The Theoretical Learning Impact of a Summer Engineering Program Curriculum for Underrepresented Middle School Students

Vaneshette Teshawn Henderson

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THE THEORETICAL LEARNING IMPACT OF A SUMMER ENGINEERING PROGRAM CURRICULUM FOR UNDERREPRESENTED MIDDLE SCHOOL STUDENTS

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Educational Theory, Policy, & Practice

by

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As I typed the last words for my dissertation, I began to cry. I was overwhelmed with joy. During the past four years, I believe I have experienced every emotion known to man during this extensive, yet fulfilling process, and it was all worth! God has blessed me and so many ways, and to Him. I give all of the glory. He is my source of inspiration and strength. Without Him, my life, love, pursuit of education and passion for educating others would not be possible.

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ABSTRACT

This mixed methods, exploratory and confirmatory study was designed to evaluate the theoretical learning impact of a innovative summer engineering program curriculum would have on its audience, middle school minority students. Several theories were used to develop the innovative curriculum including Human Constructivism, cultural learning styles of African Americans, visual spatial learning and graphic design learning. This study was completed in two phases: evaluation of existing middle school summer engineering program curriculum for best practices and development of innovative curriculum and expert evaluation of the innovative curriculum. Three existing programs from across the country participated in this study. Five engineering education experts evaluated the innovative curriculum. The innovative curriculum is composed of three extensive units that include forces and motion, earth and space science and energy topics. A mixed methods design was used in data collection and analysis to provide a complete view of the theoretical impact of the curriculum.

The resulting qualitative and quantitative data indicated the innovative program would enhance its target audience by providing a strong foundation in the fundamental understanding of science and engineering topics and spatial visualization. The qualitative narratives proved that many of the existing programs provide very similar learning environments that do not necessarily include cultural learning, meaningful learning and visual spatial learning. The expert evaluators collectively determined that the innovative program would have a positive and enriching academic impact with the chosen theoretical components. They believed that there was overwhelming evidence (3.7 rating average out of a 4.0) that the theoretical components existed in the curriculum and would provide middle school minority students with the proper knowledge to increase their interest which would inherently increase the science, technology, engineering,
and mathematics career pipelines. They also strongly agreed (4.875 rating average out of 5) that the program differed from other programs, has relevant learning theories for the target audience exceeded expectations and all the participants of the future program to “see themselves as engineers.”
CHAPTER 1. INTRODUCTION

Rationale

The American Society for Engineering Education stated:

Engineers helped turn the 20th century into the American century by designing and building everything from cars to computer chips to artificial limbs better than anyone else in the world. Now we need a new generation of engineers. A generation that reflects the vast potential and rich diversity of the new American workforce. A generation that will keep America’s science and technology enterprise hitting all cylinders.

(“Engineering: It’s everywhere,” 2005, p. 10)

When the Soviet Union launched Sputnik in 1957, the U.S. government shifted the content of the American Educational System curriculum toward science, technology, engineering, and mathematics (STEM) to increase America’s edge in the Space Race. The educational system witnessed curriculum reforms in physics, biology, and chemistry that were centered on the nature of scientific research and encouraging students to think and act like scientists (DeBoer, 1991). DeBoer (1991) found those curriculum reforms failed due to a lack of fundamental principles of curriculum and instruction (i.e., including student interest or the need to relate science knowledge to the experiential world). “Many of the projects ignored one of the most important reasons for teaching science in any culture… to provide individuals with knowledge and skills that would help them live intelligent lives in the culture in which they found themselves” (DeBoer, 1991, p. 172). Throughout all of the reforms in the past fifty years, the American educational system has still found itself trying to compete with other foreign countries.

There is mounting anxiety about U.S. economic competitiveness in regards to the ability of the educational system, secondary and higher education, producing citizens who are not only literate in STEM disciplines, but who can also contribute as scientists, technologists, engineers,
and mathematicians. In the past few years, business leaders and government and public officials have begun to increasingly amplify their concerns over out-sourcing well-educated but lower-paid foreign workers. The report submitted by the U. S. Department of Education’s Academic Competitiveness Council (2007) stated, “Even after decades of education reforms, and some improvement in K-12 education achievement in the U.S., the results from recent national and international assessments are sobering” (p. 5).

According to the National Center for Education Statistics’ (NCES) National Assessment of Educational Progress (NAEP) Report, The Nation’s Report Card (2007), 39% of fourth graders and 32% of eighth graders scored at the proficient or advanced levels in mathematics; the scores were slightly higher from 2005. In regards to science in 2005, 29% of fourth graders, 29% of eighth graders, and 18% of 12th grade students performed at or above the proficient levels. The statistics are more alarming when a comparison is made across ethnicities, showing large achievement gaps. According to the NCES, 42% of Whites, 11% of Blacks, and 15% of Hispanics students scored at or above the proficient levels in eighth grade mathematics (2007). In 2005, 24% Whites, 2% Blacks, and 2% Hispanics scored at or above the proficient levels in twelfth grade science.

Achieving Scientific Literacy for All has become the new mantra for bridging the achievement and technology gap between the United States, its citizens and other countries. According to Bell, Blair, Crawford, and Lederman (2003), scientific literacy is the ability to make knowledgeable decisions about science and technology through having an in-depth understanding of scientific concepts. Several organizations and researchers have set out to establish standards by which every student can achieve scientific literacy to understand layman scientific discussions and make every day decisions that involve scientific principles. The
**Benchmarks for Scientific Literacy** (American Association for the Advancement of Science [AAAS], 1993), **Science for All Americans** (Rutherford & Ahlgren, 1990) and the **National Science Education Standards** (Nations Research Council [NRC], 1996) stress the importance of having equal scientific learning opportunities for all American students.

We are all consumers of this world, and it is imperative that we are aware of how things work and how things are made. The likelihood of students having the same scientific experience is minimal, but the aforementioned literature stresses active learning (i.e., inquiry based approaches) as the path to achieve equity. Over the last several years certain strategies have been implemented on the K-12, the postsecondary and informal education and outreach levels to improve the community’s STEM literacy in hopes of decreasing the educational gap. Those strategies include “raising the bar for high school course-taking in math and science; offering monetary incentives for students to enter STEM fields…; establishing new schools specializing in STEM subjects; strengthening career and technical education; and supporting new approaches to STEM instruction” (“The Push to Improve STEM Education,” 2008, p. 8). The federal government alone has established and supported numerous programs designed to improve student learning and interest in STEM disciplines, especially among underrepresented and underachieving groups.

Over the past decade, there has been a resounding message of an existing shortage of engineers. Engineering involves the application of science, technology and mathematics to solve real-world problems. Research shows the shortage exists in the quality, not quantity, of talent travelling through the engineering pipeline into the workforce (Brown & Linden, 2008; Chubin, May, & Babco, 2005; Research and Development [RAND], 2003). Companies have turned to foreign workers not only because they pay them lower wages but because their educational
training is more extensive, therefore, producing highly skilled and talented employees. The implications of a shortage of skills are critical to development, competitiveness, and security in the U.S. (RAND, 2003). The shortage exists because engineering has a diversity problem.

*Merriam-Webster’s Collegiate Dictionary* defines diversity as the inclusion of various cultures, ethnicities, and genders (Merriam-Webster, 2003). The engineering profession must narrow the gap between practitioners and their clientele, it must become culturally competent (Chubin et al., 2005; National Action Council for Minorities in Engineering [NACME], 2008). “To meet the United States’ need for world class talent in science, technology, engineering, and mathematics, higher education must develop an emerging U.S. talent pool that looks very different from decades past” (Chubin et al., 2005, p. 73). Diversity makes workforces more creative, solutions more feasible and products more usable (Wulf, 1998). Diversity is an asset to any profession, increasing knowledge and therefore, increasing competence. The engineering workforce should reflect the culture and people it serves. America has an untapped pool of talent right in its own backyard, “a hidden workforce of young men and women who have traditionally been underrepresented in STEM careers--African Americans, American Indians, and Latinos” (NACME, 2008 p. 6).

NACME (2008) released research that shows a growing opportunity gap in the number of minority students pursuing degrees and careers in STEM fields. The 2008 NACME report, “Confronting the ‘New’ American Dilemma,” shows the rate of minority participation in STEM fields has flat-lined and declined in some cases. In 1979, 52,598 engineering degrees were awarded to students; of those degrees, 2,347 students were minorities. According to the Engineering Workforce Commission of the American Association of the Engineering Societies (1995), in 1994, engineering degrees were awarded to 59,507 students; 5,490 of those degrees
were awarded to minorities. One-third of the school-age U.S. school population consists of minorities, but over three-fourths of the STEM workforce is predominantly white (Chubin et al., 2005). According to NACME, African Americans, American Indians, and Latinos make up 30% of U.S. undergraduate students, a proportion that is expected to grow in the next few years by several percent. But, fewer than 12% of the bachelor degrees in engineering were awarded to underrepresented minorities.

In the 2006 State of the Union Address, former President Bush proposed the American Competitiveness Initiative (ACI) to help build success and remain a leader in science and technology. According to the U. S. Department of Education’s Academic Competitiveness Council (2007) the president stated the following:

> Education is the gateway to opportunity and the foundation of a knowledge-based, innovation-driven economy, and for the U.S. to maintain economic leadership, we must ensure a continuous supply of highly trained mathematicians, scientists, engineers, technicians, and scientific support staff as well as a scientifically, technically and numerically literate population. (p. 1)

In order to address former President Bush’s initiative, aggressive work needs to be done to help create this economic leadership as well as make sure those that young people that are trained are diverse to reflect the needs of all citizens’ cultures.

My career goals lay in the crossroads of the two things I am most passionate about, engineering and education. Ironically enough, I realized I wanted to pursue this life path while on a walk at the University of Michigan as a graduate student. While engaged in the physical act of walking, mentally, I was tracing all of the steps I had made in life that afforded me the opportunity to attend one of the most reputable research institutions in the country. I am the first graduate of a dual-degree program between Xavier University of Louisiana and the University of Michigan, Biomedical Engineering Department. I was fortunate. However, so many students are
not. At that moment I realized a Master’s Degree in Biomedical Engineering is more than a credential to gain me access to upper echelon technical careers, but also, a tool to help minority youth do the same.

As a mentor, leader, and teacher for minority engineering summer programs at several institutions, I was confronted and dismayed by the disparities that exist between minority students and their peers as it pertains to education in mathematics and science. As an honor graduate in physics and engineering, I know these differences do exist, but they do not have to. The technical side of me wants to solve the equation, figure out the $x$ factor. My scientific mind led me to examine all of the variables that exist for minority students that their peers do not have to contend with. It was apparent to me that if minority students were given the same opportunities, placed in an environment to succeed, and exposed to a rigorous curriculum of mathematics and science then the disparities may begin to disappear. I know this can happen because I am a product of these conditions, and I am determined to repeat the results.

**Research Plan**

In order to strengthen our Nation’s educational system, especially in the areas STEM, every child needs to be engaged in rigorous courses, activities, and programs that teach important analytical, technical, and problem-solving skills. The goal of this research is to devise a new strategy to increase and maximize STEM interest and achievement in the urban, middle school population. The strategy involves a theoretically designed curriculum for a summer pre-engineering program based on the role of visualization in learning, Tufte’s theory of graphical design, Paivio’s Dual Coding Theory, basic engineering concepts, the creative behavior of the urban community, and the human constructivist learning theory.
Simply, *Bridging the Gap* between school age minorities and their colleagues is my goal. It is my sincere and ultimate desire to establish a math and science boarding school, free of charge, for minority students. At the intersection of science and education is Mae Jemison Science and Engineering Academy, a learning center that would help to create avenues of opportunity for minority students and prevent them from befalling the many roadblocks that may confront them. The Mae Jemison Science and Engineering Academy, is a quasi-public academy that will give inner city youth intensive training for careers in STEM education.

Dr. Mae Jemison was the first African American woman to travel to space aboard the Space Shuttle Endeavor in 1992. A chemical engineer and general medical practitioner, Dr. Jemison was chosen as the historical figure to represent this future school because she epitomizes the true definition of a trailblazer for all aspiring scientists and engineers, especially minorities. Receiving a scholarship from Stanford University at the age of 16 to study chemical engineering, Dr. Jemison began an outstanding academic and professional career that would prepare her to be a doctor, astronaut, entrepreneur, educator, and humanitarian. Dr. Jemison’s company, The Jemison Group, focuses on bringing advanced technology to the world. Another major focus of the Jemison Group is to increase STEM interest in children ages 12 through 16 through the program, The Earth We Share (TEWS). The camp participants focus on solving global dilemmas using STEM principles. Started in 1994, TEWS hosts students from around the world and is based on an experiential science curriculum.

In the past few years, informal STEM programs have been documented to improve academic standing, produce significant changes in scientific knowledge, interest, and attitudes regarding STEM (Atwater, Colson, & Simpson, 1999). They have also shown to serve as a safe-haven for under-represented students who do not have access to a large number of resources in
low achieving urban schools or impoverished areas (Barton, 2001). Learning science already presents many challenges for students, but those challenges increase in the urban environment. Urban schools are riddled with inadequate funding, certified-teacher shortage in science and mathematics, a lack of resources and students suffering from impoverished home-life conditions. Informal STEM programs have been used as supplemental learning places to help combat the inadequate learning conditions in the urban classroom as well as the cultural-norm disposition STEM subjects’ exhibit in the classroom that urban students do not typically fit into. “Students from upper-middle- and upper-class families possess a cultural advantage for achieving school related success that lower-class students do not; schools tend to reward those who demonstrate knowledge and appreciation of upper-middle- and upper-class culture” (Tobin, Roth, & Zimmerman, 2001, p. 942).

Urban education and creative behavior of urban students’ research has detailed the importance of including the culture and interest of students in STEM education. Integrating culturally relevant curricula and creating learning modules that are aesthetically pleasing has been suggested to increase the success of African Americans in social institutions (Boykin, 1986). It is imperative that we focus not only on how students learn but the cultures they live in. There is a great connection between schools and the students’ home, and due to a present disconnect, urban students suffer academically and socially (Bouillion & Gomez, 2001). Informal programs generally do not face the challenge public school systems face, appealing to a vast amount of diversity. Informal programs have the autonomy to implement curriculums that promote meaningful learning to urban students.

Meaningful learning is the assimilation of new information into an existing knowledge of frameworks (Mintzes, Wandersee, & Novak, 2005b). This method of learning is critical in
science learning because science is built upon hierarchical, integrated information. Traditionally, teaching strategies in science education are based on rote learning techniques. According to Teaching Science for Understanding (2005), research has proven that students who practice rote learning only accumulate isolated propositions of cognitive structure which causes poor retention and retrieval of ideas, potential interference in subsequent learning and inability to use knowledge to solve problems. Meaningful learning is the exact opposite of rote learning. A very important factor of meaningful learning is the connection of learning to the real world. According to Langer (1997), there are two ways to link concepts to the real world. The first way involves the instructor presenting ideas using an approach that relates to their lives and interests. Secondly, the learning has to challenge their thoughts and change their attitudes about science, showing how science relates to their lives (Langer, 1997).

Spatial visualization plays a large role in learning and understanding science and engineering (Shea, Lubinski, & Benbow, 2001). Spatial visualization refers to the ability to mentally manipulate 2-D and 3-D figures. Proficiency in visual-spatial ability has been associated with academic and professional occupations such as architects, scientists, surgeons, graphic design artists, engineers and other disciplines/careers that visualize and manipulate images in their work. If visual-spatial ability is important and recommended, why aren’t there courses on the topic offered on any educational level? Edward Tufte developed a 4-volume theory of graphical information design. Tufte seeks to make one a better quantitative storyteller by focusing on the role of visualization and graphical integrity. Much of science and engineering entails learning, presenting, and designing quantitative information. It is imperative for future scientists and engineers to be able to effectively use, create, describe, and understand visualizations that depict mechanisms and processes involved in their perspective fields.
This study attempts to compose a curriculum for an urban middle school summer engineering program. The curriculum is based on visual thinking principles, Human Constructivism and cultural learning styles. This study will also analyze four top urban middle school summer curriculums to investigate their learning theories and approaches and look to them for best practices of an effective summer engineering program.

Research Questions

• Main Question

What theoretical learning impact will a proposed innovative summer engineering program and its integrated components have upon underrepresented middle school students’ interest in and understanding of real world engineering?

• Sub-questions

1. What set of relevant learning/visual design theories and innovative practices seems best suited to design the curriculum of such a STEM workforce-oriented summer engineering education program, and how does the proposed innovative program differ from existing programs currently serving similar populations?

2. Why is there an emergent need to increase the USA’s STEM workforce, especially with underrepresented members of the community, and how is the proposed program designed to help these students “see themselves as future engineers?”

3. What is the STEM socialization value and significance of such supplemental summer programs for teaching selected core engineering concepts and projects to the underrepresented members of the community in a visual and experiential way?

Research Vee Diagram. A Vee Diagram was constructed to illustrate and summarize the epistemological (left side) and methodological (right side) portions of the study, see Figure 1.
(Gowin, 1981). This graphic allows researchers to visualize the activities involved in their studies. The theoretical side defines the conceptual framework and includes theories, principles, and concepts driving the research. The methodological side defines the procedural activities that guide the research and includes the value claims, knowledge claims, transformations, and records. The middle of the diagram forms a wedge between the two sides and contains the focus and sub-questions that frame the inquiry (Mintzes et al., 2005b).

**Research Flow-Chart.** A flow-chart was also constructed to depict procedural knowledge, see Figure 2 (Mintzes et al., 2005b). According to Briscoe (1990), flow-charts are functional illustrations that depict pathways, hypotheses, procedures, and schema. A glossary of research terms follows the flowchart.

**Definition of Terms**

Minorities: For the purpose of this study, minorities are defined as the African American (Black but non-Hispanic) population. They are the majority minority in the Southern Region of the US.

Middle School Students: Term used to collectively refer to all students in these grades 6-8.

Visual Spatial Thinking: The ability to visualize the world with accuracy.

Multicultural Education: An epistemology which proposes that the learner’s environment, cultural background, values, beliefs, values, traditions, and customs are incorporated into their education.

Human Constructivism: A learning theory which proposes a systematic outlook in which humans actively construct their knowledge of the world.

Meaningful Learning: The integration of new information into an existing framework of knowledge.
Gowin’s Research Vee Diagram

What theoretical learning impact will a proposed innovative summer engineering program and its integrated components have upon underrepresented middle school students’ interest in and understanding of real world engineering?

Sub Questions

1. What set of relevant learning/visual design theories and innovative practices seems best suited to design the curriculum of such a STEM workforce-oriented summer engineering education program, and how does the proposed innovative program differ from existing programs currently serving similar populations?

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3. What is the STEM socialization value and significance of such a supplemental summer programs for teaching selected core engineering concepts and projects to the underrepresented members of the community in a visual and experiential way?

VALUE CLAIMS

This proposed program will increase the interest and understanding of science and engineering concepts in 6th – 8th graders. Involving students in engineering concepts early has been documented to increase participation in advanced courses in high school with the intent to enter science and engineering careers.

KNOWLEDGE CLAIMS

Supplemental science programs have been documented to improve academic standing, produce changes in scientific knowledge, interest, attitudes and confidence in science, in the lives of under-represented students who do not have access to a multitude of resources in low achieving urban public schools. Visual approaches would foster student creativity and emphasize how engineers must use their imagination and creativity increasing their interest in engineering.

TRANSFORMATIONS

Analysis of 3 top summer engineering curriculums

RECORDS

Evaluative feedback of proposed program from engineering education faculty
Summer engineering curriculum

EVENTS/OBJECTS

Researcher identifies 3 top summer engineering programs to evaluate their theoretical and scientific learning approaches, as well as science and engineering concepts covered to argue the proposed program study is innovative. Researcher develops summer engineering program curriculum based on human constructivism learning theory and visual spatial ability including design activities, evaluative methods and rubrics.

Figure 1. Gowin’s Research Vee Diagram of Proposed Research
Figure 2. Research Flow Chart
CHAPTER 2. LITERATURE REVIEW

Early Adolescence: The Middle School Student

The curriculum for this pre-college engineering summer program will include the analytical and behavioral attributes of middle school students, grades 7 and 8. Targeting middle school students was done because according to Hurd (1978), “it is evident that the early adolescents in American society are a forgotten group… the life span of this group represents a unique period in human development that is characterized by extensive social, psychological, and biological changes, yet these attributes are rarely considered in educational practices” (p. 1). The purpose of the middle school curriculum will be to provide an educational resource in which early adolescents can develop intellectually and be immersed in an academic discipline that will enable them to become scientifically literate and possibly enter a workforce that lacks diversity.

