twenty four right?	2	2	**2**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	341	B	Yeah.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	342	A	Should I draw anything on the other side?	^	^	**^**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	343	B	You draw the full version	O	O	**O**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
31:28	344	A	DRAW And then. Wait if this middle part is six inches and each of these holes are two inches apart and there's four that has to be atleast eight inches. These are each two inches apart.	2	2	**2**	**1**	**1**	**100%**	Ca	Ca	**Ca**	**1**	**1**	**100%**
	345	B	Yeah, two four six, seven eight.	2	2	**2**	**1**	**1**	**100%**	Ca	Ca	**Ca**	**1**	**1**	**100%**
	346	A	Like is it the hole right against the top?	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	347	B	I mean it's probably atleast going to be eight.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	348	A	What's twenty four minus eight? Two four six eight you're right.	2	2	**2**	**1**	**1**	**100%**	Ca	Ca	**Ca**	**1**	**1**	**100%**
	349	B	So I mean that's fine we can just do the bottom part shorter.	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	350	A	Ok two inches shorter so that'll be fifteen.	2	2	**2**	**1**	**1**	**100%**	Ca	Ca	**Ca**	**1**	**1**	**100%**
	351	B	Yeah and that's fine cause that part's going to have to be eight and then that part is nine. DRAW	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	352		How am I going to draw the handle?	1	1	**1**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	353		I know but how does it look on the thing like a	O	O	**O**	**1**	**1**	**100%**	Ka	Ka	**Ka**	**1**	**1**	**100%**

			place for your fingers goes up inside.												
	354	A	Let me draw the handle part with the rubber.	2	2	**2**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	355	B	Yeah this is what it would look like you'd have to have the hand like pressing outwards so that's the finger grip. Pressing outward.	O	O	**O**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	356	A	You'd have like three little things that come forward. How many inches across are we talking?	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	357	B	Like one and seven eights.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	358	A	But if your hand pulls. DRAW	O	O	**O**	**1**	**1**	**100%**	Ka	Ka	**Ka**	**1**	**1**	**100%**
	359		Yeah probably be three inches across	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	360		and the second piece	^	1	**1**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**
	361		would be two inches across.	^	2	**2**	**0**	**1**	**50%**	^	^	**^**	**1**	**1**	**100%**
	362		And the first piece	2	1	**1**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	363		would just be one inch. DRAW	2	2	**2**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	364	B	What's this thing called?	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	365		They thing you put your hand on and squeeze.	O	O	**O**	**1**	**1**	**100%**	Ka	Ka	**Ka**	**1**	**1**	**100%**
	366	A	A clamper thing.	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	367	B	The actual thing is the clamper.	1	1	**1**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	368	A	What?	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	369	B	Called the grip?	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	370	A	Yeah	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	371	B	Ok so this is the clamp	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	372	A	Clamp and then rubber grip. DRAW Gripper maybe. What is that.	2	2	**2**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	373	B	That's the eye.	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	374	A	Yes. Oh crap yeah I need to draw this way up. Now you have to put in	1	1	**1**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	375	B	It needs the holes on.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	376	A	You have to put in.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
37:40	377	B	So adjusting the holes.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	378	A	Yeah. We also have to discuss the width of all of it.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	379		So like this piece	2	1	**1**	**0**	**1**	**50%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	380		is three.	2	2	**2**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**

	381		This piece	^	1	**1**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	382		is two,	^	2	**2**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	383		that piece is one	^	2	**1**	**0**	**0**	**0%**	^	^	^	**1**	**1**	**100%**
	384		cause they have to fit inside of each other but yeah.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	385	B	And then how long is that piece.	2	2	**2**	**1**	**1**	**100%**	Ev	Ev	**Ev**	**1**	**1**	**100%**
	386		How long is this compared to the handle?	^	2	**2**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	387	A	Five?	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	388	B	I mean how long do you want the actual clamp to be cause it's going to have to fit around the bigger thing.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	389	A	How big is the cane?	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	390	B	Like that? Like four inches? Six?	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	391	A	I would make it like five or yeah six.	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	392	B	I make the clamp	2	1	**1**	**0**	**1**	**50%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	393		itself just five.	^	2	**2**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	394		And then the handle	^	1	**1**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	395		three, maybe two. That's nine inches.	^	2	**2**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	396	A	Maybe two inches.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	397	B	Cause this has to be two and that has to be..	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	398		How long	^	2	**2**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	399		is that little piece?	^	1	**1**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	400	A	Make it three and two.	2	2	**2**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	401	B	What?	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	402	A	I don't know. What are you talking about?	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	403	B	Like this piece by itself if you take it off I'd put like five	2	2	**2**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	404		and then do the like little rod I think should be three.	^	2	**2**	**0**	**1**	**50%**	^	^	^	**1**	**1**	**100%**
	405	A	Ok.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	406	B	Does that sound like eight inches.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	407	A	Yeah.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	408	B	Would like a three inch thing	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	409	A	If you take three inches off yeah. Maybe this should be like four.	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	410	B	Ok.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**

	411	A	Four three two maybe. DRAW	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	412		Let me make a note, not drawn to scale.	^	^	**^**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	413	B	I always like writing that cause I hate seeing that on tests. Crap to convert everything.	^	^	**^**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	414	A	It's not crap.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	415	B	Do we have the big thing up there.	1	1	**1**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	416	A	So when it's up there yeah. And oh talk about do the arrows. Like that it can go around.	O	O	**O**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	417	B	True. DRAW	^	^	**^**	**1**	**1**	**100%**	Ds	Ds	**Ds**	**1**	**1**	**100%**
	418	A	Yeah. Like flat it can lay and go around and swivel three hundred and sixty degrees.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	419	B	No.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	420	A	Yeah cause it can go all the way around. It can go towards you away from you.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	421	B	Ok ok. But what's making it do that?	O	O	**O**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	422	A	It's just a circle, its a rod, so it can.	1	1	**1**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	423	B	Yeah. It's probably more like that. Cause if it's like that is has like a little. It looks good.	1	1	**1**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	424	A	A little mechanism thing. We should give it a name. Maybe sell it in different colors. Cramper clamper. It's just cause my hands are cramping up so bad.	O	O	**O**	**1**	**1**	**100%**	Cl	Ds	**Ds**	**0**	**1**	**50%**
41:32	425	B	It's actually supposed to be the reach and grab.	O	O	**O**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	426	A	Maybe we sell it in red you can color it. That's like Christmas colors! So we're not gonna show it. Let's see if we have everything. It's operating manually right?	O	O	**O**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	427	B	Yeah.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	428	A	Operating manually. Check. Device is light weight, long enough to reach an item two feet beyond arms length.	O	O	**O**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	429	B	Yep.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**