Early adolescence is defined as youth ages 12 through 14 and is marked by many physical, mental, emotional, and social changes. “The school curriculum for the early adolescent should be unique to this particular development… but are often extensions of the elementary school program or a simplified version of a high school course” (Hurd, 1978, p. 4). Johnson (1978) believed that there are several reasons the educational system fails to support the development of the early adolescent. Johnson stated “our educational system is based on the concept of essentialism, meaning there is a body of knowledge, skills, and values that is essential for all to learn” (p. 63). Also, those essentials have to be learned in a certain amount of time, leaving little flexibility to consider the learning style, ability, and rate for each adolescent. Johnson (1978) also believes that the higher education system is very ineffective in equipping teachers leading the middle school classroom with the appropriate expertise and teaching techniques.
According to Early Adolescence: Perspectives and Recommendations (1978), a report prepared for the National Science Foundation, science and mathematics teachers for the middle school are seldom educated to teach at that level. In most states teachers certified for high school are automatically approved for teaching any of the grades 7 through 12. Typically, certification for the elementary school means approval for teaching grades 1 through 8. Most teachers in schools including grades 7 and 8 are trained as elementary school teachers (Hurd, 1978, p. 55).

In Louisiana, one out of 19 public and private universities offer undergraduate elementary and/or secondary education programs offer a Bachelor of Arts degree in middle school education. One of those universities offers a Bachelor of Science degree in Math/Science education with focus on grades 4 through 8; another university offers a Bachelor of Science degree in Elementary education with certification in grades 4 through 8; another university offers a Bachelor of Science degree in Elementary Education with a concentration in grades 4 through 8.

According to the 2000 Louisiana Census, 7.8% of the population contains students that are middle school age, 10-15. The Louisiana public and private schools possibly provide an education to approximately 348,000 students, and yet only one higher education institution offers a degree in middle school education, while three others offer focuses or concentrations in middle school education. Louisiana middle school students have very few teachers that are trained to handle their physical, mental, emotional or social changes. “The ineffectiveness of higher education institutions in equipping teachers with expertise and appropriate teaching techniques at the junior high/middle school level further complicates the matter of educating the early adolescent” (Johnson, 1978, p. 64).
Middle school students are experiencing a complex transition into their teenage years, and the literature suggests that the public school system curriculum and the teachers that lead the classroom “appear to be less and less effective in providing transitional skills for adolescents in our post-industrial society” (Barr, 1978, p. 19). In 1978, the Panel on Youth of President’s Science Advisory Committee advocated placing the students in different roles from the traditional student role in the school system to provide a supplemental form of education, which involves informal or out-of-school programming (Barr, 1978, p. 22). The panel’s report plainly stated that “learning happens through action and experience, not by being taught” (Coleman, 1972, p. 146).

“A variety of out-of-school programming is essential to provide the best possible education for the early adolescent” (Hurd, 1978, p. 5). Several reports support the use of informal learning programs in conjunction with traditional learning for early adolescents because they can provide opportunities for greater access to adult role models than is provided by parents and teachers, more experience in community social roles than can be provided in a school setting; properly planned out-of-school experiences can reinforce what students already know, and because students could explore the work places of adults to become aware of career possibilities and the meaning of work (Barr, 1978; Coleman, 1972; Faure, 1972). Accordingly, an essential part of informal learning programs for early adolescents is the curriculum.

“The curriculum of the adolescent learner should be planned to meet the needs of the student academically and socially and still provide for the encouragement of continuous progress; emphasis should be on the utilization of knowledge rather than just a mastery of it” (Johnson, 1978, p. 65). As stated previously, the early adolescent experiences multiple changes during this time of development, changes that cannot be fully developed in the traditional
classroom dominated too frequently by one adult (Johnson, 1978, p. 65). At that stage of development, students are inquisitive and enthusiastic about new subjects. They are developing critical thinking and problem solving skills as well.

Byrnes in the *Blackwell Handbook of Adolescence* (2003) defined cognition development in adolescence in terms of knowledge, cognitive processes, constraints, and metacognitive orientations. According to Byrnes (2003), declarative, procedural, and conceptual knowledge all increase with age. Knowledge does increase during adolescence, but it depends on the domain and type of knowledge (Byrnes, 2003; Keating, 2004). Evidence exists of within-domain levels of understanding during adolescence, but little evidence exists of domain general shifts in understanding that occur at a particular age (Byrnes, 2003; Johnson, 1978; Keating, 2004).

Several areas of cognitive processes dominate in the literature on adolescent thinking. These areas include deductive and inductive reasoning, decision making and memory processes. The age of onset of deductive and inductive reasoning over the adolescent period is debated among researchers, but a developmental change in deductive reasoning has been identified to occur between childhood and early adulthood (Byrnes, 2003). According to Dias and Harris (1998), deductive reasoning skills become visible around ages 5 and 6. Several years following, children begin to distinguish between conclusions drawn from conditional premises and conclusions that do not follow (Byrnes & Overton, 1986). Throughout adolescence there is a small variety of change in the ability to draw appropriate conclusions, explain ones reasoning, and test hypotheses even when premises refer to unfamiliar or abstract propositions (Byrnes, 2003; Klaczynski, 1993; Ward & Overton, 1990). Little research exists to support the development of inductive reasoning competence in adolescents (Byrnes, 2003).
“The construct of decision making refers to a set of processes that come into play when an individual is trying to figure out how to attain a particular goal” (Byrnes, 2003, p. 235). Literature on the decision making skills of adolescence is currently sparse; researchers have been interested in determining whether effective decision making increases with age (Byrnes, 1998, 2003; Klaczynski, Byrnes & Jacobs, 2001). Byrnes (2003) summarizes the findings of several researchers and determined that effective decision making skills increase with age. Several researchers suggest that adolescents are more likely to make good decisions when they have metacognitive insight into the factors that affect better decision making (Miller & Byrnes, 2001). Metacognition is the ability to think about one’s own thinking. Studies suggest that children assume all knowledge is certain and can be learned through observation, and a shift towards relativism, believing one’s own perspective is as good as another person, begins to develop in adolescence (Byrnes, 2003).

“Memory is the heart of human intellectual functioning and, consequently, is involved in all processes from perception to reasoning” (Hunt & Ellis, 2004, p. 35). A small amount of memory development studies has been conducted since the early 1990s. Paniak, Murphy, Miller and Lee (1998) studied the logical memory and visual reproduction of adolescents, ages 9-15 year old. They proved that immediate recall of logical memory improved with age, and performance increased on the visual reproduction monotonically from 73% in 9 year-olds to 89% in 15-year-olds (Paniak et al., 1998). Zald and Iacono (1998) studied spatial working memory in 14- and 20 year-olds, showing that it does improve with age. Swanson (1999) found similar results when studying the spatial working memory of those between the ages 6 and 35. Cycowicz, Friedman, Snodgrass and Rothstein (2000) conducted a study to determine if implicit memory would improve with age. Previous explicit memory studies found that it improved with
age (Paniak et al., 1998; Wood et al., 1999). Cycowicz et al. (2000) found that the implicit memory of 15 year-olds is similar to the performance of adults; therefore, implicit memory develops with age.

Several studies have shown smaller changes or no change at all in memory development. Keating, List and Merriman (1985) found a reduction in retrieval speed with age. Seamon, Luo, Schlegel, Greene, and Goldberg (2000) found no age differences among 1st grade, 5th grade and college students in identifying pictures. According to Byrnes (2003) and Keating (2004), age differences in memory do not always emerge in comparisons of children, adolescents, and adults. Byrnes (2003) found that several variables seem to affect the size of the age difference. Those variables include whether students have to learn the information during the experiment, retrieve already learned information and the length of the delay between presentation and retrieval.

**Cultural Learning Styles of African American Students**

There are many definitions of creativity. Alane Jordan Starko (2005), a professor and head of the Department of Teacher Education at Eastern Michigan University, believes that in order to be considered creative, a product or idea must be original or novel to the individual creator; the product or idea must be appropriate, meeting some goal or criterion. “Creativity is purposeful and involves effort to make something work, to make something better, more meaningful, or more beautiful” (Starko, 2005, p. 7).

Each culture has different sets of standards for creative activities. In the engineering culture, the creativity is measured by patents, inventions, publications, and funding support. The adult engineering standards are not suitable for young people interested in the discipline. “If students successfully communicate an idea or endeavor to solve a problem, in their own way, we can consider them creative” (Starko, 2005, p. 7). Students need an opportunity for creative
thinking, and the traditional classroom does not support creativity (Starko, 2005; Shade, 1990, 1994; Boykin, 1994a).

Evidence exists that there are differences in creativity amid cultures that can help students learn. It has been found that students are successful in the classroom when school activities include these differences (Boykin & Bailey, 2000; Boykin & Cunningham, 2004). “In classrooms that build on these cultural strengths, students not only have more opportunities to be creative, but they may also be more academically successful” (Starko, 2005).

The dominant culture in the United States can be characterized by the Western European culture, thus the classroom as well. According to Anderson (1988), the Western European culture has the following worldviews: individual competition, achievement for the individual, master and control nature, time is rigid and scheduled, limit affective expression, nuclear family, dualistic thinking, and religion distinct from culture, feel their worldview is superior, and task oriented. Anderson (1988) and Shade (1982, 1986) also state that the Western cognitive style reflects those who are field independent, analytical, perceive elements as separate from their background, and believe their performance is not greatly affected by the opinions of others. The aforementioned characteristics in the classroom can be very hostile to culturally diverse students. The classrooms include many students from different cultures, so teaching should reflect those cultures.

Culture is defined as a set of beliefs, values, traditions, and customs of a particular group. “These beliefs, values and traditions serve as the lenses through which African American students view themselves and others” (Moore, Ford & Milner, 2005, p. 3). A group’s cultural differences can account for different views about cooperation versus competition, about nuclear versus extended family structures, about communicating verbally versus nonverbally, about
being monochromic versus polychromic and more (Moore et al., 2005). Different cultures could also possibly view a number of variables differently, including showing emotions, asking questions, handling conflict, solving problems and personal space (Shade, Kelly & Oberg, 1997; Storti, 1989). “Clearly understanding how an individual’s culture operates and the relation of that culture to an individual’s orientations and choices may help us understand how culturally diverse students approach learning and achievement” (Moore et al., 2005, p. 3).

Nobles (1980) propositioned that there is a unique cultural ethos, with regards to African Americans, that conflict with the culture of mainstream America and its schooling. Nobles (1980) describe the Black cultural ethos as a derivation of West African beliefs, values, and traditions and, in spite of the immense variability among African Americans as a group. It characterizes the way African Americans perceive, interpret, and interact with the world (Parsons, 2003).

A. Wade Boykin (1986, 1994b), director of the Center for Research on the Education of Students Who Are Placed at Risk (CRESPAR), supported Nobles’ (1980) research and identified nine cultural styles, or his Afrocentric Model of Learning, manifested in the learning preferences of African American children: harmony, spirituality, movement, verve, oral tradition, expressiveness individualism, affect, communalism, and social time perspective. Harmony refers to versatility and wholeness, the ability to read the environment well and to read nonverbal behaviors proficiently (Moore et al., 2005). Moore et al. (2005) stated that harmony explains why students, who feel unwelcome in their classes, may become unmotivated and disinterested in learning. Spirituality is the belief in an inner strength and that a higher being influence people’s everyday lives. Movement refers to being a kinesthetic learner, the ability to use the
physical body to take in knowledge through bodily sensation. Verve is the need for intense stimulation that is energetic and colorful.

Oral tradition refers to the preference for oral modes of communication. Expressiveness individualism is the need to develop a distinct personality. “Affect refers to an emphasis on emotions and feelings with sensitivity to emotional cues and a tendency to respond emotionally” (Harmon & Jones, 2005, p. 100). Communalism refers to the need for cooperation, interdependence, and communal learning such that competition is devalued. “Hence, students with this learning preference may be unmotivated in highly individualistic and competitive classrooms, preferring instead to learn in groups” (Moore et al., 2005, p. 3). Social time perspective is the view that an event is more important than a passage of time. African-American students may exhibit one or all of these cultural learning styles. “Although Boykin did not specifically describe these as learning style dimensions, they can be observed in children in learning situations, and Boykin did offer strategies for curriculum modifications based on these dimensions” (Willis, 1992, p. 263).

Hale (1982), Jenkins (1982), and White (1984) have suggested that African Americans have a unique cognitive style that influences their participation in the learning process. Shade (1986) defines cognitive style as a culturally induced way in which individuals organize and comprehend their world. Shade (1986) conducted an exploratory study to determine if there was an African American cognitive style as previously suggested. 178 ninth grade students, 92 African Americans and 86 European-Americans, were randomly selected from two urban school districts in Southwestern Wisconsin. Shade (1986) measured three cognitive styles previously suggested by Vernon (1973), who determined that cognitive style is best conceived as a superordinate construct involving perceptual, intellectual, and social domains.
The Group Embedded Figures test was used to measure perceptual style preferences (field dependence/independence); the Clayton-Jackson Object Sorting Task was used to measure conceptual style preferences (reflective/compulsive); the Myers-Briggs Type Indicator was used to measure social interaction style (perception of people). Shade (1986) found a significant difference between two ethnic groups, Afro-Americans and Euro-Americans, on the Embedded Figures and Myers-Brigg Type Indicator tests, p=0.0001 and p=0.025 respectively. According to the researcher, the significant differences suggested that the perceptual process is the primary dimension in which African Americans demonstrate a unique preference. Shade (1986) believed that her findings lead to further studies of cognitive style involving visual information processing.

“Perception depends upon the efficient use of individual modalities to gather and send messages to the brain, so that the brain can search for prior experiences and information that can be used for interpretation and meaning” (Shade, 1994, p. 183). Mangan (1978) argued that individuals learn to perceive within the framework of their culture, thus, different parts of the environment and culture add differential meaning to perceptions. Visual images such as photographs, line drawing and geometric forms have cultural interpretations (Gibson, 1950; Shade, 1990, 1994). As a result, those same photographs and drawings convey different information to various individuals.

Educational psychologist and teacher educator, Barbara J. Shade-Robinson, examined two groups of African American students ages 12-14 in regards to the following perceptual preferences: visual, auditory, and kinesthetic (1983). The first group was tested and responded to a videotape in which an African American announcer pronounced fifty words from the Edmonds Learning Style Identification Exercise (Shade, 1983, 1994). After hearing the words,
the students had to indicate whether the word created a mental picture of the object or activity, a mental picture of the word spelled out, no mental picture only the sound of the word, or created some physical or emotional feeling (Shade, 1983). The results of this study indicated that visual images, auditory, and kinesthetic processing are involved in African American students sensory mechanism for learning; students indicate a preference for visual images on a 2:1 ratio.

The second group of students was asked to indicate the type of strategies they preferred from the James and Galbraith (1985) Perceptual Style Inventory. Visual images included photographs, tables, charts, and graphs. The auditory mode included audiotapes. The social interactive mode included discussions and debates. The haptic mode included drawing, sculpturing, and painting. The print mode included reading assignments. The rank order of learning modes for the second group was: kinesthetic, visual, aural, social, haptic, and print.

Willis (1992) also summarized the observations and theories of several researchers in regards to the learning styles of African American children. According to Willis (1992), African American learning styles can be integrated into four groupings of characteristics:

1. Social/affective: people-oriented, emphasis on affective domain, social interaction is crucial, social learning is common.

2. Harmonious: interdependence and harmonic/communal aspects of people and environment are respected and encouraged, knowledge is sought for practical, holistic approaches to experiences, and synthesis is sought.


4. Nonverbal: nonverbal communication is important (intonation, body language, etc.), movement and rhythm components are also vital.
In *Culturally Responsive Teaching: Theory, Research and Practice* (2000), Geneva Gay argued that in order to improve learning, curriculum content must be meaningful to students. Meaningful is described as relevant curriculum content that “includes information about the history, culture, contribution, experiences, perspectives, and issues of their respective ethnic groups” (Gay, 2000, p. 111). Gay (2000) and Delpit (2006, 2008) support the belief that curriculum should help to assert and accentuate student’s capabilities, attitudes and experiences using their natural settings. Delpit’s (2008) research found that traditional classrooms devalue collaboration and interaction, two characteristics found in communities of color. Ultimately, we will “risk failure in our educational reforms by ignoring the significance of human connectedness” by continuing to ignore the culture of our underrepresented students.

There are many critical opponents to multicultural education. Davidman and Davidman (1994) identified six factors that they believe contribute to the opposition of multicultural education:

1. It weakens the theories and beliefs of those who fight to maintain the existing social order;
2. Offering a new definition of Americans, multicultural education threatens the historical unity of the nation;
3. Multicultural education challenges the belief that the United States is a monocultural society;
4. The theme of equity causes those in power to reduce sources available to ethnic groups;
5. Many researchers believe that multicultural education to be antiracist, and find it difficult to embrace;
6. Educators are unsure how to implement multicultural education in their classrooms causing critics to view it as a weakness. Many curriculum theorists oppose multicultural education. Gay (1994) describes the works of Chester Finn, Dinesh D’Souza, Diane Ravitch and William Bennett, traditional essentialists, as being major opponents of multicultural education. Collectively, they oppose multicultural education because they believe it contradicts the basic purpose of schooling in the United States, which is to teach skills that help students to participate in the shared national culture and to ensure national unity. Multicultural educators simply want to validate the personal experiences and heritages of underrepresented students to optimize their learning, combating the stereotypical ideas of who they are.

Traditionally, engineering classroom instruction follows essentialism. Essentialism is defined as learning through traditional methods of rote memorization and carrying out classroom activities in a standardized mechanism. According to multiculturalists and human constructivists, people learn in varying styles and their cultural surroundings help them to make meaning of and connections to past, present and future knowledge. This research demonstrates how culture can be infused in what has been traditionally viewed as a discipline of essentialism. The curriculum created throughout this research effectively and clearly connects an innovative way of learning with conventional topics.

**Urban Science Education: Cultural Awareness in Science**

As stated in the previous chapter, equity has been the core message for national science education support. *A Nation at Risk* (National Commission on Excellence in Education [NCEE], 1983) states foreign countries were beginning to overpower the United States in STEM disciplines and production. But our concern goes beyond commercial industry and business; it
extends to what *A Nation at Risk* (NCEE, 1983) calls the new raw materials of intellectual commerce: knowledge, learning, information and skilled intelligence. When individuals are science illiterate, lacking the above attributes, they are unable to have full participation in all aspects of life (i.e., they are unable to solve basic scientific household problems, participate in basic scientific conversation, unable to help others, etc.). Knowledge is truly powerful and lacking STEM knowledge in a STEM driven society, renders you powerless.

*A Nation “Still” at Risk: An Education Manifesto* (Allen, 1998) provides a sound argument supporting the existence of inequitable science education for American students. Almost fifteen years after the initial report, Allen (1998) discusses the following:

A dual system, separate and unequal, is being created, almost 50 years after it was declared unconstitutional. Equal educational opportunity is the next great civil rights issue. By this is meant the true equality that comes from providing every child with a first-rate elementary and secondary education, and to the development of human potential that comes from meeting intellectual, social and spiritual challenges. (p. 6)

The inequalities that exist within our STEM disciplines are staggering, especially in the American urban cities. Ethnographic research produced by Tobin (2000) suggests that a crisis exist in urban high schools because we are struggling to provide quality education due to budget cuts and qualified teacher shortages. Our urban students attend schools where the ceilings are caving in, the restroom facilities are in deplorable conditions and textbooks are outdated. The physical environment alone creates a sense of hopelessness and lack of self worth. Due to lack of funding, science education is typically the first core subject to suffer in urban schools. STEM education requires the use of fairly expensive materials and resources and qualified educators who are fluent in STEM. According to the 2000 U.S. census, about 75% of the U.S. population lives in urban areas. Millions of students are suffering from inequitable STEM learning environments because urban schools typically mirror their urban environments.
According to Barton (2001) there are several key factors that characterize urban areas and affect the quality of STEM education: home to large numbers of ethnic minorities, home to immigrant families. Poverty is also a key issue, and poverty disproportionately affects urban minorities, particularly African American and Latino/Hispanic children. According to the 2006 American Community Survey (ACS), African Americans make up 12.3% of the total United States population and 20.95% of the Southern states population. In the state of Louisiana, African Americans are the largest minority group at 32.5%; Baton Rouge has 32.4% and New Orleans has 37.5% of African Americans (2000 U.S. Census). Barton (1998, 2001, and 2003) believes that in order to understand and eventually change urban science education, we have to look at it from a critical and political perspective.