	430	A	Two feet beyond arms? Oh yeah cause you're holding it in your hand. You're not holding it in your armpit.	O	O	**O**	**1**	**1**	**100%**	Ka	Ka	**Ka**	**1**	**1**	**100%**
	431	B	I'm like that would be a problem.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	432	A	Clamping mechanism sturdy enough to grab and hold an average size size glass good jar. So yeah. that's a pretty sturdy little clamp with the rubber and then safety mechanism to ensure glass jar will not be dropped.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	433	B	Thats the rubber.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	434	A	Ok. Device can be no longer than twenty four inches and any dimension when not being used.	2	2	**2**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	435	B	Yep we did that.	^	^	**^**	**1**	**1**	**100%**	^	Ep	**Ep**	**0**	**1**	**50%**
	436	A	To allow for easy storage. Glass food jars being retrieved must not be damaged in any way during your retrievel process. Watch out! Using the assistive technology device must not cause damage or leave marks on cupboard. I think that would be fine.	O	O	**O**	**1**	**1**	**100%**	Cp	Cp	**Cp**	**1**	**1**	**100%**
	437		Yeah. Crap there's something I hadn't thought about. Crap I thought about something and completely forgot.	^	^	**^**	**1**	**1**	**100%**	Lb	Lb	**Lb**	**1**	**1**	**100%**
	438	B	What?	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	439	A	I don't remember.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	440	B	Did we do everything.	O	O	**O**	**1**	**1**	**100%**	Ep	Ep	**Ep**	**1**	**1**	**100%**
	441	A	Yeah that was everything on there.	O	O	**O**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	442	B	Cool.	^	^	**^**	**1**	**1**	**100%**	^	^	**^**	**1**	**1**	**100%**
	443	A	Oh, what's the weight of it. The whole thing. It has to be lightweight.	O	O	**O**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	444	B	Plastic is here. Thats the metal. Like the light metal.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**
	445	A	This is plastic? Or is it metal.	2	2	**2**	**1**	**1**	**100%**	Cl	Cl	**Cl**	**1**	**1**	**100%**
	446		Let's just leave it metal like a light weight metal and then the gripper is plastic.	^	^	**^**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	447	B	I don't know maybe like ten pounds.	2	2	**2**	**1**	**1**	**100%**	An	An	**An**	**1**	**1**	**100%**

	448	A	Maybe like five. Cause what you're going to be holding is going to be heavier than the thing itself.	2	2	**2**	**1**	**1**	**100%**	Ev	Ev	**Ev**	**1**	**1**	**100%**
	449	B	How about five pounds.	2	2	**2**	**1**	**1**	**100%**	Ps	Ps	**Ps**	**1**	**1**	**100%**
	450	A	Is that heavy?	^	^	^	**1**	**1**	**100%**	Ev	Ev	**Ev**	**1**	**1**	**100%**
	451	B	I don't know. Is that heavy? What's five pounds?	^	^	^	**1**	**1**	**100%**	Ev	Ev	**Ev**	**1**	**1**	**100%**
	452	A	My backpack probably.	^	^	^	**1**	**1**	**100%**	Kd	Kd	**Kd**	**1**	**1**	**100%**
	453	B	I mean it's definitely not yeah ok.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
	454	A	I'm thinking of a bowling ball. That's probably six pounds, not even.	^	^	^	**1**	**1**	**100%**	Kd	Kd	**Kd**	**1**	**1**	**100%**
	455	B	Nah. Lets do four pounds. Why not.	2	2	**2**	**1**	**1**	**100%**	Dd	Dd	**Dd**	**1**	**1**	**100%**
	456	A	Four lbs. Sounds good.	^	^	^	**1**	**1**	**100%**	^	An	**An**	**0**	**1**	**50%**
	457	B	Don't forget it.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
44:43	458	A	I think we're done.	^	^	^	**1**	**1**	**100%**	^	^	^	**1**	**1**	**100%**
									88%						88%
				Calculations											
				Coding Scheme 1			**Coding Scheme 2**								
				0	84	24.0%	**Ap**	4	1.1%	**9.39%**					
				1	69	19.7%	**Cp**	21	5.8%						
				2	197	56.3%	**Ep**	8	2.2%						
				^	108		**Pp**	1	0.3%						
							Ps	47	13.0%	**45.86%**					
							Cl	73	20.2%						
							Re	6	1.7%						
							Dd	28	7.7%						
							Co	2	0.6%						
							Pd	0	0.0%						
							La	6	1.7%						
							Lb	4	1.1%						
							Ju	11	3.0%	**31.77%**					
							An	71	19.6%						
							Pa	0	0.0%						
							Ca	14	3.9%						
							Ev	19	5.2%						

							Ka	13	3.6%						
							Kd	16	4.4%	**12.98%**					
							Ds	18	5.0%						
							^	96							