What are some of the reasons urban environments are faced with such struggles? Racial, class, and gender equity are critical reasons given for poor urban science education conditions (Barton, 2001; Ferreira, 2002). Barton (2001) also believes that the greatest struggle lies within class. If the urban community has less money, less access to better schools and academic programs, inequalities in academic achievement, resources and the culture of schools will continue to produce STEM illiterate citizens. Therefore, unequal education for all will continue to be a problem.

It has been widely publicized that children of all ages in poor urban areas typically score much lower on standardized tests across all academic subjects. The Trends in International Mathematics and Science Study (TIMMS) (NCES, 2001) not only showed that Americans are lagging behind, but the disaggregation of scores by race in the United States is alarming. Berliner (2001) analyzed TIMMS data and showed that there are two Americas, urban and suburban.
Only one nation, Singapore, beat 14 states in 4th grade and eighth grade science and mathematics assessments. Berliner (2001) made the following statement,

> Do we know where we have failing schools? You bet we do! The TIMSS-R tells us just what is happening. In science, for the items common to both the TIMSS and the TIMSS-R, the scores of white students in the United States were exceeded by only three other nations. But black American school children were beaten by every single nation, and Hispanic kids were beaten by all but two nations. A similar pattern was true of mathematics scores. (p. B3)

Urban students are unable to compete country- or nation-wide due to lack of various resources. Resources include materials, human capital, and extracurricular activities. Oakes (1990) reported that children attending poor urban schools lack updated books, scientific equipment, and extracurricular science activities such as clubs or competitions, all of which are necessary objects that foster a nurturing STEM environment. Darling-Hammond (1999) found that the total number of uncertified and unqualified science teachers outweighs the total number of certified and qualified teachers from all disciplines in New York City and Los Angeles school districts. Certified and qualified teachers bring an assurance of proper STEM information being relayed to students. This unbalance also decreases the ability to offer high level math and science courses.

A major overwhelming inequality that decreases the likelihood of success in STEM education in urban environments is what Barton (2001) calls the culture of schooling. The cultural differences between school and home cause major conflict in learning. Historically, public school culture would mimic upper-middle-class values and ideas, and students who deviate from the norm were viewed as being less worthy than their counterparts (Rothstein, 1993). Major cultural differences exist between the students and teachers and the curriculum. People who want to be teachers generally do not mirror, socially and ethnically, the students they are eventually going to teach.
As an instructor of Critical Issues in Secondary Science Education at Louisiana State University, 90% of the researcher’s students were Caucasian and from upper- to middle-class backgrounds. A major topic in the course was Urban Education, but students viewed the topic as a means to behavioral/classroom management instead of a way to understand and relate to the students they were soon to be educationally responsible for. “Teachers need to understand the socioeconomic conditions that are most prevalent in urban schools in order to adjust and design teaching and learning to effectively meet the needs of the diverse populations” (Kopetz, Lease & Warren-Kring, 2006, p. 36). Understanding and Educating African American Children (2004) reiterates that urban children need teachers who have been trained in diverse, multicultural settings so a learning or personal disconnect may not exist between teachers and students.

Schools’ STEM curriculum creates a greater gap between urban students and STEM. In learning settings that serve culturally and linguistically diverse populations, students will benefit best from coursework that relates to their world. Schools are in communities but often not of communities. That is, teaching and learning are often disconnected from the day to day life of the community, and students’ do not see how the skills they acquire in school have currency in business, at home, and in other communities beyond school. (Bouillion & Gomez, 2001, p. 880)

STEM teaching and learning research suggests that minorities struggle in STEM subjects because they fail to find the relevance in the culture and practice of science in the classroom and the world (Atwater et al., 1999; Barton, 1998). If you live in a culture that is surrounded by concrete buildings and high volume traffic, you will have a better chance of making meaningful connections with a science curriculum that infused those facts and applies those facts to solve real-world problems. Bouillion and Gomez (2001) demonstrated the success of connecting school and community with science learning and observed that the disconnect lead to students
perceiving school learning separate from life learning. The success stemmed from the idea and implementation of bridging contextual scaffolds known as mutual benefit partnerships. Along with a school-community business partnership, the students sought out to solve a real-world problem that existed in their community through problem based learning.

Infusing the students’ community into a STEM curriculum, involves adding the important concept of cultural capital. Cultural capital includes “material artifacts that surround us,… social behavior, language, commonly held values, ethics, moral codes and socially ratified goals, aspirations and beliefs, and other factors that combine to constitute a cohesive, recognized group’s cultural identity” (Tobin et al., 2001, p. 942). The phenomenology, or lived experiences, of children’s lives play an inherent role in improving cognitive functions (Bouillion & Gomez, 2001).

Connections or learning blocks are continuously built when our own personal lives and community are imbedded within school-learning. “Culturally relevant pedagogy is the best means of achieving successful teaching and learning with urban children” (Kopetz et al., 2006, p. 43). Educators, organizations and sources of higher learning have been breaking the inequity cycle in STEM education by providing supplemental STEM programs.

**Supplemental Science and Engineering Programs**

Research findings have shown that students do not receive adequate STEM instruction and learning in their schools. Therefore, the function of informal settings in making science appealing to youth and ultimately providing a better understanding has become widely recognized, utilized and appreciated (Jones, 1997). Over the past several decades, science and engineering programs sponsored by universities, non-profit organizations and other educational entities, have become increasingly popular for addressing achievement and STEM access gaps to
those less fortunate (Carnegie Council on Adolescent Development, 1997; Griffin, 1993; Halpern, 2002). Also noted by Jones (1997), informal settings make STEM accessible and provide multidimensional opportunities for learning. Those needed opportunities supply participants with various avenues, motives, and tools to investigate STEM topics of interest to them (Atwater et al., 1999; Bell et al., 2003; Bouillion & Gomez, 2001; Knox, Moynihan, & Markowitz, 2003; Richmond & Kurth, 1999).

“Claims vary as to the effectiveness of these efforts in regards to raising test scores, increasing high school graduation and college matriculation rates, and reducing school drop-out rates and crimes” (Rahm, Moore & Martel-Reny, 2005, p. 1). Studies have also examined the detailed reasons behind the success of such programs, moving beyond the usual quantitative statistics and towards qualitative findings (Rahm et al., 2005). Several researchers have documented the success of programs, such as changes in scientific knowledge, interest, attitudes, and confidence in science, as well as career trajectories, while being vague regarding the actions leading to successful outcomes (Atwater et al., 1999; Fadigan & Hammrich, 2004; Hofstein, Maoz, & Rishpon, 1990).

The Government Accountability Office (GAO) identified 207 separate STEM education programs administered by 13 federal agencies and totaling $2.8 billion in federal funding. The Department of Education’s Institute of Education Science’s What Works Clearinghouse thoroughly reviewed 75 middle school mathematics programs and determined that only three had strong evidence of effectiveness (U.S. Department of Education, 2007). The clearinghouse typically found that most programs lacked the evidence necessary to determine their effectiveness. In 2006, the ACI was charged with evaluating the effectiveness of current STEM education programs. According to the Report of the Academic Competitiveness Council (2007),
very few researchers provide an in-depth vision to their efforts and greater understanding to the mechanics behind the scenes of their respective programs.

Many of the programs researched for this study used traditional hands-on and inquiry based learning. There are a variety of definitions for hands-on learning. Hands-on learning is learning by doing, an activity based approach. Rutherford (1993) defines hands-on learning by having students manipulate the things they are studying – plants, rocks, insects, water, magnetic fields – and handle scientific instruments – rulers, balances, test tubes, thermometers, microscopes, telescopes, cameras, meters, calculators. In a more general sense, it means learning by experience (p. 5)

The National Research Council (2000) defines inquiry as activities that involve students to make observations, pose questions, perform research through literature, gather and analyze data, and answer those previously designed questions. Inquiry based learning allows students to become scientists and experience every aspect of the involvement of the scientific process. Inquiry and hands-on learning are deeply embedded within one another; one cannot be done without the other. Take, for instance, an afterschool science program in California where the theme "community unity" entailed activities such as the planting and maintaining of a community garden and the starting of a recycling program, among other non-science-related activities (Bergstrom & O’Brien, 2001). The participants of the program worked diligently to build a garden and design a recycling plan through the NRC (2000) defined inquiry method. This inner city youth gardening program focused on youth development and entrepreneurship rather than a pure STEM focus. Within such programs, science is typically a tool for action and hence, youth rarely think of themselves as doing science (Lawson & McNally, 1995; Rahm, 2002).

The Young Scholars Program (YSP) is a 6-year pre-collegiate STEM program at The Ohio State University. The purpose of YSP is to expose disadvantaged, minority students to various types of engineering and science fields/disciplines. The current YSP initiative “is
conceived as an attempt to recontextualize their experiences by dramatically changing the nature of their traditional science experiences” (Jones, 1997, p. 664). The curriculum of YSP focuses on making STEM personally and culturally relevant to the target audience through aesthetic and kinesthetic experiences. The science done in YSP is typically defined and often aligned with the critical science definition laid out by Barton and Osborne (2001), which acknowledges its social, cultural and political nature along with the traditional composition.

The Life Sciences Learning Center at the University of Rochester School of Medicine and Dentistry has several science summer and winter programs that also use the hands-on and inquiry-based learning methods as well as problem-based learning to enhance science literacy and skills. Summer Science Explorers: CSI is the middle school program that focuses on placing participants in the daily life of STEM researchers. Students use laboratory equipment, library research, field trips and student-scientists collaboration to solve crimes, medical cases and perform new and groundbreaking research (Knox et al., 2003). According to Knox et al. (2003),

Summer science programs held in university research facilities provide ideal opportunities for pre-college students to master new skills and renew, refresh, and enrich their interest in science. These types of programs have a positive impact on a student’s understanding of the nature of science and scientific inquiry and can open a youngster’s eyes to the many possible career opportunities in science. (p. 471)

Finally, a number of afterschool and community science programs emerged that targeted specific groups of inner city youth and examined the question of what science education for all truly means (Barton, 1998). For instance, the development of an afterschool science club in a homeless shelter by Barton and associates (1998) was initiated to develop community science projects together with youth. It led to much insight into ways low income inner city youth construct science. In essence, youth relied much on their own intuitive understandings of the world and their creativity, along with some expert knowledge to resolve issues they deemed
pertinent, such as restoring a polluted lot next to the shelter with the goal of improving life in their community (Barton, 2003).

As this brief review makes apparent, there is a vast array of afterschool and community science programs, some of which are specifically designed for science literacy development and increasing the number of science graduates from underrepresented groups (Atwater et al., 1999). It is clear also that as a group, low income urban youth still have fewer opportunities than do their affluent peers to participate in quality science clubs and afterschool and summer science programs (Larson & Verma, 1999; McLaughlin, Irby, & Langman, 1994).

**Human Constructivist Learning Theory**

*Teaching Science for Understanding* (Mintzes et al., 2005b) and *Assessing Science for Understanding* (Mintzes, Wandersee, & Novak, 2005a) focuses on a series of promising new intervention strategies and assessment techniques based on a Human Constructivist view of learning and understanding science. Traditional teaching strategies in education, especially science education, have been centered on a strengthening mental disciplines or rote learning techniques, instead of strategies that enhance conceptual understanding of scientific concepts.

This section will describe a proven theory and practice to learning science that is the totally opposite of rote learning, the Human Constructivist view of meaningful learning. Building heavily on David Ausbel’s assimilation theory of meaningful learning, Joseph Novak developed the Human Constructivist view of learning (Mintzes et al., 2005b). In order to understand the foundations of Human Constructivism, Ausbel’s theory will be explained first.

Meaningful learning is the *assimilation* of new information into existing knowledge frameworks (Mintzes et al., 2005b). For this process to occur, three criteria must be met:
1. The material must have potential meaning to the learner. The scientific and engineering interests of students differ according to their ethnic background and in order to retain the learned knowledge, the material needs to be connected (Catsambis, 1995). Carter G. Woodson (1933) said, “It is merely a matter of exercising common sense in approaching people through their environment in order to deal with conditions as they are rather than as you would like to see them or imagine they are” (p. 3).

2. The learner must already possess relevant concepts to anchor new ideas. Novak (1984, 1990, and 2002) defines concepts as perceived regularities in events or objects, or records of events or objects. Underserved students are filled with scientific concepts that they have witnessed in their urban environments. Ausbel would say that the most important single factor influencing learning is what the learner already knows; if we can discover that, we can teach them accordingly (Mintzes et al., 2005b).

3. The learner must voluntarily choose to incorporate the new knowledge in a non-verbatim fashion. Knox et al. (2003) discovered that when students are provided the opportunity to learn non-traditionally, in a non-traditional environment, they are more susceptible to new ideas, therefore increasing their knowledge and skills. Novak and Canas (2007) believed this is the one condition over which the teacher has indirect control, the choice of instructional strategies and assessment strategies that foster meaningful learning.

When these requirements are not met, rote learning occurs (Mintzes et al., 2005b).

Rote learning is a technique that involves memorization of facts through repetition. Students who learn by rote memorization tend to gather isolated facts or ideas instead of a well-built hierarchy of frameworks, therefore, not gaining a full understanding of concepts. Students
who study STEM disciplines do not benefit from rote learning because STEM concepts need to be applied and used to solve real-world problems. It would be detrimental to society and human life if a biomedical engineer designed prosthetic heart valves on the basis of isolated anatomy and tissue mechanic facts. For these societal reasons alone, “meaningful learning is generally more productive unless the goal is to retain and retrieve verbatim knowledge” (Mintzes et al., 2005b, p. 39).

According to Ausubel (1968) the assimilation theory of meaningful learning can be further explained by four basic principles: subsumption, obliterative subsumption, superordinate learning, and integrative reconciliation. These four cognitive processes are necessary in the course of remediation of Limited or Inappropriate Propositional Hierarchies (LIPH) (Novak, 2002). Much of the theory of learning can be explained in subsumption, existing concepts are subsumers of new concepts. The existing concept provides a base linkage between the new information, which is more specific and less inclusive, and previously acquired knowledge, which is more general and inclusive. An example of this concept is when a student learns Newton’s Laws of Motion and understands how they apply to car crashes. Subsumption results in a steady increase of domain-specific knowledge (Mintzes et al., 2005b).

The limitation to subsumption is obliterative subsumption. Ausubel (1968) defines the process of repeated subsumption as obliterative subsumption. Obliterative subsumption occurs when learning results in an important change of concept meanings over time, inhibiting recall of previously learned, less inclusive knowledge. Although more powerful learning enhances robust frameworks, failure to retrieve specific, less inclusive concepts can cause the learner to not have the full understanding of the concept, including right and wrong (Mintzes et al., 2005b).
The third learning process, superordinate learning, results in significant reorganization of cognitive structure which can produce creative, insightful, “ah-ha” moments when new concepts are constructed that pull together and integrate larger domains of knowledge not previously recognized (Ausubel, 1968). *Teaching Science Understanding* (2005) uses the example of when students first learn that gravity explains much about the behavior of falling bodies, the students now think about that behavior with new insight and creativity.

Novak (2002) describes integrative reconciliation as the “form of meaningful learning where concepts or propositions in two somewhat different knowledge domains are seen as clearly similar and related, or clearly different and unrelated” (p. 558). Many natural science concepts have very similar meanings and can easily confuse students who learned them by rote memorization. Meaningful learning allows students to develop well-integrated “knowledge structures that enable them to engage in the type of inferential and analogical reasoning required for success in natural sciences” (Mintzes et al., 2005b, p. 41).

Human Constructivism encompasses both a cognitive theory of learning and an epistemology of knowledge building to enhance understanding and conceptual change in the science classroom (Mintzes et al., 2005b). Hewson, Beeth, and Thorley (1998) define conceptual change as learning that changes as existing belief, idea or way of thinking. “Conceptual change, or more accurately conceptual reconstruction, requires meaningful learning to modify Limited or Inappropriate Propositional Hierarchies (LIPH)” (Novak, 2002, p.548). Novak (2002) defines LIPH’s as misconceptions that arise from an improper or incomplete hierarchical level of thinking.

Novak suggests, according to Mintzes et al. (2005b), there are three assertions fundamental to human constructivism:
1. Human beings are meaning makers. With use of existing knowledge, humans form connections with new concepts.

2. The goal of education is the construction of shared meanings. The classroom is filled with different cultures, backgrounds, and opinions; education should attempt to link those differences through negotiations. Human Constructivists use the term negotiate not to mean compromise, but as an “ongoing struggle to construct robust, heuristically powerful explanations” in regards to the science being learned (Mintzes et al., 2005b, p. 50).

3. Shared meanings may be facilitated by the active intervention of well-prepared teachers. In order for teachers to be the “middlemen” of dynamic constructions, they have to be well-versed in strategies that promote understanding and conceptual change. Osborne and Wittrock (1983) proposed the Generative Learning Model (GLM) to assure conceptual change will occur. GLM suggests that teachers must determine the student’s ideas before instruction begins, facilitate that exchange of views between student and challenge students to compare ideas amongst each other (Osborne & Wittrock, 1983).

According to Novak (2002), creating new knowledge is a form of meaningful learning that does not differ from individual to individual or novice to expert. In How People Learn (2000), the authors found that experts have acquired extensive knowledge that affects what they notice, how they organize, represent, and interpret information. Bransford, Brown, and Cocking (2000) imply that the study of expertise shows what the results of successful learning should resemble and the Human Constructivism view supports this implication.

Cognitive scientists have explored the knowledge structures of novices and experts in science (Chi, Glaser, & Farr, 1988), and according to Bransford et al. (2000), there are several
key principals of expert knowledge: experts notice features and meaningful patterns of information that are not noticed by novices; experts have acquired a great deal of content knowledge that is organized in ways that reflect a deep understanding of their subject matter; experts knowledge cannot be reduced to sets of isolated facts or propositions but, instead, reflects contexts of applicability, the knowledge is conditional on a set of circumstances; experts are able to flexibly retrieve important aspects of their knowledge with little effort.

Novak (1993, 1998) supports the ideas in *How People Learn* (2000) and argued that meaningful learning is accomplished best by those who have a well organized knowledge structure, thus becoming an expert in their perspective fields; key to expert performance lies in the organization of the expert’s domain knowledge (Mintzes et al., 2005a).

Human Constructivism attempts to help students organize their learning according to key concepts in a hierarchical, integrated manner. All humans, whether you are a toddler who is learning how to walk or a scientist discovering DNA, you have constructed meaning by forming connections based on some sort of existing knowledge. Meaning making starts with less inclusive concepts and it experiences restructuring which results in conceptual change. That conceptual change produces a strong hierarchy of cohesive interrelated concepts, a conceptual framework (Mintzes et al., 2005b). The total view of Human Constructivism embodies quality over quantity, meaning over memorizing and understanding over awareness. In *Teaching for Understanding* (2005), the authors have provided many theory-driven strategies and methods that teachers should utilize based on the Human Constructivist view. Below you will find several descriptions of teaching and assessment strategies that will be applied to the proposed pre-college engineering curriculum.
**Hypermedia.** As a student on all academic levels, creating my own personal artifacts for assignments has always been a beneficial learning experience because I learned more by constructing the product, preparing to present the product and presenting the product to my colleagues. At each level of construction, I was able to correct misconceptions and mistakes and promote understanding by demonstrating knowledge gained. Spitulnik, Zembal-Saul, and Krajcik (2005), introduced the use of hypermedia in the classroom and its connections to Human Constructivism. Hypermedia is a technical document that contains text, graphics, animations, video or sound hyperlinks that connect to other documents (integrating technology and digital media in the classroom). Research on the use of artifacts in the classroom has proven that they assist students in promoting and constructing understanding, as well as serve as external representations of that emerging understanding.

The author argues that artifact building engages students in selecting and organizing concepts, representing those concepts and developing connections among them (Mintzes et al., 2005b). Hypermedia helps students build rich conceptual understanding by working with and synthesizing ideas, facilitating the development of meaningful understanding. According to Spitulnik et al. (2005), the steps students take to construct artifacts, organizing and synthesizing information from various sources, designing the artifact, and representing the information through the technology chosen, help the student to integrate new information into existing knowledge. Physically building the artifact that describes the forces that affect the design and movement of an airplane can allow students to create thoughtful connections and construct meaningful relationships among various representations of those scientific forces (Novak & Gowin, 1984).
By constructing the connections among their explanations in the scientific representations, Hypermedia can also show how the students’ misconceptions turn into developed understanding. Through each draft of the artifact, students revise their ideas and their understanding of the scientific ideas. Each revision, whether due to correcting misconceptions or a change in aesthetic design, contributes to the development of understanding over time (Spitulnik, 1995). Those conceptual changes help the students to develop stronger conceptual understanding.