Appendix M

Master Results

NSF-HS ENG Edn 2015-2016 - YR 2 DATA

CS # 1	Team1	Team 2	Team3	Team4	Team5	Team12	Team13	Team14	Team19	Team20	MEAN	SD
0-System	16.75	12.10	3.60	18.30	9.10	30.60	7.07	16.91	24.07	17.23	**15.57**	**8.03**
1-Subsystems	33.00	52.30	38.20	41.70	21.00	28.70	36.36	15.44	13.70	21.72	**30.21**	**12.38**
2-Detail	50.25	35.50	58.20	40.00	69.90	40.80	56.57	67.65	62.22	61.05	**54.21**	**12.05**

CS # 2	Team1	Team2	Team3	Team4	Team5	Team12	Team13	Team14	Team19	Team20	MEAN	SD
Ap	0.42	4.00	0.00	2.90	2.10	3.50	0.94	2.60	1.94	0.00	**1.84**	**1.45**
Cp	2.51	5.60	0.70	2.10	6.90	1.50	2.83	2.60	4.65	4.65	**3.40**	**1.96**
Ep	0.42	1.60	2.90	0.70	4.20	3.00	1.89	0.00	0.00	0.00	**1.47**	**1.50**
Pp	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00	0.00	**0.11**	**0.23**
Ps	17.57	17.70	28.10	14.30	18.80	10.60	29.25	14.94	18.99	15.12	**18.54**	**5.90**
Cl	16.32	25.00	16.50	28.60	18.80	13.10	10.38	25.32	17.05	7.75	**17.88**	**6.74**
Re	3.35	1.60	3.60	0.70	2.80	2.50	2.83	0.00	0.78	3.88	**2.20**	**1.35**
Dd	16.32	5.60	3.60	3.60	6.90	3.50	16.98	9.09	5.43	8.91	**7.99**	**4.99**
Co	0.00	0.00	0.70	2.10	0.00	6.00	0.94	1.95	0.39	0.39	**1.25**	**1.84**
Pd	0.42	0.80	1.40	0.00	0.00	3.50	0.94	0.00	0.78	0.39	**0.82**	**1.05**
La	3.35	2.40	2.20	2.10	2.80	2.00	3.77	1.95	2.71	3.10	**2.64**	**0.62**
Lb	0.84	0.80	0.00	0.70	0.70	4.50	1.89	2.60	0.78	1.94	**1.48**	**1.31**
Ju	2.09	6.50	5.80	3.60	4.20	4.50	5.66	5.19	7.75	5.04	**5.03**	**1.57**
An	19.67	15.30	11.50	25.00	15.30	15.10	13.21	11.69	17.83	29.84	**17.44**	**5.93**
Pa	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.14**	**0.44**
Ca	2.09	0.00	1.40	0.00	0.70	0.00	0.00	0.65	0.00	0.39	**0.52**	**0.72**
Ev	2.51	7.30	9.40	2.90	4.90	5.00	4.72	3.90	3.88	2.33	**4.68**	**2.21**
Ka	3.77	0.00	0.00	0.00	2.10	2.50	0.94	4.55	7.75	6.20	**2.78**	**2.74**
Kd	2.51	0.80	2.20	2.90	4.90	6.00	0.94	2.60	7.75	6.59	**3.72**	**2.43**
Ds	5.44	4.80	8.60	7.90	4.20	13.10	1.89	9.74	1.55	3.49	**6.07**	**3.69**

NSF-HS NON-EngEdn 2015-2016 - YR 2 DATA

CS # 1	Team6	Team7	Team8	Team9	Team10	Team11	Team15	Team16	Team17	Team18	MEAN	SD
0 - System	24.00	26.80	30.20	25.40	16.70	27.10	22.90	11.30	24.26	34.21	**24.29**	**6.47**
1-Subsystems	19.70	29.30	20.20	32.70	37.30	17.60	28.24	19.57	35.74	25.44	**26.58**	**7.19**
2-Detail	56.30	43.90	49.60	41.90	46.10	55.30	48.85	69.13	40.00	40.35	**49.14**	**9.06**