**Concept Mapping.** Concept Maps is a theory-driven graphic organizer proposed by Novak and Gowin (1984) that supports the constructivist learning perspectives, promoting meaningful learning, as a way of organizing and representing knowledge. Concept maps were originally devised as a way to represent large amounts of knowledge and understanding of concepts changes in interviewees of a 12-year longitudinal study (Novak & Musonda, 1991). According to Novak and Gowin (1984) concepts maps were intended to “tap into a learner’s cognitive structure and to externalize, for both the learner and the teacher to see, what the learner already knows” (p. 40).

Concept maps represent knowledge structure before and after instruction, and they are a useful tool to help students move from rote learning to meaningful learning (Novak, 1990). Students construct maps in which they hierarchically ordered and connect concepts using linking words producing a framework of knowledge. Concept maps help students to portray their knowledge as an integrated framework instead of isolated facts. Novak and Canas (2007) believe one of the reasons concept mapping is so powerful for the facilitation of meaningful learning is that it serves as a kind of template or scaffold to help to organize knowledge and to structure it, even though the structure must be built up piece by piece with small units of interacting concept and propositional frameworks. (p. 7)
Concept Maps are a two-dimensional, visual representation of a set of concepts related to a particular subject matter, a domain of knowledge (Mintzes et al., 2005b). The concepts, defined earlier as a perceived regularities in events or objects, or records of events or objects, are arranged hierarchically with the superordinate concept at the top of the map. Novak and Canas (2007) instruct that a good way to define the context of a concept map is to construct a focus question that the concept map will clearly answer. The next step is to identify the set of key concepts that apply. Usually 15 to 25 concepts are sufficient to begin to resolve the question (Novak & Canas, 2007).

The concepts are enclosed in circles and boxes, and the relationships between each concept are shown by connecting lines. The connecting lines are labeled with connecting words that form propositions that unite the concepts. “Propositions are statements about some object or event in the universe, either naturally occurring or constructed. Propositions contain two or more concepts connected using linking words or phrases to form a meaningful statement” (Novak & Canas, 2007, p. 1). Trowbridge and Wandersee (2005) provide instructions to aid in the construction of concept maps, as shown in Table 1. An example of a concept map is shown in Figure 3.

Novak (2002) states that as

Meaningful learning proceeds, new concept meanings are integrated into our cognitive structure to a greater or lesser extent, depending on how much effort we make to seek this integration, and on the quantity and quality of our existing cognitive structure. (p. 551)

Concept mapping allows students to visually integrate new facts, theories and ideas. Students can visualize the interconnections between concepts and construct new meanings that include their feelings and cultural content. Concepts and the structure of the map can include “emotional connotations associated with the concepts, derivative in part from the experiences,
and the context of learning during which the concepts were acquired” (Novak, 2002, p. 551). Research on how African Americans learn includes the concept that emotional connotations, along with cultural aspects, are imperative to the learning and understanding of forming new knowledge (Moore et al., 2005).

Concepts should also be supported with examples and pictures when available to enhance understanding. Gaines and Shaw (1995) proposed that concept maps be regarded as basic components of hypermedia systems, complimenting the text and images with diagrammatic maps.

Hypermedia and concept maps are both visual languages that provide a different type of learning and communication of knowledge. Figure 4 depicts an image of combined hypermedia and concept map tools created by software developed by the Institute for Human and Machine Cognition.

If your teaching style reflects the Human Constructivist view of learning science, then your assessment strategies should reflect that view. Concept Mapping is also a great tool for assessing the understanding of science (Mintzes et al., 2005a; Ruiz-Primo & Shavelson, 1996; White & Gunstone, 1992). Concept mapping provides teachers with an avenue for developing insight into student understanding over time and it helps to identify errors and misunderstandings (Mintzes et al., 2005a). It can be used for formative (improve the process of learning and teaching) and summative (make judgments about learning outcomes) assessment purposes (Mintzes et al., 2005a). Concept map test can be administered several ways eliciting evidence of a student’s conceptual knowledge. Ruiz-Primo and Shavelson (1996) reported approximately 21 different types of tasks that can be given to students in the form of concept map tests. They include instructing the student to: construct a concept map with a number of concepts provided,
### How to Construct Concept Maps

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<tr>
<td>1.</td>
<td>Select ~1-12 concepts from the science content material being considered</td>
</tr>
<tr>
<td>2.</td>
<td>Write each concept on a separate note card. Lay these cards down on a large sheet of paper.</td>
</tr>
<tr>
<td>3.</td>
<td>Select a superordinate concept to be placed at the top of your map. This is the organizing concept for the map.</td>
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<tr>
<td>4.</td>
<td>Arrange the other concepts in a distinct hierarchy under the superordinate concept. The concepts should be arranged from general to specific, in levels from top to bottom of the map.</td>
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<tr>
<td>5.</td>
<td>Once the concepts have been arranged, draw lines between related concepts and label each linking line with words that characterize the relationship between those concepts.</td>
</tr>
<tr>
<td>6.</td>
<td>If you wish to cross-link two concepts in different branches of your map, use a dashed line and label their relationship by writing on the linking line.</td>
</tr>
<tr>
<td>7.</td>
<td>If you wish to provide examples of certain concepts, enclose these in broken ovals.</td>
</tr>
<tr>
<td>8.</td>
<td>Examples should be connected to their source concepts by an labeled linking line.</td>
</tr>
<tr>
<td>9.</td>
<td>Review and reflect. Once you are satisfied with the concept map’s revised arrangement, redraw the map in final form.</td>
</tr>
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Figure 3. Concept map representing the understanding of why we have seasons.²

construct a concept map with no concepts provided, fill-in a map with/without provided concepts, develop an essay based on a pre-constructed concept map, and use a computer to complete and/or organize a concept map.

Assessments are used in all facets of life (school, job, etc.) and are needed to gauge the degree of a person’s competence and understanding. Many studies have been conducted on the pros, cons and effectiveness of assessment strategies, and it has been determined that high quality assessment can facilitate high learning and poor assessment can facilitate and hinder and reward poor performance (Mintzes et al., 2005a).

*Assessing Science Understanding* (2005) has suggested that the quality of an assessment strategy is measured by how well it reveals a student’s understanding and conceptual change.

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Teaching Science Understanding (2005) suggests the Human Constructivist view of how to learn science and suggests teaching strategies that support that view. Learning, teaching and, assessment strategies must be built upon a strong, intellectual theory that enhances human learning and knowledge structure, that theory is Human Constructivism. The Human Constructivist view supports and structures teaching and assessment around the fact that human beings are meaning makers and in the true nature of education can experience shared meanings may be facilitated by the active intervention of well-prepared teachers.

Interactive Historical Vignettes. The art of storytelling has been an educational tool used before people could portray their thoughts on stone tablets or paper. In Western Africa, a griots sole responsibility as a storyteller, perpetuating the oral traditions of family and the village through poems, songs, and dances. Interactive Historical Vignettes (IHVs) allow students to become griots in their own right. IHVs is a strategy that supports the human constructivism theory of learning because they act as cognitive links in a narrative form, allowing students to make connections between knowledge they already know and need to know. IHVs were invented in response to finding a way to incorporate the history science into a curriculum that is overwhelmed with science content (Wandersee & Roach, 2005). Wandersee and Roach (2005) suggests that if you incorporate a carefully chosen “slice” of history, presented in a dramatic, interactive way, to illustrate a single aspect of the nature of science, you have the ability to reveal the stories about quests for knowledge and historical traits. The extracted piece of life demonstrates scientific debates, ideas, decision making, a love for the discipline and sometimes humorous and dramatic facets of a scientist’s life (Wandersee & Roach, 2005).

The stories can trigger the activation of related concepts and thus facilitate the reconstruction of knowledge. The stories griots tell are typically passed down, and each time it is
retold by the griot it carries a deeper meaning. Each time a student retells their scientific stories to family members and friends reflection and discussion will occur, supporting progressive conceptual change. Supporting the conceptual change theory, the IHV strategy is an interactive process in which the learner is actively involved in the revision of their ideas when presented with new information (Wandersee & Roach, 2005)

Wandersee and Roach (2005) suggests the use of the following steps in properly using and implementing the nature of science using IHVs:

1. Read the history of science about the life of the chosen scientist;
2. Choose a pivotal incident, intellectual or behavioral action, in the life;
3. Decide what attributes of the nature of science is conveyed;
4. Write a IHV using the following format:
   a. Introduce the scientist
   b. Describe the context of the incident
   c. Provide options in the story
   d. Describe the final outcome of the incident
5. Write the vignette in docudrama style with a presentation time of 5 minutes or less;
6. Present the IHV;
   a. Present the first three parts;
   b. Then interrupt the story to give students time to decide what choice they think the scientist made and/or what choice would they make;
   c. Tell the rest of the story;
7. Have the class generate and discuss nature of science attributes the IHV taught them.
The history and nature of science in the classroom is essential to meaningful learning and conceptual change. Matthews (1994) concluded that the history of science seeks to humanize the sciences by showing students that science is not performed by robots. The history also seeks to enhance meaningful comprehension of science content by constructing and representing idealized objects. Wandersee and Roach (2005) defines the nature of science as discipline-specific knowledge of the natural objects, events and properties to be studied, the presuppositions and assumptions about them, theories, methods and strategies used in development of them. Interactive Historical Vignettes, when implemented correctly, infuses the nature of science by showing the aforementioned definitions in “little science stories.”

**Visual Spatial Learning Theory**

The Study of Mathematically Precocious Youth (SMPY), currently located at Vanderbilt University and directed by Camilla Benbow and David Lubinski, is a 50-year longitudinal study that researches the optimal development and realization of intellectual talent over the lifespan. SMPY searched for youth who reason exceptionally well mathematically and/or verbally from 1972 through 1980. Gifted students in the seventh and eighth grade participate in talent searches by taking the SAT or ACT, those who score in the top 0.5% are chosen for the program. The SMPY Program provides residential and commuter academic programs in several disciplines to qualified youth at several universities across the country. SMPY provides information about the development, needs and characteristics of precocious youth. The long-term goal of the 50-year study is to characterize the key factors that lead to creative work and/or high, academic achievement, primarily in science and mathematics.

SMPY has published over 300 articles and book chapters based upon their findings. Their research has determined that attention to the unique information afforded by verbal and
quantitative abilities has proven quite useful for purposes of identification and appropriate
developmental placement, providing educational opportunities corresponding with students’
level and pattern of abilities (Shea et al., 2001). Traditionally, those students who do well
verbally tend to gravitate toward the humanities and social sciences; students who are
quantitatively talented lean more toward engineering and the physical sciences (Achter,
Lubinski, Benbow, & Eftekhari-Sanjani, 1999). At some point, especially during the latter high
school career, everyone has determined their collegiate academic interests/careers by asking
themselves what subject they enjoyed the most in high school (Webb, Lubinski, & Benbow,
2007).

Although verbal and quantitative ability measurement has proven to be useful, the
researchers of SMPY suspected that other cognitive abilities might also have an added benefit,
thereby improving educational counseling and appropriate developmental placement for
intellectually talented youth (Humphreys, Lubinski, & Yao, 1993). Prior research conducted on
the structure and organization of human abilities (i.e., human visual system, problem solving,
spatial ability, motor skills, etc.), made aware to the SMPY researchers that there was a
possibility another cognitive ability, spatial ability, was missing from their program studies
(Lubinski & Humphreys, 1990; Shea et al., 2001; Webb et al., 2007). Studies in the early 1990s
regarding predicting group membership through standardized tests from SMPY research revealed
that the physical science and engineering disciplines appear to be losing many talented persons
by restricting assessment to only conventional mathematical and verbal abilities (Humphreys et
al., 1993). SMPY started to test their gifted youth for high visual spatial abilities by using the
Differential Aptitude Test (DAT) Space Relations (SR) and Mechanical Reasoning (MR) to
subtests to test their hypothesis. Currently visual spatial ability is not tested on standardized tests.
Spatial visualization refers to the ability to mentally manipulate 2-D and 3-D figures. An example of spatial visualization would be to identify the letter that results if you rotate the letter “b” on its horizontal axis 180 degrees. An example of a spatial visualization is shown in Figure 5.

*Principles and Standards for School Mathematics* (NCTM, 2000) recommend that 2-D and 3-D spatial visualization and reasoning are core skills that all students should develop. Students in grades 3 through 5 “should become experienced in using a variety of representations for three-dimensional shapes” (NCTM, 2000, p. 168), such as isometric drawings, a set of views and building plans (Christou et al., 2007). Numerous correlation studies have shown that spatial ability is positively related to mathematics achievement (Fennema & Sherman, 1977; Battista, Wheatley, & Talsma, 1989). Howard Gardner, a cognitive psychologist who has done extensive work on intelligence and education, suggests that spatial ability is a skill that will determine how far someone will go in the physical sciences.

In *Frames of Mind* (1983), Gardner defined spatial intelligence as “the ability of forming a mental model of the spatial world and maneuvering and working with this model” (p. 9). Gardner (2006) uses an example of a navigator to provide a depiction of using and having spatial intelligence. “Spatial problem solving is required for navigation and for the use of the notational system of maps. Other kinds of spatial problem solving are brought to bear in visualizing an object from different angles and in playing chess” (Gardner, 2006, p. 14). Maier (1998) developed Gardner’s theory into five branches of spatial intelligence:

1. Spatial perception: the perpendicular and horizontal fixation of direction regardless of troublesome information;
2. Visualization: it is the ability of depicting of situations when the components are moving compared to each other;

3. Mental rotation: rotation of three dimensional solids mentally;

4. Spatial relations: the ability of recognizing the relations between the parts of a solid;

5. Spatial orientation: the ability of entering into a given spatial situation.

The definition of visual spatial ability in regards to engineering students was defined by Sera, Karpati, and Gulyas (2002) as “the ability of solving spatial problems by using the perception of two and three dimensional shapes and the understanding of the perceived information and relations” (p. 19). Sera et al. (2002) approached spatial ability from the type of activity or exercise to be completed. Sera et al. (2002) proposed ten spatial exercises and definitions of those exercises:

1. Projection illustration and projection reading: establishing and drawing two dimensional projection pictures of three dimensional configurations

2. Reconstruction: creating the axonometric image of an object based on projection images

3. The transparency of the structure: developing the inner expressive image through visualizing relations and proportions

4. Two-dimensional visual spatial conception: the imaginary cutting up and piecing together of two-dimensional figures
5. The recognition and visualization of a spatial figure: the identification and visualization of the object and its position based on incomplete visual information

6. Recognition and combination of the cohesive parts of three-dimensional figures: the recognition and combination of the cohesive parts of simple spatial figures that were cut into two or more pieces with the help of their axonometric drawings

7. Imaginary rotation of a three-dimensional figure: the identification of the figure with the help of its images depicted from two different viewpoints by the manipulations of mental representations

8. Imaginary manipulation of an object: the imaginary following of the phases of the objective activity

9. Spatial constructional ability: the interpretation of the position of the three-dimensional configurations correlated to each other based on the manipulation of the spatial representations

10. Dynamic vision: the imaginary following of the motion of the sections of spatial configuration

Nagy-Kondor (2007) used several of the activities developed by Sera et al. (2002) to test 80 students. Nagy-Kondor (2007) researched the spatial ability of first year engineering students based on their fundamental knowledge of descriptive geometry and on the work of Sera and others, and determined their students did not have good spatial ability but the ability could be developed with the help of a visualization skills course and the use of modeling.

Proficiency in visual-spatial ability has been long associated with academic and professional occupations such as architects, scientists, surgeons, graphic design artists, engineers, painters, photographers, surveyors, and all other disciplines/careers that visualize and manipulate
images in their work. Engineers use creativity, technology, and scientific knowledge to solve practical problems. Gary Banta, former CEO and current board member of Stretch, Incorporated, a software configurable processors company, defined engineering is the design, analysis, and construction of works for practical purposes. In order to design any object, the engineer has to be able to see in various dimensions as well as artists and scientists. James Watson and Francis Crick, the biologist and physicist who were credited for discovering the structure of DNA, were able to use spatial visualization in order to build the 3-D model of the double helix.

In Shea et al. (2001), the researchers give several possibilities regarding the lack of assessments for spatial ability: false beliefs that spatial ability is more relevant to the vocational trades than to academic or professional efforts, considering that the academic/professional efforts tend to place a heavy emphases on verbal competence; evidence of the differential and incremental validity of multiple abilities over and above verbal and mathematical abilities has been lacking. Most course pedagogy, grades and academic assessments are saturated with reasoning with words and numbers to indicate accomplishments. Shea et al. (2001) suggest that if students were required to operate more in a spatial environment regarding laboratory work, art and design courses when necessary, there is reason to suspect that measures of spatial ability can greatly contribute to mathematical and verbal reasoning assessments.

Some scholars have expressed the concern about our failure to identify individuals with nonverbal intellectual gifts, possibly those with exceptional spatial ability, causing a disservice to our society due to the decrease of our future scientific, technical, and engineering workforce that is needed to sustain a strong economy, furthermore a high quality of life (Saurino, Saurino, & See, 2002; Shea et al., 2001; Webb et al., 2007). According to the SMPY project at Vanderbilt,
we are currently leaving some of our brightest learners behind in math, science, and engineering (and other artistic disciplines) by not testing for or developing those who are visually inclined.

**Graphic Design Learning Theory**

The researcher designed a middle school pre-engineering program based upon a visual spatial approach, partially focusing on the role of visualization and drawings as tools to understand science using Edward Tufte’s theories on visual explanations. Much of science and engineering, whether in secondary or higher education or professional careers, entails learning, designing and presenting quantitative information from design projects and world changing research to prove a theory or cause-effect relationship. Edward Tufte developed a 4-volume theory of graphical information design complete with the do’s and do not’s on properly depicting data to provide explanations and make critical decisions, while maintaining graphical integrity. Tufte seeks out to make one a better quantitative storyteller. All four books complement each other, reiterating the importance of quantitative storytelling in decision making and explanations. Visual concepts discussed below will be incorporated into my intended program design.

**Visual Display of Quantitative Information.** *The Visual Display of Quantitative Information* (2001) emphasizes how to properly depict pictures of numbers while enforcing statistical honesty. Tufte (2001) argues that graphics are instruments for reasoning about quantitative information; therefore, designing graphics should be practiced with integrity by using theoretical concepts. As early as kindergarten students are required to sort, represent, and use information in simple tables and bar/picture graphs (Louisiana Department of Education Grade Level Expectation D-2-E and D-3-E or GLE 23), but according to standardized test scores in the state of Louisiana, children continue to have trouble understanding mathematical graphics. If students and teachers learn how to reveal data and simplify complex ideas without distortion,
they will be able to effectively interpret the numbers and draw appropriate conclusions. An example of GLE 23 for kindergarteners is shown in Figure 6.

The time-series plot is one of the oldest and most frequently used forms of graphic design showing changing values over time. Tufte (2001) uses a distinguished 1980 New York City weather map to successfully display and clearly organizes a large collection of numbers, makes comparisons between different parts of the data. In order to enhance the use of time-series displays, Tufte (2001, 2006) shows how multivariate data is used to tell a richer story. Adding more spatial dimensions to a time-series display shows that data is actually moving over space and time. As a student experiences more advanced scientific/mathematic principles, the ability to show simple and complex quantitative data visually demonstrates greater understanding of concepts.

Statistical graphical displays are no different than words; they can be used to deceive as well. There are several principles used to ensure graphical integrity including not quoting data out of context, showing and not designing data variation and using clear and detailed labeling to defeat graphical distortion (Tufte, 2001). Data ink, chart-junk, and multi-functioning graphical elements are theories used to describe how to provide powerful and ethical statistical graphics. The theory of data-ink supports the importance of the information that cannot be erased without the loss of data. According to the theory of data-ink, if the ink does not depict statistical information it should be erased; redundant ink should also be erased (Tufte, 2001).

Chart-junk describes the abstaining of effects used to merely take up space and trick the eye. Moiré effect, the grid and the duck are examples of chart junk. Moiré effects are graphical noise that produces the distracting appearance of vibration and movement clouding the flow of information; gridlines tend to clutter up graphics and generate activity unrelated to data; the duck
Figure 6. An example activity of sorting and representing information in tables and bar/picture graphs by kindergarteners.

describes an entire graph that is decorated, the data measurements become design features (Tufte, 2001, 2006). An example of moiré effect and the type of shading that should be used in place of moiré effects is shown in Figure 7. Multi-functioning graphical elements explain that when necessary, ink should serve more than one graphical purpose. Tufte (2001) uses an example of a stem-and-leaf plot. A stem-and-leaf plot creates a distribution graph with the numbers themselves, the data forms the data measure and constructs the grid (Tufte, 2001).
Envisioning Information. How do we portray a multidimensional, dynamic world on paper that is static and flat? Envisioning Information (1990) emphasizes how to properly depict pictures of nouns on paper and the visual strategies to do so. In engineering disciplines, students are always asked to design mechanical, electrical, civil, chemical, and biomedical systems that are multi-dimensional. As a scientists and engineer, I was required often to display 3-D mechanical and static systems, objects and graphs, organs and equipment used to sustain livelihood. I was never required to take a single course (if such a course was available) that laid down the ground work for displaying such information correctly on paper. I was expected instead to depict these images with computer aides only. Tufte (1990) outlines design strategies that sharpen the resolving power of paper and video screens.

What are the options to escape the flatland of 2D paper? All of the worlds that we seek to understand are multivariate in nature. One of the first and direct methods of displaying 3D dimensions is to construct models (Tufte, 1990). Models are 3D alternatives for a 2D, shown in Figure 8, representation of a physical object that can be mechanical or static. In the 1570 edition of Euclid’s Elements, he introduced the making of paper constructions to teach solid geometry (Tufte, 1990).

When building models, whether with paper, or with the use of construction toys like Legos or K’nex, students get the hands-on experiences of designing a multivariate world they are
Figure 8. Depiction of a 2-D triangle and a computer generated 3-D triangle.

studying. Tufte (1990, 1997, 2001) also suggests the use of small multiples to create graphical excellence and provide a 3D understanding of data. Small multiples are a series of graphics, showing the same combination of variables, indexed by changes in another variable (Tufte, 2001). Small multiples allow our eyes to move from one image to the next providing a consistent focus of changes of information or dimensions in graphical composition (Tufte, 1990). If we are envisioning information in order to make decisions or problem solve, we must do our best to envision it in the proper dimensions. Micro/Macro Readings, another option of displaying 3D data on a 2D surface, is often used by civil and architectural engineers.

One of the most used and best design strategies in civil and architectural engineering and graphic design is the use of micro/macro readings. In Micro/Macro Readings, small details accumulate into larger coherent structures, portraying large quantities of data at once (Tufte, 1990). Tufte (1990) uses thermal and electrical conductivity graphs for solid materials. An example of the thermal and electrical conductivity graph is show in Figure 9. Each of these examples contains massive but necessary amounts of information to tell their story. Both graphics report at least 1,000 pieces of information necessary for visitors of a city and engineers who need conductivity numbers for an equation. Visual displays such as micro/macro readings are complimentary to human capabilities of existing and thriving in an information thick world
(Tufte, 1990). But in order to depict massive amounts of information properly, the graphic designer has to know how to layer and separate information and use effective colors.

**Visual Explanations.** *Visual Explanations: Images and Quantities, Evidence and Narrative* (1997) emphasizes how to properly depict pictures of verbs, processing causes and effects in order to reach conclusions and make decisions. Most jobs of scientists and engineers entail determining cause and effect relationships and effective decision-making. Tufte (1997) uses two great scientific and engineering examples to prove that quality of methods in showing data is highly imperative especially when life and death decisions are being made. Because of

![Figure 9. Micro/Macro Readings Graph of Thermal Conductivity of Elements.](image)

John Snow’s, a 19th century British physician, understanding of evidence and his clear logic of displaying them he was credited with finding the mode of communication of cholera. Engineers,

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project managers and government officials were not as lucky, when the wrong decision to launch the space shuttle Challenger was made based on misinterpretations and vague graphic displays, losing seven lives.

Snow used a graphical display that showed locations of water pumps, fatalities, streets, and buildings of London that led him to make comparisons of causes of the spread of cholera by possible infected water pumps (Tufte, 1997). The graphical display allowed him to consider other explanations; assess possible errors due to lack of information on the map such as population density (Tufte, 1997).

The previous stated methods were not followed in the case of the Challenger accident. The engineers who opposed the launch of the rocket due to the prediction that a critical part of the rocket, the O-ring, could fail in extreme temperatures, failed to make a proper and convincing causal graphical argument to NASA officials although the evidence was there. The engineers made the following graphical errors in the initial presentation and congressional presentation: legends were non-existent, chart-junk was present on most of the graphs, graphs lacked causal explanations due to missing temperature values and included irrelevant causes, and redundant data-ink was present along with massive amounts of non-data ink in the form of unnecessary pictures (Tufte, 1997, 2001). An example of the graphical errors presented in the Challenger preparation is shown in Figure 10.

Visual Explanations: Images and Quantities, Evidence and Narrative (1997) has a fascinating chapter called “Explaining Magic.” Explanations of magic, the production of illusions, is an excellent way to make verbs visible (Tufte, 1997). Although magic relies on deception, explaining the acts involves step-by-step demonstrations of the process. The effects of layering and separation (methods widely used in demonstrating magic tricks on paper) are used
Figure 10. The History of O-Ring Damage chart does not report an incident of erosion on an O-ring, which was crucial information in determining the safety of the O-rings.\textsuperscript{5}

to create demonstrations of surgical procedures as well. The exact same techniques can be used when physical demonstrations are unavailable for dissecting animals in school and showing 3D parts and functions of mechanical systems. A familiar method used in learning biomedical

Figure 11. An illustration used to show the human mechanics of walking by use of multiple overlapping images.\textsuperscript{6}

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\textsuperscript{6} Permission has been granted for use of this image.
engineering anatomy and physiology is ghosting of multiple images to demonstrate body mechanics. Ghosting of multiple images entails blurring or overlapping images to track movements (Tufte, 1997). An example of ghosting used by Tufte is shown in Figure 11.

Other design strategies used to predict verbs are parallelism, the use of multiples in space and time and the use of visual confections. Parallelism is another term for before and after pictures displayed side by side (Tufte, 1997). Parallelism allows you to recognize change with active comparison, a method effectively used in the hospitals by doctors who have to view x-rays and other bodily images to determine defects and illnesses. Multiples images in space and time also depict comparisons but they can represent sequences of motion (Tufte, 1997). Visual confections are assemblies of many visual events illustrating an argument, while combining the real and imagined, enforcing visual comparisons (Tufte, 1997).

**Beautiful Evidence.** *Beautiful Evidence* (2006) provides methods for showing evidence and analytical tools that could be used to assess the credibility of evidence. Two techniques that are used to effectively show evidence are mapped pictures and links and causal arrows. Mapped pictures are images of evidence and explanation combining scales, diagrams, overlays, numbers, words, and images (Tufte, 1997, 2006). Links and causal arrows provide direction and connections to multiple sources of data, focus on causality and enhance credibility by directing the story. *Beautiful Evidence* (2006) reminds us to be aware of corruption of evidence. Tufte (2006) introduces the idea of cherry-picking, presenters picking and choosing information that advances their point of view. Tufte (2006) suggests that a clear sign of cherry-picking is that a report appears too good to be true; you should look for imprecise theories and a slack in data.

The 4-volume theory of information provides many techniques for analytically designing evidence and explanations through graphic designs. There are several principles that are stressed
throughout the series to improve any scientist/engineer’s ability to communicate their research, theories and results. These principles and techniques can improve student learning in visual concepts.

**Other Researchers in Visual Learning.** Before Edward Tufte wrote his 4-volume series on visual design, Francis Dwyer, of Penn State University, studied the use of visual materials in the classroom for over forty years. His work primarily focuses on the effective and efficient design, development and use of visualization in learning environments to facilitate achievement of different types of performance outcomes. In his 1972 work, *Guide for Improving Visualized Instruction*, Dwyer presented and summarized the results of over 25 of his visual learning materials research articles. During the time of Dwyer’s research, the use of visual materials to complement traditional classroom instruction became popular at all educational levels (Dwyer, 1972). Dr. Dwyer began to examine the effectiveness of visual learning materials and their modes of presentation especially because the use of the materials began to increase the cost of education.

His research centered on how externally paced visual instruction via slides and television and internally paced visual instruction via programmed and textbook like instruction affected student achievement. Visualizations were used to provide reality to instruction, bring ideas/concepts that were inaccessible, increase student interest and clarify and reinforce oral and printed communication (Dwyer, 1972). One of the major problems with the use of visuals was that they were not produced for instructional purposes. They were produced based on the subjective feelings of the designer, cost, and attractiveness (Dwyer, 1972).

Based on Dwyer (1972), educators made the assumption that the use visualizations in the classroom improved student achievement, but there was no evidence that supported the use of
one type of visualization over the other, nor did they know if instruction complemented by
visualizations were as effective as instruction without visualizations. Professor Dwyer sought out
to establish guidelines for the use of visuals in the classroom that would maximize learning.

Although only a few studies during that time had investigated the effectiveness of visuals,
several researchers developed theoretical orientations regarding the use of visuals, collectively
they are known as the realism theories for visual education (Dwyer, 1972). The basic
assumption is that an increase in realism increases the probability that learning will be facilitated,
thus an increase in achievement (e.g. realistic color photographs facilitate higher learning than
simple black and white line representations of the same object) (Dwyer, 1972). But according to
Dwyer (1972), other researchers argued that black and white line representations provided the
essence of the information to be conveyed, while others argued that the use of color was either
insignificant or significant. Dwyer sought out to clarify previous studies and determine the true
effectiveness of visualizations in the classroom.

In order to establish guidelines for usage of visuals in all classrooms, Dwyer (1972)
asked many questions in a series of experiments. Several of them include:

1. Is the realism theory an appropriate and reliable predictor?
2. Are visuals used to complement verbal and printed instruction increase achievement?
3. Are all types of visuals equally effective? Are identical visuals equally effective
   complementing both oral and printed instruction?
4. Does the method in which the visuals are presented affect the ability of the visuals to
   facilitate achievement?
5. Do visuals increase the achievement for all educational objectives?
6. Is color important?
7. Are different cueing techniques (questions, knowledge of learning objectives, motion) equally effective in complementing visual instruction?

Dwyer (1972) used eight types of visual illustrations pertaining to the anatomy and physiology of the heart to answer the proposed research questions:

1. Oral/Verbal Presentation – students received no visuals of the heart
2. Simple black and white (b/w) line drawings – complemented the verbal instruction
3. Simple color line drawings – complemented the verbal instruction (blue lines on a pink background used to possibly facilitate rapid identification of parts)
4. Detailed, shaded b/w drawings—complemented the verbal instruction
5. Detailed, shaded color drawings—complemented the verbal instruction
6. B/W heart model photographs—complemented the verbal instruction
7. Color heat model photographs—complemented the verbal instruction
8. Realistic b/w heart photographs—complemented the verbal instruction
9. Realistic color heart photographs—complemented the verbal instruction

Dwyer (1972) wanted to evaluate the effectiveness of all the aforementioned illustrations to provide a baseline to make the decision regarding what type of illustration will work the best in the classroom. Over 1,000 high school students and over 5,000 college level students were tested. In each study, each student received a pretest, four individual criteria tests and one total criteria test.

The drawing test emphasis was not placed on the quality of the drawing but on whether or not students knew the specific locations of the parts of the heart; the student was provided with a list of parts and was asked to draw and label a diagram of the heart. The identification test was multiple-choice, and it required students to identify the numbered parts on a detailed
drawing of the heart. The terminology test was designed to evaluate student knowledge of terms. According to Dwyer (1972), the comprehension test was designed to measure whether or not students understood the material enough to apply to various situations of the heart functions. The total criteria test was a compilation of all four tests designed to measure a student’s total understanding. Analysis of Variance and Covariance was used to detect significant differences between the treatment groups’ performance achievement.

Dwyer (1972) studied the effectiveness of visualization in slide and television formats and via programmed and textbook instruction. The slide and television methods were externally paced, controlled by the teacher. Therefore, all students received the same oral instruction and saw the same visual at the same time. In the programmed and textbook instruction research studies, the students were allowed as much time as they wanted to interact with the visuals. The programmed instruction included paragraph type frames with the appropriate visual; the entire booklet contained fill-in-the-blank questions on each frame to encourage student interaction. The textbook studies were much like the programmed instruction, but it did not contain the questions to focus the student’s attention.

**Externally Paced Instruction.** When the use of visuals did improve achievement, the simple illustrations (those with less realistic detail) proved to be most effective mostly on the drawing, identification and total criteria tests. Dwyer (1972) quotes authors who indicated that they believed the addition of relevant stimuli may be limited by the information-processing capacity (memory system) of a human which prevents much of the realistic information from reaching long-term memory. He also quotes other researchers such as Roberts Travers and Jerome Bruner who said that learners do not need highly realistic objects to increase learning because lines bordering the object provide the essence of the information to be conveyed.
Travers (1972) also believed that visual information is stored in an isomorphic form in the brain, therefore, line drawings permitted an individual to organize and remember the information better.

**Internally Paced Instruction.** When the use of visuals did make a difference in achievement, the illustrations containing reasonable to high amounts of realistic detail were most effective. When students are given more time to view and study the more realistic photographs, they were able to mentally process and absorb more information. Therefore, time does matter when viewing information. The author made special mention that the type of visualization found to be most effective depended greatly on the method by which it was presented. In many of the cases in the research, instruction without visuals was just as effective. In most of the studies, students performed statistically better on the comprehension and terminology tests with instruction without visuals.

Tufte complements Dr. Dwyer’s research studies by supporting and proving the “less is more” concept. The work of both Tufte (1990, 1997, 2001) and Dwyer (1972) emphasize that we only need to study and present and view the information most valuable and purposeful during the needed time. If we only need to focus on the valves of the heart, then in essence that is the part of the heart we need to visualize. Other graphics and/or color could overload the learner and focus his/her attention away from the necessary and pertinent information. Some of the concepts of Tufte that support Dwyer are data ink, chart-junk, data-ink maximization, qualities of graphical excellence, and color and information (Tufte, 2001).

*The Visual Display of Quantitative Information* (2001) calls for graphical excellence. Graphical excellence simply means that graphics should only show the data, induce the viewer to think about the information to be studied instead of the design or production and avoid
distortions of the data. Dwyer’s studies prove that in order for visual data to be effective the visuals only need to show the important information.

Dwyer stated that if students are studying the parts and functions of the tricuspid and mitral valves, then the only visuals they should see should focus on those parts of the heart. Other graphics and/or color could overload the learner and focus his/her attention away from the necessary and pertinent information. Basically you only want to show the concepts that are necessary for understanding at that time. If the brain is seeing the information for the first time, adding too much information can cause an overload by trying to process too much information.

Dwyer (1972) also only advises the use of color when realistic versions of material are appropriate to help enable the students to identify and interact with the relevant characteristics, thereby increasing their achievement. Tufte (1990) supports the use of color but he first points out that the human eye is exquisitely sensitive to color variations. He believes tying color to information simply means putting the right color in the right place; being subtle allows you to avoid the catastrophe of misrepresentation and misinformation. Tufte also suggests the use of color to label the important parts and represent or imitate reality, but the colors used to represent and illuminate information need to be found in nature. Colors found on the lighter side of the spectrum, blues, yellows, and grays are familiar and coherent to the human eye (Tufte, 1990).

Dwyer (1972) and Tufte (1997, 2001, 2007) emphasize that visuals are effective in enhancing achievement and learning, but only when used properly. Dwyer has taught us that prettier is not always better in education; if we are going to use visuals in science and mathematics, then those visuals need to be clear and concise in illustrating the evidence that needs to be learned. Tufte complements Dwyer, not only because he emphasizes simplicity, but because he has shown the importance of expressing information that is not meant to deceive or
hide the true nature of the graphic. Educational visuals should only be implemented to enhance conceptual learning by reinforcing reality and knowledge learned.

Paivio’s Dual-Coding Theory

“The old saying that a picture is worth a thousand words has considerable validity when applied to memory” (Hunt & Ellis, 2004, p. 154). Visual-spatial researchers believe that the learning process is greatly predisposed by the way information is presented (Clark & Paivio, 1991; Webb et al., 2007; Mayer & Anderson, 1992). According to Wandersee (2005), educators tend to focus minimal time towards the use and meaning of the photographs, but Cognitive scientist, Donald Norman, claims that cognitive artifacts consist of the basis of intellectual power. Cognitive artifacts are units of key information abstracted into a representational form (Wandersee, 2005). Therefore, photographs, 2D and 3D pictures, and other representational forms of knowledge, are considered experiential artifacts that help students to experience and reason about objects and events in-depth that they would not necessarily occur in traditional classroom settings (Wandersee, 2005).

Research conducted by Mayer and Anderson (1992) suggests that Paivio’s dual-coding theory provides the strongest support regarding the use of imagery to increase learning, retention and problems solving abilities. Dual-coding theory suggests that information in memory may be stored in two forms, verbal and imaginal codes (Paivio, 1971, 1991). According to de Jong et al. (1998), “dual coding is the principle which proposes that texts are processed and encoded in the verbal systems [of the cerebral cortex] whereas pictures or graphics are process both in the image and verbal systems” (p. 11). Any event or object that can be described may be stored in a verbal code, and any event or object that can be visualized can be stored in an imaginal code. But most
importantly, most events (i.e., visual items) can be stored through both coding systems (Paivio, 1971).

According to Fundamentals of Cognitive Psychology (2004), Paivio argues that pictures will produce better memory for events because they can be encoded through verbal and imaginal codes, thus, increasing the probability of retrieving the information. Mayer and Sims (1994) reported that the “advantage of having more than one kind of memory codes is that one code can serve as a backup when another code is forgotten” (p. 390). Paivio argues that the picture will produce a better memory because the visual image retains more detail than the verbal code. “The superior memory for pictures is due to the ease with which they are visually stored and the amount of detail maintained in the image” (Hunt & Ellis, 2004, p. 155).

Hunt and Ellis (2004) believe the basis of Paivio’s research lies in his discovery that concrete words are better remembered than abstract words. Concrete words are words that are tangible, the physical object that describes the word can be visualized. “Abstract words, generally are more difficult to encode in an imaginal form, and when they can be coded as an image, the image is not the same thing as the object” (Hunt & Ellis, 2004, p. 155). Paivio used the observation of the memory and use concrete and abstract terminology to develop dual-coding theory (Paivio, 1971, 1995; Hunt & Ellis, 2004). “This theory proposes people can encode information as language-like propositions or picture-like mental representations” (Wandersee, 2005).

Wandersee (2005) uses Paivio’s dual coding theory to imply that a well chosen photographic image can serve as an alternative cognitive portal; teachers should implement more visuals into their courses to produce better memory and understanding of scientific events. Wandersee suggests that teachers ease different levels of photographs into the class. Choose
photographs that have an obvious center of interest, and as the school years moves along, introduce more complex images when testing students.

**Human Memory**

Individuals have different ways of processing information. Cognitive psychologists study how human beings process information (i.e., collecting, organizing, storing, retrieval, and use of information). “Memory does not operate in isolation but, rather, is one of the cognitive processes servicing some goal such as comprehension or problem solving” (Hunt & Ellis, 2004, p. 12). Hunt and Ellis (2004) state that our prior knowledge is important to the restructuring of experiences and the recalling of those same experiences; therefore, memory is affected by the conscious intent of the individual. The importance of information-processing to abstract reasoning skills has become an important research area to science educators due to the realization that cognitive processes such as memory can place restraints on learning if not taken into consideration (Eylon & Linn, 1988). Understanding how information is processed in the human mind can help educators develop more effective curricula and environments for learning.

“All of your experience of the world begins when physical energy from the environment contacts appropriate sensory receptors” (Hunt & Ellis, 2004, p. 38). When pattern recognition occurs, the information-processing sequence begins. Once sensory receptors are activated, the sensory registry, a memory system, stores the information received. The sensory registry stores information in veridical form (Hunt & Ellis, 2004). The most important characteristic of the sensory registry is that the information must remain for a brief time (Hunt & Ellis, 2004). If the registry is not cleared quickly, information can possibly be superimposed. Information on the sensory registry is considered precategorical, or without meaning (Sperling, 1960). “Pattern recognition is the process in which meaning is derived, a process that interprets sensory
information by matching the information to previous experiences stored in long-term memory” (Hunt & Ellis, 2004, p. 55).

According to Atkinson and Shiffrin (1968), information flows from the sensory registry to the short-term memory (STM) and then to long-term memory (LTM). The level of attention controls the transfer of information from the sensory registry to the STM. Once the information is in STM, certain control processes, rehearsal and coding, affect the ability of the information flowing from STM to LTM. The most important control process is rehearsal (Hunt & Ellis, 2004). The rehearsal control process operates in two forms, maintenance and elaborative rehearsal. Maintenance rehearsal, or simple repetition, functions to keep information active in STM. Elaborative rehearsal involves relating new information to other known information; it functions to transfer information to LTM. The control process called coding “involves attaching appropriate information from long-term memory to the short-term information” (Hunt & Ellis, 2004, p. 113).