CS # 2	Team6	Team7	Team8	Team9	Team10	Team11	Team15	Team16	Team17	Team18	MEAN	SD
Ap	1.10	3.10	3.80	0.90	0.90	2.80	4.23	1.72	3.31	0.78	**2.26**	**1.33**
Cp	5.80	9.40	8.70	2.00	4.60	6.00	7.04	3.00	1.47	4.69	**5.27**	**2.66**
Ep	2.20	1.00	2.60	0.00	1.90	0.70	0.70	0.86	2.21	0.78	**1.30**	**0.86**
Pp	0.30	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	**0.07**	**0.15**
Ps	13.00	15.60	14.30	12.80	18.50	22.30	14.79	17.60	10.29	9.38	**14.86**	**3.88**
Cl	20.20	13.50	18.10	21.70	24.10	10.60	13.38	8.58	16.54	8.59	**15.53**	**5.48**
Re	1.70	1.00	2.30	2.30	1.90	1.10	0.70	2.58	2.94	1.56	**1.81**	**0.73**
Dd	7.70	6.30	14.00	4.90	10.20	5.30	11.27	9.44	4.78	10.16	**8.41**	**3.11**
Co	0.60	2.10	4.50	0.30	0.00	0.40	0.70	0.00	1.84	13.28	**2.37**	**4.07**
Pd	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	1.84	0.00	**0.21**	**0.58**
La	1.70	1.00	0.80	4.10	1.90	1.40	1.41	6.01	4.04	4.69	**2.71**	**1.83**
Lb	1.10	1.00	0.00	0.90	0.00	1.10	2.11	0.43	0.74	0.00	**0.74**	**0.66**
Ju	3.00	2.10	8.30	2.30	4.60	4.60	4.93	3.00	2.57	7.03	**4.24**	**2.09**
An	19.60	24.00	10.60	29.00	13.90	20.50	11.97	26.61	22.43	18.75	**19.74**	**6.13**
Pa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**0.00**
Ca	3.90	4.20	0.40	0.30	0.90	0.00	0.00	0.43	0.00	0.78	**1.09**	**1.59**
Ev	5.20	8.30	5.30	4.30	0.90	3.90	1.41	3.00	6.25	7.81	**4.64**	**2.46**
Ka	3.60	1.00	1.10	4.10	6.50	8.80	6.34	3.43	2.94	1.56	**3.94**	**2.58**
Kd	4.40	1.00	2.30	4.90	2.80	5.70	6.34	1.72	3.68	7.81	**4.07**	**2.17**
Ds	5.00	5.20	3.00	4.90	6.50	4.60	12.68	11.59	12.13	2.34	**6.79**	**3.87**

Appendix N

t-test Results

Coding Scheme 1: Problem Domain: Degree of Abstraction – System (0)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	15.573	24.287
Variance	64.55333	41.90311
Observations	10	10
Hypothesized Mean Difference	0	
df	17	
t Stat	-2.67074	
P(T<=t) one-tail	0.008065	
t Critical one-tail	1.739607	
P(T<=t) two-tail	0.01613	
t Critical two-tail	2.109816	

Coding Scheme 1: Problem Domain: Degree of Abstraction – Subsystems (1)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	30.212	26.579
Variance	153.2614	51.72792
Observations	10	10
Hypothesized Mean Difference	0	
df	14	
t Stat	0.802416	
P(T<=t) one-tail	0.217861	
t Critical one-tail	1.76131	
P(T<=t) two-tail	0.435722	
t Critical two-tail	2.144787	

Coding Scheme 1: Problem Domain: Degree of Abstraction – Details (2)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	49.143	54.214
Variance	82.11416	145.1936
Observations	10	10
Hypothesized Mean Difference	0	
df	17	
t Stat	-1.06362	
P(T<=t) one-tail	0.151188	
t Critical one-tail	1.739607	
P(T<=t) two-tail	0.302377	
t Critical two-tail	2.109816	

Coding Scheme 2: Strategy Classification: Analyzing the Problem (Ap)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	1.84	2.264
Variance	2.088622	1.764316
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-0.68308	
P(T<=t) one-tail	0.251628	
t Critical one-tail	1.734064	
P(T<=t) two-tail	0.503256	
t Critical two-tail	2.100922	

Coding Scheme 2: Strategy Classification: Consulting Information about the Problem (Cp)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	3.404	5.27
Variance	3.840204	7.093289
Observations	10	10
Hypothesized Mean Difference	0	
df	17	
t Stat	-1.78456	
P(T<=t) one-tail	0.046094	
t Critical one-tail	1.739607	
P(T<=t) two-tail	0.092188	
t Critical two-tail	2.109816	

Coding Scheme 2: Strategy Classification: Evaluating the Problem (Ep)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	1.471	1.295
Variance	2.245566	0.739094
Observations	10	10
Hypothesized Mean Difference	0	
df	14	
t Stat	0.322155	
P(T<=t) one-tail	0.376048	
t Critical one-tail	1.76131	
P(T<=t) two-tail	0.752095	
t Critical two-tail	2.144787	

Coding Scheme 2: Strategy Classification: Postponing the Analysis of the Problem (Pp)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	0.107	0.07
Variance	0.053823	0.022333
Observations	10	10
Hypothesized Mean Difference	0	
df	15	
t Stat	0.423982	
P(T<=t) one-tail	0.338798	
t Critical one-tail	1.75305	
P(T<=t) two-tail	0.677596	
t Critical two-tail	2.13145	

Coding Scheme 2: Strategy Classification: Proposing a Solution (Ps)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	18.537	14.856
Variance	34.85465	15.06614
Observations	10	10
Hypothesized Mean Difference	0	
df	16	
t Stat	1.647499	
P(T<=t) one-tail	0.059475	
t Critical one-tail	1.745884	
P(T<=t) two-tail	0.118951	
t Critical two-tail	2.119905	

Coding Scheme 2: Strategy Classification: Clarifying a Solution (Cl)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	17.882	15.529
Variance	45.395	30.05134
Observations	10	10
Hypothesized Mean Difference	0	
df	17	
t Stat	0.856649	
P(T<=t) one-tail	0.201777	
t Critical one-tail	1.739607	
P(T<=t) two-tail	0.403553	
t Critical two-tail	2.109816	

Coding Scheme 2: Strategy Classification: Retracting a Previous Design Decision (Re)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	2.204	1.808
Variance	1.824227	0.536107
Observations	10	10
Hypothesized Mean Difference	0	
df	14	
t Stat	0.815096	
P(T<=t) one-tail	0.214333	
t Critical one-tail	1.76131	
P(T<=t) two-tail	0.428667	
t Critical two-tail	2.144787	

Coding Scheme 2: Strategy Classification: Making a Design Decision (Dd)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	7.993	8.405
Variance	24.93593	9.653361
Observations	10	10
Hypothesized Mean Difference	0	
df	15	
t Stat	-0.22153	
P(T<=t) one-tail	0.413835	
t Critical one-tail	1.75305	
P(T<=t) two-tail	0.82767	
t Critical two-tail	2.13145	

Coding Scheme 2: Strategy Classification: Consulting External Information for Ideas (Co)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	1.247	2.372
Variance	3.371134	16.58224
Observations	10	10
Hypothesized Mean Difference	0	
df	13	
t Stat	-0.79642	
P(T<=t) one-tail	0.220044	
t Critical one-tail	1.770933	
P(T<=t) two-tail	0.440088	
t Critical two-tail	2.160369	