According to Tulving (1983), information is stored in long-term memory (LTM). “Long-term memory is the concept that represents the vast store of knowledge we have about the world, ranging from everyday events such as how to use a knife and fork to more esoteric information as axioms of geometry” (Hunt & Ellis, 2004, p. 140). LTM is composed of three systems: episodic, semantic, and procedural. Episodic memory contains specific events and experiences. When we retrieve information, we start to re-experience it in different ways. Semantic memory contains generic knowledge of world, facts; facts that can be remembered with no experiences attached. Procedural memory contains information on how to perform an action. Tulving (1985) states that most of the information stored in LTM remain inactive without being affected by
one’s own thoughts. Accordingly, it is only likely to access the stored information when it is retrieved to the working memory (Hunt & Ellis, 2004; Shiffrin, 1993).

Working memory is an elaboration of the concept of STM. Psychologist Alan Baddeley developed the concept of working memory, not simply as unique storage concept, but as a way of retaining information used for other cognitive work (Hunt & Ellis, 2004; Baddeley & Hitch, 1974; Baddeley, 1990, 1994). Baddeley and Hitch demonstrated that working memory is a critical part of mental processes such as problem solving, reasoning and comprehension, very important activities needed in STEM education.

Baddeley’s (2000) current concept of working memory includes four components: central executive, visuo-spatial sketchpad, episodic buffer and phonological loop. “The central executive is the controlling, decision making mechanism of working memory that functions to recruit and perform operations required by the current task, as well as to allocate capacity in the working memory system” (Hunt & Ellis, 2004, p. 127). The central executive is highly related to problem solving (Baddeley & Hitch, 1974) and the coordination of the three aforementioned systems which serves as temporary storage systems (Baddeley, 1990, 1994, 2000).

The visuo-spatial sketchpad is the component of working memory that stores and works with visual-spatial information (Hunt & Ellis, 2004). The episodic buffer accounts for observation that cannot be explained by the other three components, information that is integrated across time and space (Baddeley, 2000). Tulving (1972) suggests that the episodic buffer provides an interface between the systems of working memory and long-term memory. The phonological loop stores verbal materials and a subvocal rehearsal process called articulatory control (Hunt & Ellis, 2004). Baddeley’s depiction of the model is shown in Figure 12.
Baddeley and Hitch (1974) and Baddeley (2000) provides a working memory model that accounts for the processing and storage of information, cognitive functions that are required in problem solving, reasoning, and comprehension, important characteristics in engineering.

**Engineering Outreach Vision of ASEE**

In 2005, the National Academies Press published a paper written by the Committee on the Engineer of 2020 of the National Academy of Engineering called “Educating the Engineer of 2020: Adapting Engineering Education to the New Century.” The research of this committee attempted to answer the question “what will or should engineering education be like today, or in the near future, to prepare the next generation of students for effective engagement in the engineering profession in 2020?” The committee determined that engineering education must produce technically excellent and innovative graduates by broadening engineering education. This can be accomplished in two ways: improving recruitment and retention of students by

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making the learning experience more meaningful to them and improving the public understanding of engineering.

In order for the aforementioned tasks to be accomplished, the committee made several recommendations. “Engineering educators should introduce interdisciplinary learning and explore the use of case studies of engineering successes and failures as learning tools” (Committee on the Engineer of 2020, 2005, p. 12). Engineering education should also address the problems faced by society through the development of new technologies, including addressing the society, geopolitical, and professional context of engineering. Most importantly, the committee highly supports the increase of advertisement of engineers through encouraging primary and secondary school students to consider engineering and then preparing them intellectually so that engineering is accessible to them.

Founded in 1893, the American Society of Engineering Education (ASEE) has embarked on an ambitious effort to promote and improve K-12 engineering education. ASEE is a collaboration composed of engineering industry leaders, higher education leaders and K-12 teachers. ASEE has implemented several efforts to increase engineering awareness including a guidebook to engineering education for high school students (Engineering, Go for It!), an e-newsletter (Go Engineering! for teachers, guidance counselors, and outreach program leaders), and an annual leadership and exposition on engineering outreach.

ASEE is motivated by the United States of America’s technological progress. The society believes that corporate growth and economic development are inextricably tied to technological advancement (Douglas, Iverson & Kalyandurg, 2004). However, to continue to grow, America needs a technically literate society and an engineering-minded workforce (Douglas et al., 2004).
Unfortunately, poor test performance and outsourcing proves that our education system fails to meet the mark.

During the 2004 annual ASEE engineering education leadership workshop, experts, which includes K-12 teachers, university professors and industry and government representatives provided reasons for poor performance and suggestions for improvements: teachers do not have time to implement engineering lessons; the classroom should move more to an interdisciplinary approach to teaching that way engineering will be easier to infuse; state standards and assessment seem to be a major obstacle; teacher preparation is highly important to implementing engineering in the classroom; engineering should be made cool in order to reach out more aggressively to urban schools and female groups; engineering mentors and role models are needed; educators need to understand the current pedagogy and its implications on women and minorities.

Current programs are underway to address the aforementioned issues. As reported in the report entitled “Engineering in the K-12 Classroom: An Analysis of Current Practices and Guidelines for the Future,” in 2003, ASEE surveyed almost 300 outreach program leaders to better understand the composition of their programs, and only 66 program leaders responded to the survey. The survey included open-ended questions regarding budget, reach, expertise of instructors and curriculum.

The annual budgets of the programs that responded to the survey request ranged from $1200 to $5 million, with the average at $410,485. Most of the programs reached a small amount of students in their local area. One of the programs reached one student per year, while another reached 700,000. 46% of the programs reached 100 or fewer students and 72% reached 1,000 or fewer students. Out of the 66 program respondents, only 44 answered regarding their program
demographics; 32 out of 44 reach white students, Hispanic, and Asian students. Furthermore, 12 out of 44 specifically targeted minorities. Although 79% of the programs target African American students, only about 15% of the participants reach African American students. Only 5% of Hispanics and Asians participate in the 73% of the programs that target them. Only 2% of Native Americans participate in the 41% of the programs that target them. It is clear that engineering education outreach programs are dominated by white students. The programs also reach high school students more than they do middle school students. Seventy-seven percent of the programs have high school students; 49% reached middle school students; 21% reached elementary school students.

The outreach programs utilized several different types of instructors. Eighty percent of the programs used engineering faculty, graduate students, and undergraduate students, 7% use only engineering faculty, 3% used only engineering graduate students, 3% used only engineering undergraduate students, and 7% used no engineering education affiliates. The curriculum was also designed by several different engineering education sources. Sixty-two percent of the programs used a combination of engineering faculty, K-12 teachers, and engineering specialists to write the curriculum, while 28% used only K-12 teachers and 21% only used engineering faculty.

The ASEE analysis of the programs active in 2003 showed that K-12 engineering outreach programs introduce many students to engineering through much collaboration. Ultimately, ASEE experts believe outreach programs should do a better job of recruiting more diverse and younger students, and build additional partnerships to write the curriculum.

ASEE has attempted to provide a visionary pathway to improve the future of engineering education in America. Six key guidelines for K-12 engineering education were developed by
The development of the following guidelines was influenced by “the concerns of teachers and experts, the shortfalls of current outreach programs, and the vital importance of improving the knowledge of engineering concepts for all students, and especially younger students, females and underrepresented minorities” (Douglas et al., 2004, p. 18).

1. Hands-on learning: K-12 science should be less theory-based and more context-based, emphasizing the social good of engineering and demonstrating its social relevance.

2. Interdisciplinary approach: Add a technological spin to all subjects and lessons, and implement writing guidelines in math and science courses.


5. Make engineers cool: Outreach to urban schools and females more aggressively, and create mentors and role models to attract these constituencies.

6. Partnerships: Create better incentives for all groups to engage in K-12 outreach.

The American Society of Engineering Education believes that the above guidelines can be easily implemented in the classrooms and outreach programs. “By refocusing our efforts along the lines suggested with these guidelines, we can answer the call of society to provide a better prepared, technologically savvy, and diverse workforce for years to come” (Douglas et al., 2004, p. 19).

**Proposed Innovative Curriculum Background Information**

Each curriculum’s science and engineering topic was chosen based on recommendations from the National Science Education Standards (1996) and literature that supports their importance in building a strong foundation in understanding STEM. The science and engineering
focus within each topic was demonstrated by hands-on, as well as minds-on, activities to showcase how the two disciplines are related but have distinct roles. Students learn that scientists acquire information about the physical universe using the scientific methods, while engineers research and discover ways to apply that acquired information using the engineering design method.

**Forces and Motion.** In 2009, the American Society of Civil Engineers (ASCE) researched the current state of and graded the United States infrastructure. Sadly, American’s infrastructure received an average grade of D. The infrastructure is aging and failing rapidly as witnessed by the most recent bridge collapses. According to the ASCE, the problem is advanced in urban areas due to growing populations, natural disasters and accidents causing stress on the support systems. The National Academy of Engineering has considered the United States infrastructure restoration and improvement one of the Grand Challenges for Engineering (2008). According to the Academy (2008), the government and civil engineers should focus on maintaining, improving and building a better infrastructure with new approaches and methods to keep the citizens safe. There is only one major issue; the ASCE has estimated that 2.2 trillion dollars is needed to do the job.

In order for engineers to design and build bridges, they must have full understanding about the forces that maintains the strength and stability of those structures as they are being used by millions of people per day. Halliday, Resnick, and Walker (2008) define forces as a push or pull upon an object as a result of an interaction between the objects. All forces can be placed into two categories: contact or noncontact forces. Halloun and Hestenes (1985) reported that students have a well-established system of beliefs about the physical world, including forces, from their personal experiences. Unfortunately, those beliefs have been found incompatible with
the concepts of force and motion (Halloun & Hestenes, 1985; Hestenes, Wells, & Swackhamer, 1992). Many students struggle to understand high school and college freshman level physics due to evidently not learning the basic Newtonian concepts properly. “Typically students have been forced to cope with the subject by rote memorization of isolated fragments and by carrying out meaningless tasks. No wonder so many repelled!” (Hestenes et al., 1992, p. 141).

Physics education researchers have found that effective instruction requires more than just representing subject knowledge and dedication and has to start long before high school and collegiate years. Hestenes et al. (1992) believe that it requires new teaching and learning methods, as well as technical knowledge about how students think and learn. Force is the central concept to understanding physics and Newton’s laws, and the misconceptions students have about the subject must be corrected in the early years of education if students are to become scientifically literate and seek careers in the STEM fields. The National Science Education Standards (1998) chose forces and motion as a major topic students should focus on during middle school years. The researcher chose force as a curriculum topic to dispel misconceptions about physics during early education years (see Appendix A). Bridges were chosen as an avenue to introduce forces because of their importance in the engineering community, to the government and to communities that use them daily.

**Earth and Space Science.** In 2001, the National Science Foundation (NSF) and the American Geological Institute Foundation (AGIF) sponsored the National Conference on the Revolution in Earth and Space Education to help to establish earth and space science as a major science through initiatives, reforms, partnerships and professional development. The National Science Education Standards (NSES) also has a strong emphasis on the subjects as a core science discipline. The conference proceedings revealed that earth and space science education
are being neglected in the middle school system. “This is ironic since earth and space science is
such an accessible domain of science learning, as it related directly to students’ immediate
environment and daily experiences, and is full of opportunities for hands-on learning” (Center
for Earth and Space Science Education [CESSE], 2001).

The American Geophysical Union (AGU) believes that middle school students need a
positive and enriching experience to inspire them to pursue the study of earth and space science
(2009). AGU (2009) and CESSE (2001) has found that students are not interested in one of the
most profound fields due to public perception and lack of time devoted to the full understanding
of earth and space science in schools. The earth is a critical, complex system whose systems,
components and processes allow its inhabitants to survive. Earth science is a comprehensive term
used to describe the origin, structure, physical, chemical, and geological make up of the earth
(Glencoe McGraw-Hill, 2008). Furthermore, space exploration performed by the National
Aeronautics and Space Administration has provided a new point of view of earth by satellite
data, allowing scientists to investigate and enhance the life systems. Space science is also a
comprehensive term used to describe the study of the phenomenon occurring in space and its
effect on earth (Glencoe McGraw-Hill, 2008).

The NSF, AGU, CESSE, and the NSES have recommended that educators take a
proactive and innovative role in helping students to understand and appreciate the world around
them by strongly emphasizing a hands-on approach with the use of visualization technologies.
The CESSE (2001) has also recommended the use of informal educational settings to create new
opportunities for students to learn about earth and space science.

The researcher chose the topic to help change the nature of earth and space science
education, to expand the participation in earth and space science (see Appendix B). Earth and
space science is usually experienced through the textbooks and a teacher’s knowledge. The new curriculum seeks to enhance student learning those subjects by presenting the information in a more meaningful manner. According to the CESSE (2001) only 7% of high school students will take a high school earth and space science course, contrasting the 88% who will take biology.

According to the AGU (2009), earth and space science are traditionally perceived as a subject for schools that are rural. Urban areas are closely connected to the environment because they grow in patterns defined by physical environments. “Cities are often found near rivers. Construction of buildings and highways require deep knowledge of what lies underground. Natural disasters such as severe flooding require strategic planning and recovery” (CESSE, 2001, p. 17). All of those topics need a great knowledge foundation of earth and space science. The curriculum also seeks to introduce earth and space science in a greater depth to students who traditionally have shown little interest (see Appendix B).

Conserving Energy. The world’s natural resources are diminishing everyday due to an increase in the population, therefore, causing an increase in energy use and misuse. As nonrenewable energy sources come to a shortage, measures are being taken to conserve those irreplaceable sources. A slight change in human behavior, conserving energy, can preserve depleting energy sources. Energy efficiency is important because it reduces the size and cost of the amount of energy needed.

The United States Department of Energy has created numerous consumer education resources to increase the awareness of the importance of energy conservation and the adverse environmental and societal impacts associated with energy production and consumption. The United States Environmental Protection Agency (EPA) supports conserving the limited amount of nonrenewable energy sources on earth so natural resources will be available in the future.
“Energy conservation is also important because consumption of nonrenewable sources impacts the environment because use of fossil fuels contributes to air and water pollution” (EPA, 1997). The EPA concluded that mass energy consumption is causing negative effects that include air pollution, acid rain and global warming, oil spills and water pollution, and loss of wilderness areas. The National Energy Education Development (NEED) Project was created to promote an energy conscious through education. Many environment supporting agencies are creating educational components and asking the education community to contribute new lessons regarding energy depletion awareness and solutions to solve the existing energy crisis.

The curriculum seeks to make underrepresented students stewards of their environment, in particular, their personal communities (see Appendix C). It is intended that the students will learn about how energy impacts their lives, the importance of its conservation, as well as the renewable energy sources that are currently being developed.

Summary

In order to strengthen our science, technology, engineering, and mathematics educational system, it is imperative that people of all ages be engaged in rigorous courses, activities and programs that teach important analytical, technical, and problem-solving skills. The goal of this research is to devise an innovative strategy to increase and maximize STEM interest and achievement in the urban, middle school population. This study attempts to compose a curriculum for an urban middle school summer engineering program. The curriculum is based on the early adolescent, the cultural learning styles of African Americans, cultural awareness, the theory supporting supplemental engineering programs, human constructivism, graphic design, dual-coding, human memory, and the engineering outreach vision of the American Society of Engineering Education.
Early adolescents have been a forgotten group in American education for several reasons (Hurd, 1978; Johnson, 1978). Whether it is lack of teacher preparation for the adolescent or the concept of essentialism, middle school students are being left behind educationally (Johnson, 1978; NCES, 2000). Minority or urban middle school students are especially left behind, not only for the aforementioned reasons, but the urban school population faces its own inequitable educational opportunities (Tobin, 2000; Barton, 2001). A suggested method of improving the education of adolescents and the urban middle school population is through supplemental or informal education programs. The American Society of Engineering Education has a strong vision to use outreach programs to make engineers cool and reach the urban population.

Informal learning programs have been proven to provide opportunities for greater access to multidimensional opportunities for learning (Jones, 1997; Hurd, 1978; Coleman, 1972; Bouillion & Gomez, 2001). Research has documented the success of such programs in regards to an increase in scientific knowledge, interest, attitudes, and confidence in science, as well as STEM career trajectories (Fadigan & Hammrich, 2004; Atwater et al., 1999; Hofstein et al., 1990). The curriculum of the informal learning program is essential to the success of the program. The curriculum should meet the needs of the students academically and socially (Johnson, 1978).

Human Constructivism and the creative cultural learning styles of African Americans have been identified as two important theoretical concepts by which people relate to their previous knowledge and their environments to enhance learning. Human Constructivism allows learners to build knowledge to enhance understanding and conceptual change in the classroom (Mintzes et al., 2005b). Imbedding the cultural learning styles of African Americans into curriculum activities will allow the creative abilities to best utilized to help the target population
of students learn. Starko (2005) believes classrooms that build upon culture helps students to be more academically successful.

The success of STEM education relies heavily upon visual spatial learning, graphic design learning and dual-coding. Visual spatial is defined as the ability to mentally manipulate multidimensional objects and use of multidimensional perception to solve problems (Sera et al., 2002). Graphic design learning is the role of visualization and drawings as tools to understand science. Paivio’s dual-coding theory is the principle which uses verbal and visual systems to process, understand and remember information. Being able to visualize the world and its problems gives scientists and engineers a global perspective on solving those problems.

In conclusion, this literature review has identified and demonstrated important components to include when designing an effective curriculum for an urban middle school summer engineering program. The inclusion of the researched components into a program will assist the educational system to provide a better STEM workforce that is diverse, better prepared to problem solve and scientifically literate.
CHAPTER 3. RESEARCH METHODS

Mixed Methodology

According to Tashakkori & Teddlie (2003), there have been three methodological movements in the social and behavioral sciences: quantitative, qualitative, and mixed methodologies. Quantitative research investigates phenomenon through numerical analysis. Quantitative methods can be defined as using techniques associated with gathering, analyzing, interpreting and presenting numerical information (Teddlie & Tashakkori, 2009). Patton (2002) defines quantitative research as the required use of standardized measures to measure the reactions of a large population and fit their varying perspectives and experiences into a limited number of predetermined categories.

Qualitative data collecting traditionally includes interviews, observations and documents. Qualitative methods can be defined as using techniques associated with gathering, analyzing, interpreting and presenting information in narrative form (Teddlie & Tashakkori, 2009). “Qualitative methods facilitate study of issues in depth and detail” (Patton, 2002, p. 14). While quantitative studies provide limited information of a large population, qualitative studies “typically produce a wealth of detailed information about a much smaller number of people and cases” (Patton, 2002, p. 14). Although both methodologies are very distinct, they can be combined into a single or multiphase study to provide a broader perspective to research questions (Tashakkori & Teddlie, 1998).

Mixed methodology is defined as “a type of research in which qualitative and quantitative approaches are used in types of questions, research methods, data collection and analysis procedures, and/or inferences” (Tashakkori & Teddlie, 2003, p. 711). Morse in Handbook of Mixed Methods in Social & Behavioral Research (2003) states that by combining
and increasing the number of research strategies used within a particular project, you are able to broaden the dimensions and hence the scope of your project. Tashakkori & Teddlie (2003) name three reasons or areas in which mixed methods are superior to a single research method:

1. Mixed methods research can answer research questions that the other methodologies cannot.
2. Mixed methods research provides better or stronger inferences.
3. Mixed methods provide the opportunity for presenting a greater diversity of divergent views.

Mixed methodology is recommended to be used in studies where there is a mixture of quantitative and qualitative approaches in different phases of the research process (Tashakkori & Teddlie, 1998). Tashakkori & Teddlie (2006) summarized several sources on the purposes for and benefits of mixed methods research (Greene, Caracelli, & Graham, 1989; Patton, 2002; Tashakkori & Teddlie, 2003; Creswell, 2003; Rossman & Wilson, 1985). They include being able to gain complementary views regarding phenomenon or relationships; assuring a complete picture has been obtained; expanding the understanding of a phenomenon; corroborating the credibility of inferences from a single research method; compensating for weaknesses of a single research method; obtaining divergent views of the same phenomenon; developing questions from one research method that can be tested by the next one.

**Research Design**

The researcher used a mixed methods design, in which qualitative and quantitative data collection methods and analyses were used to answer the proposed research questions. This study had two phases. The first phase consisted of examining top-rated minority middle school summer engineering programs through library and archival research, interviews and mixed methodology.
analysis. Phase two consisted of synthesizing an innovative curriculum with pre-defined theoretical and principled sources identified in the literature review along with established successful components identified in phase one.