Coding Scheme 2: Strategy Classification: Postponing a Design Action (Pd)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	0.823	0.214
Variance	1.09969	0.335293
Observations	10	10
Hypothesized Mean Difference	0	
df	14	
t Stat	1.607659	
P(T<=t) one-tail	0.065111	
t Critical one-tail	1.76131	
P(T<=t) two-tail	0.130222	
t Critical two-tail	2.144787	

Coding Scheme 2: Strategy Classification: Looking Ahead (La)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	2.638	2.705
Variance	0.383507	3.351739
Observations	10	10
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.10963	
P(T<=t) one-tail	0.45734	
t Critical one-tail	1.795885	
P(T<=t) two-tail	0.91468	
t Critical two-tail	2.200985	

Coding Scheme 2: Strategy Classification: Looking Back (Lb)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	1.475	0.738
Variance	1.724828	0.440907
Observations	10	10
Hypothesized Mean Difference	0	
df	13	
t Stat	1.583671	
P(T<=t) one-tail	0.068642	
t Critical one-tail	1.770933	
P(T<=t) two-tail	0.137284	
t Critical two-tail	2.160369	

Coding Scheme 2: Strategy Classification: Justifying a Proposed Solution (Ju)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	5.033	4.243
Variance	2.470334	4.35669
Observations	10	10
Hypothesized Mean Difference	0	
df	17	
t Stat	0.956118	
P(T<=t) one-tail	0.176206	
t Critical one-tail	1.739607	
P(T<=t) two-tail	0.352413	
t Critical two-tail	2.109816	

Coding Scheme 2: Strategy Classification: Analyzing a Proposed Solution (An)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	17.444	19.736
Variance	35.21247	37.54705
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-0.84971	
P(T<=t) one-tail	0.203324	
t Critical one-tail	1.734064	
P(T<=t) two-tail	0.406648	
t Critical two-tail	2.100922	

Coding Scheme 2: Strategy Classification: Postponing an Analysis Action (Pa)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	0.14	0
Variance	0.196	0
Observations	10	10
Hypothesized Mean Difference	0	
df	9	
t Stat	1	
P(T<=t) one-tail	0.171718	
t Critical one-tail	1.833113	
P(T<=t) two-tail	0.343436	
t Critical two-tail	2.262157	

Coding Scheme 2: Strategy Classification: Performing Calculations to Analyze a Proposed Solution (Ca)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	0.523	1.091
Variance	0.51749	2.533388
Observations	10	10
Hypothesized Mean Difference	0	
df	13	
t Stat	-1.02834	
P(T<=t) one-tail	0.161273	
t Critical one-tail	1.770933	
P(T<=t) two-tail	0.322545	
t Critical two-tail	2.160369	

Coding Scheme 2: Strategy Classification: Evaluating a Proposed Solution (Ev)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	4.684	4.637
Variance	4.882582	6.062112
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	0.044926	
P(T<=t) one-tail	0.482331	
t Critical one-tail	1.734064	
P(T<=t) two-tail	0.964661	
t Critical two-tail	2.100922	

Coding Scheme 2: Strategy Classification: Explicitly Referring to Application Knowledge (Ka)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	2.781	3.937
Variance	7.513543	6.634223
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-0.97188	
P(T<=t) one-tail	0.171994	
t Critical one-tail	1.734064	
P(T<=t) two-tail	0.343989	
t Critical two-tail	2.100922	

Coding Scheme 2: Strategy Classification: Explicitly Referring to Domain Knowledge (Kd)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	3.719	4.065
Variance	5.891632	4.715583
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-0.33595	
P(T<=t) one-tail	0.370396	
t Critical one-tail	1.734064	
P(T<=t) two-tail	0.740792	
t Critical two-tail	2.100922	

Coding Scheme 2: Strategy Classification: Explicitly Referring to Design Strategy (Ds)

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	6.071	6.794
Variance	13.63394	14.9554
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-0.4276	
P(T<=t) one-tail	0.337008	
t Critical one-tail	1.734064	
P(T<=t) two-tail	0.674015	
t Critical two-tail	2.100922	