This research study was exploratory and confirmatory in nature. “Exploratory research involves investigations concerned with generating information about unknown aspects of a phenomenon” (Teddlie & Tashakkori, 2009, p. 25). This research study was an exploratory investigation of the curriculums of several middle school summer engineering programs. “Confirmatory research involves conducting investigations aimed at testing propositions that are based on a specific theory or a conceptual framework” (Teddlie & Tashakkori, 2009, p. 23). This research was also a confirmatory investigation in which the proposed visual-spatial curriculum will be confirmed to be an innovative approach to introducing engineering in an informal setting through expert evaluation.

Morse (2003) introduced eight types of multi-method designs, four with an inductive foundation and four with a deductive foundation. Morse’s QUAL + quan method was used in this study. The QUAL + quan multi-method design occurs in which qualitative and quantitative methods will be used simultaneously with an inductive theoretical thrust. This method was chosen for its ease of implementation and flexibility. Although this research is qualitatively driven, minimal quantitative information was able to be drawn out through the qualitative phase adding to the discovered conclusions based on the data collected. The QUAL + quan method is highly recommended to use when research involves combining tested theories or concepts to establish a conclusion that is untested.
Protection of Human Subjects and Participant Consent

An application for exemption from the oversight of the Louisiana State University Institutional Review Board (IRB) was submitted and approved by the board (see Appendix D). This study met the qualifications for exemption: (a) the research was conducted in an educational setting involving normal educational practices, (b) the study involved survey and interview procedures in which the subjects will not be at risk, (c) the consent of the persons who were interviewed was obtained prior to beginning the study, and (d) the research participants and schools will remain anonymous when reporting the findings by assigning pseudonyms and unique user identifications.

The consent forms for the engineering education faculty/administrator and an existing programs administrator explained: (a) the purpose for the study which includes the potential benefits for being included in the study, (b) the potential risk associated with being in the study, (c) the right to refuse participation in the study, and (d) the assurance of confidentiality of study participants. The Engineering Education Faculty/Administrator Interview Consent Form is included in Appendix E, as is the Existing Program Administrator Interview Consent Form which is in Appendix F.

Data Collection Procedures

The data collecting strategies used in this research were designed to provide optimal amounts of information for the study. Data collecting strategies in this study followed the within-strategy and between-strategies mixed method data collecting techniques. The within-strategy technique involved gathering both qualitative and quantitative data using the same data collection strategy, while the between-strategy technique involves gathering both qualitative and quantitative data using more than one data collection strategy (Teddlie & Tashakkori, 2009).
Three current middle school summer engineering programs were selected for this study. The technique for selecting the three programs was purposive in nature and is described in the sampling procedure section of this proposal. The programs’ curriculum was analyzed to determine the trend of current programs’ curriculum and the innovation of the proposed curriculum. The following questions were asked to determine the curriculum components of each program using the following data collection procedures. The additional research questions make this proposal more information rich and informative.

1. What are the similarities/differences in each curriculum?

   Each program generally follows a curriculum developed by the administrators. The curriculum maps out the concepts and objectives the students should learn by end of the program. There are several different defined curriculum theories that could be followed: learning centered, problem based learning. The most common curriculum theories followed by STEM programs are based upon problem based learning with real world applications and hands-on activities. What are the administrators’ reasons for choosing the curriculum for the program? The data collection methods for this question are the use of unobtrusive measures, artifacts, archival records, documents, program websites, and reports and teaching modules, that demonstrates the curriculum chosen and used; administrators will also be interviewed with the use of open-ended questions to determine the reasons the named curriculum was chosen.

The following are sub-questions under the umbrella of curriculum that were answered with the use of the aforementioned data collection strategies.
2. What is the curriculum based upon (e.g. state and/or national education and/or professional engineering organization standards)? Why were these particular standards chosen?

Data collecting strategies include: artifacts, archival records, documents, program websites, and reports and teaching modules provided by the program, and open-ended and close-ended interviews.

3. Do these programs use tested cognitive learning theories to justify their methods? Why or why not?

Data collecting strategies include: artifacts, archival records, documents, program websites, reports, teaching modules, and open-ended closed-ended interviews.

4. What are the similarities/differences in pedagogical approaches?

Previous research has supported the use of various pedagogical approaches for teaching minorities. Do these programs use the approaches proven to be useful in non-traditional settings?

Data collecting strategies include: artifacts, archival records, documents, program websites, reports, teaching modules, and open-ended interviews.

To assess the theoretical learning impact of the proposed middle school engineering curriculum, the curriculum was evaluated by engineering education administrators or faculty. The evaluators were chosen based on areas of expertise and pre-college engineering program involvement (see sampling procedure section). The selected administrators or faculty were given an online survey, powered by SurveyMonkey, composed by the researcher to evaluate the proposed curriculum. The survey included open-ended and closed-ended responses. A sample copy of the online survey can be found in Appendix G.
Teddlie & Tashakkori (2009) describe unobtrusive measures as research techniques that allow researchers to examine aspects of a social phenomenon without interfering with or changing the phenomenon. Artifacts, archival records, program websites, and teaching modules are considered qualitative unobtrusive data collection methods, but can yield non-numeric and numeric information. Webb, Campbell, Schwartz, and Sechrest (2000) believe that unobtrusive measures are more valuable than interviews and questionnaires because there is less chance of methodological weakness occurring. Archival records are considered written public records, written private records, archived databases from research studies conducted previously, and information stored in non-written formats (Teddlie & Tashakkori, 2009; Denzin, 1989; Johnson & Turner, 2003; Webb, Campbell, et al., 2000; Creswell, 1998).

Open-ended and closed, or fixed-response, interviews/surveys were chosen because they are a powerful method of data collection, entailing one-to-one interaction between the researcher and the individuals or phenomenon being studied, yielding non-numeric and numeric information (Teddlie & Tashakkori, 2009; Patton, 2002; Creswell, 1998). Interviews/surveys can take place in person, over the phone, as a focus group, or via interactive sessions on the internet (Teddlie & Tashakkori, 2009; Creswell, 1998; Crichton & Knash, 2003). Patton (2002) described the variations in interview instrumentation defining the characteristics, strengths, and weaknesses in open-ended and fixed-response interviews/surveys. Patton (2002) did not recommend using closed, fixed-response interviews because he believed that the questions forced interviewees to fit their knowledge, experiences and feelings into the researchers’ categories.

The characteristics of open-ended interviews/survey included using predetermined exact words and sequence of questions, in which all interviewees are asked the same question in the same order. Patton (2002) describes the strengths of open-ended interviews/survey as being able
to increase comparability of responses due to interviewees being asked the same questions; it reduces effects and bias when several interviewers are used; it also facilitates organization and analysis of data. A weakness of open-ended interviews/surveys is that there is little flexibility in relating the interview to particular individuals and circumstances. The characteristics of closed, fixed-response interview/survey is that the questions and response categories are determined in advance. The strength of using this method is that the data analysis is simple, easily comparing and aggregating the responses. Patton (2002) believes that the interview/survey technique can be perceived as impersonal, irrelevant and mechanistic, in which the true meaning of interviewees’ responses are distorted. Table 2 presents the data collecting techniques and variables associated with each question. Table 2 can be found in Appendix H. The open- and closed-ended interviews were conducted using an online survey software tool, Zoomerang. The existing programs’ survey can be found in Appendix I.

**Middle School Summer Engineering Curriculum Preparation**

Using visual spatial theories, human constructivist learning theory, national science standards, American Society of Engineering Education suggestions, graphical design theory, cultural learning behavior of minority students, and the psychology of middle school students, a summer engineering program curriculum were designed. The subject content includes topics regarding improving the urban infrastructure, understanding the world around you, and making the world greener.

**Sampling Procedure**

The three programs studied were selected by two purposeful sampling strategies, criterion sampling and convenience sampling. Purposeful sampling involves strategically and purposefully selecting information-rich cases (Patton, 2002). The purpose of criterion sampling
is to pick all of the cases that meet criterion set by the researcher; the purpose of convenience sampling is to select the cases from the population based on easy availability and/or accessibility (Patton, 2002).

There are several incomplete engineering education databases that provide a listing and description of middle school summer engineering programs for all types of students. The programs that fit the criteria were compiled into a complete list (along with other programs that were not advertised in those databases). The following criteria guided the selection of programs: First, programs had to be long term (at least 4 weeks), making possible the study of change over time. Second, the programs had to target low income and ethnically diverse inner city youth (the underrepresented in STEM careers). Third, the participants of the program had to be entering the sixth, seventh or eighth grades. Fourth, each program had to have at least 25 participants. Fifth, each program had to have a reputation for increasing academic achievement in the educational community (typically the programs that are reputable have been in existence longer or have a proven/documentated record statistically for enhancing achievement). Sixth, programs had to be voluntarily sought out and in no way remedial or academically oriented. Seventh, programs had to be currently funded by a government agency (i.e., NSF, NIH, NASA, etc.) to ensure that reporting of programs structure, success, and actions is taking place. Eighth, programs had to have varying pedagogical and curriculum approaches to enhance learning. This criterion was especially important, in that it allowed the researcher to study, compare and contrast various types of programs. After the programs met the criteria chosen, three programs were conveniently selected that were accessible to the researcher.

The engineering education administrators or professors, that evaluated the proposed curriculum, were also selected by criterion sampling and convenience sampling. A total of five
evaluators were selected. The following criteria were used to select the evaluators: First, the evaluators must not have been associated with the programs selected to study in order to decrease bias in their evaluation. Second, the evaluators must have been involved in designing engineering curriculums for minority elementary or secondary students. Once chosen, the demographics and summary of each evaluator’s Curriculum Vitae is included.

**Data Analyses**

The aforementioned questions’ data were analyzed by the use of partitioned constant comparative analysis. Lincoln and Guba (1985) presented constant comparative analysis as a system that utilizes inductive logic to develop emerging themes or categories from narrative data. The information gathered was summarized and written in narrative form. Table 3 (found in Appendix J) depicts the data collection procedures, variables and data analysis for each research questions.

The data from the proposed curriculum survey assessment was analyzed by quantitative and qualitative data analysis by the researcher. The closed-ended questions followed the format of a 5-point Likert-type survey and were analyzed statistically using descriptive methods. The open-ended questions were content analyzed. The survey included questions to better understand the evaluators’ agreement or disagreement of the curriculum and any changes they believe were needed in the curriculum to make it stronger and more align to educating the future engineer.

**Mixed Method Inference Process**

Tashakkori & Teddlie (2006) suggest using “inference quality as an umbrella for evaluating the quality of conclusions and interpretations that are made on the basis of the findings and inference transferability to indicate the degree to which these conclusions may be
applied to other specific settings, people, time periods, contexts, and so forth” (p. 7). The mixed method inference process can employ using quantitative and qualitative inference.

**External Validity Issues.** External validity is “the validity of the inferences about whether the cause-effect relationship holds over variation in persons, settings, treatment variables, and measurement variables” (Shadish, Cook, & Campbell, 2002, p. 38). This study only represents a small population of STEM programs. Many STEM programs employ their own curriculum and pedagogical methods to benefit their community. A study will have to be done on every different program to represent the entire STEM program population. The idea represented here is to look at four successful programs and their methods. The sampling methods were chosen carefully to study four top programs. The criteria for selecting each program were formed to attempt to get the “same” population of students in each group.

**Trustworthiness and Credibility Issues.** Lincoln & Guba (1985) defined trustworthiness as “the extent to which an inquirer can persuade audiences that his/her findings are worth paying attention to” (p. 290). Criteria for trustworthiness include credibility, transferability, dependability, and confirmability (Lincoln & Guba, 1985). The trustworthiness issues in this study include coding bias, stereotyping participants and trustworthiness of research. As a researcher it is imperative to interview and study artifacts with a completely open mind, so that the researchers own personal beliefs, education, experience, cultural, and personal stereotypes do not interview with what is actually being seen. The trustworthiness of research issues focuses on the overall layout of the study. These issues were addressed with the use of member checking, peer debriefing, triangulation techniques, and thick description.

“Member checking is a particularly powerful technique for determining the trustworthiness of interpretations that involves asking informants and other members of the
social scene to check on the accuracy of the themes, interpretations and conclusions” (Tashakkori & Teddlie, 2006, p. 17). The researcher composed survey that was used by the engineering education administrators and faculty also served as a member checking technique. Tashakkori & Teddlie (2006) also go on to say that if the members of the scene agree with the interpretations of the researcher, their agreement provides evidence for the trustworthiness of the results. Collecting data through unobtrusive measures and using constant comparative analysis, quantitizing, and descriptive methods provided extensive information supporting the innovation of the proposed curriculum.

**Transferability Issues.** Transferability describes the process of applying the results of research in one situation to other similar situations. The transferability issues in this study reflected whether or not the qualitative results are transferable to other groups. Each program has a different structure, so the program questions/answers will only be transferable to similar programs. The research questions/answers regarding the participants could possibly be transferable to other urban youth with similar backgrounds, but various ethnic groups have different experiences and issues regarding education and culture. Youth STEM programs generally have participants from the same community and/or background. The proposed research is not limited by a geographic region. This proposal is designed to capture a comprehensive look at STEM programs geared for American minority students by using a detailed and extensive selection process.
CHAPTER 4. RESULTS AND DISCUSSION

Overview

This exploratory study examined three top-rated minority middle school summer engineering programs to discover effective curriculum techniques currently used to increase the STEM interest of minority students. The programs were selected based on eight criteria: programs are at least two weeks long; programs target low income, ethnically diverse students; programs have at least 25 participants per year; programs have a reputation for increasing academic achievement; programs are voluntarily sought out by participants; programs are funded by a government agency; programs utilize various pedagogical approaches.

This study was also confirmatory in nature. An innovative curriculum was developed by the researcher and evaluated by experienced engineering education administrators and professors. The new curriculum was developed with pre-defined theoretical concepts identified in the literature review along with established successful components in the exploratory phase of this study. The evaluators were selected by the following criteria: no association with the programs selected to study and involvement in designing curriculums for minority elementary or secondary students.

A mixed method approach was used in the data collection and analysis. Qualitative and quantitative data was collected in the forms of documents, reports, teaching modules, and closed- and open-ended surveys and interviews. The data was analyzed using constant comparative analysis and descriptive methods.

Originally, four programs were to be examined. Although 11 programs were identified by the criteria and contacted to participate, only three programs volunteered to participate in the study on condition of anonymity. The programs that elected to not participate did so for a variety
of reasons. Several programs stated that they did not want to share their programs' secrets with anyone not affiliated with the program. Other programs also informed the researcher of intellectual property concerns. A few programs communicated with the researcher that they did not have the time to answer survey questions or locate program reports in a timely manner, while two programs did not respond to the researchers' request to participate.

**Existing Non-participating Program Profiles**

Out of the eight programs that elected not to participate in this study, three programs are no longer in existence due to funding cuts and have removed their information from websites during the completion of the research. Below are brief descriptions of the five nonparticipating programs. The information was discovered from the program’s websites.

Since 1973, Program One hosts 25 to 30 minority sixth, seventh, and eighth grade students in their five-week summer program. Participants are from several cities throughout the United States and Puerto Rico. The program lists several goals they set to accomplish each summer: to assist students to enroll in college and gain financial assistance; increase students' awareness of career options available to engineers and technologists; facilitate students' access to and interaction with positive role models from the STEM fields; to provide hands-on laboratory experiences and academic instruction similar to engineering undergraduate students; to demonstrate engineering work environment. Program One is sponsored by private corporations and the university where the program resides.

During five weeks of the summer, Program Two hosts at least 50 minority students entering the sixth, seventh, and eighth grades in the local area. The Institute combines lectures, projects and experiments to support learning. Students are introduced to a college preparatory curriculum with courses in physics, chemistry, probability, and statistics. Program Two’s
curriculum has four levels developed to engage participants in stimulating coursework that will develop curiosity and understanding about math and science. In Level one, students concentrate on algebra and biology. Level two introduces students to physics and chemistry to better prepare them for careers in engineering and science. Level three increases mathematical reasoning with the introduction of statistics and probability and helps to develop engineering intuition with the study of vector mechanics. In level four, participants focus on mathematical and scientific analysis. Program Two is sponsored by several foundations and the host university.

Program Three was instituted in 2004. This program introduces 20 middle school minority students to building and programming robots using LEGO Mindstorms. Students learn mechanical design, construction, programming, and teamwork skills through a design project. Students work in small teams using LEGO blocks, motors, and sensors, and use a computer to teach their robot to move, react, and make sounds in order to solve challenges.

Program Four also began in 2004. This program introduces 30 middle school minority students to the science of flight. Program participants learn about the science of flight through exciting hands-on activities, a field trip and guest speakers. Students also study the compression and expansion of air, history of flight, flight patterns, and aerodynamic forces. The students are given the opportunity to build flight gliders to test the theories learned. At the end of the program, students are given an opportunity to showcase their projects during an academic festival in which family and friends are invited to participate.

Program Five introduces 40 underrepresented middle school students to science, mathematics and technology. Since 1992, participants learn about chemistry, marine and earth sciences, physics and statistics through laboratory experiments and research projects. The mission of the academy is to increase student awareness and enthusiasm for learning science and
mathematics through hands-on learning activities. The objectives of the program are to strengthen academic abilities, expose students to STEM, provide mentorship, and build self-confidence and self-esteem.

**Existing Participating Program Profiles**

All of the programs that were identified and agreed to participate in this study met at least seven out of eight selection criterion. Table 4 lists the programs and the selection criterion.

Programs were contacted by phone and email and sent a formal invitation to participate in the study. Upon their acceptance to participate in the study, programs were asked to submit recent annual reports, teaching manuals, program schedules and agendas, and other related material that would prove beneficial to this study. Each program was sent a survey that asked program administrators to describe program components (Appendix I).

Table 4. Programs and the selection criteria

<table>
<thead>
<tr>
<th>Program Selection Criteria</th>
<th>Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Long-term (~2 weeks)</strong></td>
<td>A</td>
</tr>
<tr>
<td><strong>Target low income and/or ethnically diverse inner city youth</strong></td>
<td>X B C</td>
</tr>
<tr>
<td><strong>Participants entering the sixth, seventh or eighth grades</strong></td>
<td>X X X</td>
</tr>
<tr>
<td><strong>Serves at least 25 participants</strong></td>
<td>X X X</td>
</tr>
<tr>
<td><strong>Positive reputation (documented or been in existence long time)</strong></td>
<td>X X X</td>
</tr>
<tr>
<td><strong>Voluntarily sought out</strong></td>
<td>X X X</td>
</tr>
<tr>
<td><strong>Funded by government agency</strong></td>
<td>X X C</td>
</tr>
<tr>
<td><strong>Have varying pedagogical and curriculum Approaches</strong></td>
<td>X</td>
</tr>
</tbody>
</table>

**Program A Overview.** Established in 1988, Program A is for minority middle school students, entering the seventh and eighth grades who are interested in learning about and pursuing an engineering career. Opening its doors to students from around the country, it is a
nationally recognized program. The three-week residential summer engineering program provides experiences for 40 to 60 underrepresented minority students to increase their academic knowledge in mathematics, science, physics, computer skills, and language arts. In addition, personal career development techniques were also addressed.

The program director describes Program A as being designed to build students’ confidence in their ability to succeed in the world both academically and professionally. The major components of Program A are mentorship, career preview, academic coursework, and introduction to college life. In order to accomplish its overall goal, the program has seven program objectives:

1. Strengthen students’ skills in mathematics, physics, computer science, and language arts;
2. Teach written communication skills;
3. Increase students’ preparedness for college;
4. Increase motivation and ability to achieve in college classes and research;
5. Provide exposure to the college environment;
6. Expose participants to field trips to enhance them culturally and socially about engineering topics;
7. Introduce participants to engineering careers and research opportunities.

The target student population of Program A is African Americans, Hispanics, Asian-Pacific Islanders and females. In the past twenty years, the program has hosted over 1500 hundred students. In 2009, Program A’s demographics included 88% African-American, 10% Hispanic, 2% Asian-Pacific Islander and 48% female middle school students. The program director reports that most of the students were from low-income households, a description
determined by submission of free and reduced lunch forms. The program recruits participants by email, websites, announcements to school districts, church and local organizations, as well as alumni.

Today, Program A is supported by the generous participation of several corporations, the National Science Foundation and the host university. Program A is hosted by the largest university in a state located in an urban area of the Midwest region of the United States. Over 28,000 students attend the university, and enrolled in one of 300 degree programs, 14 of which are engineering undergraduate and 21 graduate programs. The university’s underrepresented demographics include 51% female, 8.7% African-American population, 1.5% Hispanic and 2.9% Pacific Islander. The College of Engineering Diversity Programs department uses Program A as a recruitment effort.

Program A reports that their objectives have been achieved over the past five years due to 60% of their student participants having majored in science or engineering upon entering their college career. The participants complete a post-program survey yearly to track their progress and careers. Of the students surveyed, 63% obtained Bachelor of Science degrees, 22% obtained Master of Science degrees, and 8% obtained other professional degrees.

**Program B Overview.** Since 2000, Program B was instituted to be a comprehensive program for students entering the seventh and eighth grades and for middle school science, mathematics, language arts, and social studies teachers in their local area. The overall goal of Program B is to identify underrepresented minority middle school students and teachers from both a rural and urban setting and progress them through a pre-designed, intensive science and engineering training program that focused on student outreach and curriculum development. This is the only summer STEM program found to provide professional development to middle school
teachers and have those same teachers introduce STEM education to middle school students. The teachers attend at least 4 professional development sessions, and the students attend a four-week day program.

In order to accomplish its overall goal, Program B has two objectives:

1. Combine information technology supported instruction in STEM teaching, learning, and mentoring in a systematic manner, via teacher professional development activities;
2. Provide standard-based, challenging courses in curricula, but also a secure properly sequenced enrollment of all students in the introduced courses.

The major components of Program B are career preview, academic coursework, and increasing students and teachers STEM content knowledge and interest. The teachers also acquire knowledge and skills that transfer directly into their regular classrooms. The students are presented and immersed in the world of STEM by showcasing the critical role of engineers with real-world scenarios that affect their community.

The target student population of Program B is African Americans. In the past nine years, the program has hosted over 500 hundred students and 100 teachers. In 2009, Program B’s student demographics included 100% African American and 42% female middle school students. Program B’s teacher demographics in the same year included 100% African American and 60% female; 30% of the teachers taught mathematics, 50% taught science, 15% taught language arts and 5% taught social studies. The program director reports that most of the students were from various socioeconomic backgrounds. The program recruits from two local public school systems, rural and urban, through distribution program advertisement to teachers and parents.
Program B’s community partners include the National Science Foundation, two local school systems, the host university, local community organization and professional societies. Program B is hosted by a Historically Black College and University located in the Southern region of the United States. Over 4,000 students attend the university, and enrolled in one of 60 degree programs, 6 of which are engineering undergraduate and 6 engineering graduate programs. The university’s demographics include 58% female, 96% African American population, 1% Hispanic, and 3% Caucasian.

Program B has not yet begun to track their participants’ interest and/or success in the STEM disciplines. They intend to track their past and current participants through mailings and internet social networks in the near future.

Program C Overview. Founded in 1998, Program C is a two-week residential program seeking to enhance the middle school learning experience and to increase participants’ interest and career choice of science, mathematics and engineering discipline. African American students entering the sixth, seventh, and eighth grades are introduced to an integrated approach of science, technology, engineering and mathematics that includes the knowledge, skills, and experiences students need for academic success, life-long learning, and to become active participants in a technological rich society.

The major components of Program C are mentorship, urban education, project based inquiry learning, career preview and academic coursework. Program C has six guiding principles in which the program administrators attempt include in their curriculum and program activities to enhance the STEM knowledge, skills and experiences of the students:

1. Develop students’ research, problem-solving, and communication skills;

2. Incorporate technology into all program activities;
3. Include hands-on activities requiring the involvement of students in exploring real-world problems, questions, and answers;
4. Include career awareness;
5. Provide a structured and safe environment during the learning process.

The mission of Program C is to reach middle school students who may have little interest in science, get them excited about science so that they can become science literate and choose STEM as a career.

The target student population of Program C is African Americans. In the past twelve years, the program has hosted over 5,000 students. In 2009, Program C’s demographics included 100% African American and 45% female middle school students. According to Program C’s 2009 annual report, the program targets students from low-income households but accepts students from all socioeconomic backgrounds. The program recruits participants by promoting STEM education to public school teachers, administrators, community leaders, and youth advocates.

Generously supported by a private foundation and the host university, Program B is located on a Historically Black College and University campus located in the Southeast region of the United States. During the 2008-2009 school year, approximately 5,500 students attended the university, and enrolled in one of 100 degree programs, 10 of which are engineering undergraduate and 12 graduate programs. The university’s demographics include 62% female, 98% African American population, 2% Other.

Program C reports that their objectives have been achieved over the past twelve years due to at least 50% of their students having majored in science or engineering upon entering their college career. The participants complete a post-program survey yearly to track their progress.
and careers. Of the students surveyed, 80% obtained Bachelor of Science degrees, 30% obtained Master of Science degrees, and 12% obtained other professional degrees.

**Existing Program Evaluation Results Summary**

The programs’ curriculum was analyzed to determine the trend of current best practices. The additional research questions, in conjunction with the overall research questions, were asked in survey format, analysis of curriculum materials and follow-up interviews to determine the curriculum components of each program. The additional research questions were composed to make this study more information rich.

Analysis of the three programs reveal a pattern of best practices, curriculum components, motivation techniques, learning theories and pedagogical approaches that are currently used in today’s summer engineering programs.

Several additional research questions were asked to provide a holistic view of the program’s curriculum components: What are the similarities/differences in each curriculum? Do these programs use tested cognitive learning theories to justify their methods? What are the administrators’ reasons for choosing the curriculum for the program? What is the curriculum based upon and why were these particular standards chosen? What are the similarities and differences in pedagogical approaches? Do these programs use the approaches proven to be useful in non-traditional settings, especially with minority students?

Each program followed a curriculum developed by their administrators, including instructional staff comprised of engineering faculty, undergraduate and graduate students. Table 5 summarizes the guiding curriculum components of each program.

Program’s B and C use hands-on learning activities. Program C also defined their activities through inquiry based learning theories in their annual report. In 2009, Program B
<table>
<thead>
<tr>
<th>Program Components</th>
<th>Program A</th>
<th>Program B</th>
<th>Program C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defined Learning theories</td>
<td>No Evidence</td>
<td>Hands-On</td>
<td>Hands-On, Inquiry-Based</td>
</tr>
<tr>
<td>Defined Teaching Methods</td>
<td>Learner Centered</td>
<td>Community Centered</td>
<td>Community Centered</td>
</tr>
<tr>
<td>Visual Spatial Techniques</td>
<td>No Evidence</td>
<td>Computer Software Usage</td>
<td>Computer Software Usage</td>
</tr>
<tr>
<td>Academic Coursework</td>
<td>Mathematics, Physics, Chemistry,</td>
<td>Middle School Science and Mathematics</td>
<td>Middle School Science, Mathematics, and</td>
</tr>
<tr>
<td></td>
<td>Computer Science, and Language Arts</td>
<td></td>
<td>Technology</td>
</tr>
<tr>
<td>Real-World Application</td>
<td>No Evidence</td>
<td>GIS Technology for Stewardship</td>
<td>Saving the Planet</td>
</tr>
<tr>
<td>Cultural Components</td>
<td>No Evidence</td>
<td>No Evidence</td>
<td>No Evidence</td>
</tr>
<tr>
<td>Middle School Cognition</td>
<td>No Evidence</td>
<td>No Evidence</td>
<td>Journaling</td>
</tr>
<tr>
<td>Science Standards</td>
<td>State Standards</td>
<td>State Standards</td>
<td>Science, Technology, and Mathematics</td>
</tr>
<tr>
<td>Science Standards</td>
<td>State Standards</td>
<td>State Standards</td>
<td>Standards</td>
</tr>
<tr>
<td>Introduction to College Life</td>
<td>Residential</td>
<td>No Evidence</td>
<td>Residential</td>
</tr>
<tr>
<td>Career Preview</td>
<td>Industry Field Trips</td>
<td>No Evidence</td>
<td>Industry Field Trips, Engineering</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Representatives</td>
</tr>
<tr>
<td>ASEE focus</td>
<td>No Evidence</td>
<td>No Evidence</td>
<td>No Evidence</td>
</tr>
<tr>
<td>Mentorship</td>
<td>Special Activities</td>
<td>No Evidence</td>
<td>No Evidence</td>
</tr>
</tbody>
</table>

introduced two engineering topics to their participants, Geographic Information Systems (GIS) and robotics. During the robotics camp, students were placed in teams and instructed to build robots to perform various tasks. The robotics camp created the opportunity for the students to use technology while involved in learning STEM concepts. Students also used GIS computer software to examine coastal properties of their state. In order to prepare the students for the engineering based projects, the students attend science and mathematics lecture and laboratories.
Program B’s administrator stated that “all of our activities provide students with coursework that is aligned to our state’s content standards and benchmarks. We choose these projects because we believed they were relevant to our students’ education, interest, and state objectives, as well as providing a good engineering foundation.” This program also used community centered learning because the administrators believed it was important for the “students and teachers to work together to develop their projects and discover the roles of engineers.” Program B’s teachers participated in a four to five week professional development institute to help prepare for teaching during the summer engineering program and bring the learned information back to their respective schools.

Program C used hands-on and inquiry-based learning to introduce their participants to engineering. During their science courses, the students participated in hands-on demonstrations. Students also applied inquiry-based learning in their research projects. Under the camp theme, “Planet Earth in Crisis,” the participants researched various ways to create sustainable energy sources to gain a more in-depth knowledge and appreciation to the scientific and engineering topics covered in the science, mathematics and technology courses. Program C based their curriculum on the Science, Technology, and Mathematics National Standards. They also used a community centered approach in their classrooms. To reinforce engineering as a career, the program invited practicing engineers to various camp functions and also planned visitations to local engineering facilities.

Program A’s approach to their curriculum was to provide mathematics, physics, chemistry, computer science, and language arts courses to prepare to their students for the rigorous academic course load that undergraduate engineering students endure. The program administrators wanted to strengthen the academic skills of their students to increase college
preparedness. Engineering demonstrations were used in courses to demonstrate that engineering is the application of science and mathematics. Program A used a learner-centered approach, in which the teachers focused on what the students were learning and reinforced learning through lectures and hands-on demonstrations. Program administrators also organized field trips to local engineering facilities so their participants can experience the real-world of engineering.

Program administrators were asked if they considered their program to have visual spatial learning, middle school cognitive, and cultural awareness foci. Programs B and C found that students learn visual spatial techniques through their computer software activities. “Students use GIS software in our program that helps them to visualize the world in 3-D. We believe that the use of the GIS software helps the students use a familiar tool, the computer, to build a technique that will help them in engineering,” said Program B administrator. The Program C administrator informed the researcher that “the use of graphing tools like Microsoft Excel and ArcView help the students learn how to visualize data like engineers do in their workplace.”

The researcher asked all program administrators whether or not they considered the cognitive and social changes of middle school students when composing their program’s curriculum. The only program to have evidence of considering the middle school cognitive and social abilities was Program C. Program C uses journaling sessions with their students in which the students are given writing prompts to help express their ideas, beliefs, and feelings about the program and potential engineering careers. The journaling sessions also asked the students to describe their thoughts regarding their home environments, greatest fears, fashion trends, and other issues that currently affect their lives. Programs A and B both reported that they believed the program’s instructors would be able to effectively “deal” with middle school students.
Cultural awareness was described to the administrators as a component in which the program inserted student’s community attributes and learning styles through activities, instructional methods field trips or more. None of the programs had evident cultural awareness components in their curriculums and on the survey all answered that they did not have cultural awareness embedded in their curriculum. When asked about the decision not to include their participants’ background, culture, and community in the program, each program administrator had similar responses.

Administrators for Programs A and B both believed that students will receive natural cultural awareness by interacting with the undergraduates leading program events and with their fellow participants. “Our students experience the culture of engineering. It is imperative that they learn about the facets of engineering life, as a student and an engineer,” said the administrator for Program A. The administrator for Program B stated that “it is important that students know what it is like to be immersed in the culture of engineering and understand that engineers think in a particular fashion to solve the world’s issues. We understand that their culture is important, but it is important that they understand engineering fully to become engineers.” Program C also admitted that their program is about students learning the importance of the engineering culture. Program A discussed how mentorship plays a role in their students’ cultural awareness.

According to MentorNet (2010), an online mentoring network for underrepresented students in engineering, mentorship is defined as “supportive relationship established between two individuals where knowledge, skills, and experiences are shared. The mentor is a person who has expertise and is able to share their wisdom in a nurturing way.” Program A is the only program that had a structured mentorship program in place for their participants. Program A scheduled mentorship activities with their program counselors, engineering undergraduates. The
program counselors were assigned three to five students in which they served as personal mentors. During various times of the program, the counselors would hold focus groups and social activities to discuss college life, engineering studies, and the importance of internships, resume building, and other topics of interest to the program’s participants. Program A’s director believed that his undergraduate students were “great role models for our participants. The participants could use them as an example of a person who they can relate to and view as similar as themselves.”

Programs B and C did not have definite mentorship activities scheduled. Those program administrators believed that their counselors would assume a natural mentor role and have discussions during various times of the program.

**Innovative Curriculum**

The following curriculum was designed by the researcher and used the theoretical concepts identified in the literature review, as well as the use of best practices identified in the evaluation of Programs A, B, and C.

**Unit One Summary.** America’s infrastructure is currently aging and failing. The National Academy of Engineering, commissioned by the National Science Foundation, is calling for the modernization of the fundamental structures that provide transportation and support, particularly in the urban areas where the populations are large. The purpose of this unit is to study forces and motion through learning about various bridges, especially those in the students’ community that may experience failure due to natural disasters, i.e., hurricanes, earthquakes, and more. The students will study and develop ideas on how to build natural disaster-safe bridges and eco-bridges with limited resources in an urban environment. After the unit, those ideas will be
presented to experts in civil engineering and urban infrastructure. Unit One can be found in Appendix A.

**Unit Two Summary.** Many people do not understand the purpose of NASA and how it relates to their world. Students will be introduced to the components of the solar system by taking on the role of astrologer, researcher, and project designer. The main focus of this unit is discussing the differences and similarities in planets, the earth’s characteristics and space exploration. Students will study the earth and what makes it different from other planets and celestial bodies. Students will also be asked to discover the personal lives, experiences, and history of underrepresented astronauts to provide a historical perspective of how astronaut’s research and background has impacted the students’ lives. Unit Two can be found in Appendix B.

**Unit Three Summary.** With the current use of personal or at-home technology at an all time high, it is imperative for students of all ages to understand how the electronics they use actually operate, and how the use or misuse of energy affects their everyday lives. The purpose of this unit is to look at the transfer and conservation of energy through the use of electricity, heat and light of everyday household items such as, cell phones, games consoles, iPods, and more. After students learn about energy, they will devise a strategy that their families could adopt that would help save energy. Students will present their plans to experts in the energy field, which will consist of parents, scientist, teachers and energy executives. Unit Three can be found in Appendix C.

**Innovative Curriculum Evaluators Profiles**

The proposed curriculum was evaluated by five expert engineering program administrators and/or educators. All evaluators selected are not associated with the programs
studied and they are all involved in designing engineering curriculums for elementary and secondary students. Evaluators were identified through various sources. Of the five evaluators, three were suggested by the administrators of the existing programs that were evaluated. The remaining two evaluators were administrators from the programs that did not want to have their curriculums evaluated during phase one of this study. Table 6 provides a full summary of teachers’ demographics, including teachers’ educational and teaching backgrounds.

Evaluator One is an African American female, who earned a Bachelor of Science degree in Mechanical Engineering and a Master of Science degree in Higher Education. She is currently employed with a university located in southern California as a Minority Engineering Program Director in which she oversees programs for middle and high school students interested in engineering. After graduating from her undergraduate program, Evaluator One taught middle school and high school science and mathematics for six years.

Evaluator Two is a White female, who earned a Bachelor of Science degree in Biology, a Master of Science degree in Environmental Science, and Doctor of Philosophy in Science Education. She is currently employed with a university in New York as an Associate Professor in the School of Education and as an administrator of an urban, science education institute that introduces STEM concepts to middle school students in the community through outreach programs.

Evaluator Three is an African American female, who earned a Bachelor of Science degree in Chemical Engineering and a Master of Science degree in Secondary Education. Evaluator Three is currently a Master Teacher and Curriculum Developer with a school system located in the state of Louisiana. Evaluator Three teaches middle and high school teachers how
Evaluator Four is an African American male, who earned a Bachelor of Science degree in Physics, a Master of Science Degree in Secondary Education, and a Doctor of Philosophy in Physics. He is a Professor of Physics and Executive Director of a engineering academy that introduces STEM to middle school, high school, and incoming college freshman at a university in Alabama. Evaluator four has taught at the middle school, high school, and collegiate levels for over thirty years.

Evaluator Five is an African American female, who earned a Bachelor of Science degree in Chemical Engineering and a Doctor of Philosophy in Science and Technology Education. She is currently employed as an Assistant Professor in a College of Education in Florida. She also serves as a Co-Director for a program that introduces engineering and technology to underrepresented middle and high school students. Before becoming a professor, Evaluator Five served as a middle school teacher in the states of Texas, Michigan, and Florida.

**Innovative Curriculum Evaluation Results Summary**

The evaluators assessed the innovative curriculum to determine if it contains the concepts identified in the literature review and best practices that have been proven to be successful using the survey provided in Appendix G. Part one of the assessment survey required the evaluators to rate the level of evidence each category exists in the proposed curriculum. The rating scale was a 5-point Likert Survey, ranking categories from 0 for no evidence to 2 for moderate evidence to 4 for overwhelming evidence. Evaluators ranked each category with either a 3 or 4. The researcher contacted each evaluator, by phone, after they completed the survey to ask for
clarification regarding their responses to survey questions. Table 7 summarizes the rating results for each category.

Table 6. Demographics of curriculum evaluators

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Evaluators</strong></td>
<td>5</td>
</tr>
<tr>
<td><strong>Evaluators Gender</strong></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>80%</td>
</tr>
<tr>
<td>Male</td>
<td>20%</td>
</tr>
<tr>
<td><strong>Evaluators Race</strong></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>20%</td>
</tr>
<tr>
<td>Black</td>
<td>80%</td>
</tr>
<tr>
<td><strong>Education Background</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60% earned Doctoral Degrees</td>
</tr>
<tr>
<td></td>
<td>40% earned a Masters Degree</td>
</tr>
<tr>
<td></td>
<td>60% earned a Bachelor's Degree in Engineering</td>
</tr>
<tr>
<td><strong>Areas of Specialty</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100% Engineering Education</td>
</tr>
<tr>
<td></td>
<td>60% Science Education</td>
</tr>
<tr>
<td></td>
<td>20% Technology Education</td>
</tr>
<tr>
<td></td>
<td>40% Educational Leadership</td>
</tr>
<tr>
<td></td>
<td>20% Adult Education</td>
</tr>
<tr>
<td><strong>Dominate Grade Level Taught</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100% College</td>
</tr>
<tr>
<td></td>
<td>80% Sixth, Seventh and Eighth Grades</td>
</tr>
<tr>
<td></td>
<td>40% Ninth, Tenth and Eleventh Grades</td>
</tr>
<tr>
<td><strong>Average Years Teaching Experience at the Middle School Level</strong></td>
<td>7.5</td>
</tr>
<tr>
<td><strong>Average Years Teaching Experience at the High School Level</strong></td>
<td>8</td>
</tr>
<tr>
<td><strong>Average Years Teaching Experience at the Collegiate Level</strong></td>
<td>13.5</td>
</tr>
<tr>
<td><strong>Board Certified to Teach at the Middle or Secondary School Level</strong></td>
<td>100%</td>
</tr>
</tbody>
</table>

All of the categories had a rating average of 3.4 or higher. Two categories, spatial visualization development and support of the ASEE vision of improving knowledge of
Table 7. Rating results for the categories of the proposed curriculum evaluation survey

<table>
<thead>
<tr>
<th>Category/Component</th>
<th>Rating average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>The curriculum contains activities to help students gain/increase spatial visualization or the ability to mentally manipulate 2-D and 3-D figures.</td>
<td>100%</td>
</tr>
<tr>
<td>The curriculum contains activities that enhance meaningful learning. Are the activities relevant to the learner? Do they have the potential to be meaningful?</td>
<td>40%</td>
</tr>
<tr>
<td>The curriculum contains activities that enhance students’ graphical design ability, focusing on the role of visualization and drawings as tools to properly understand and convey engineering principles.</td>
<td>20%</td>
</tr>
<tr>
<td>The curriculum contains the important concept of cultural capital (i.e., factors that constitute a cohesive, recognized group’s cultural identity).</td>
<td>60%</td>
</tr>
<tr>
<td>The curriculum contains activities and concepts that take into consideration the cognitive abilities of middle school students in grades 7 and 8 to perform analytical reasoning.</td>
<td>20%</td>
</tr>
<tr>
<td>The curriculum contains activities and concepts that take into consideration the behavioral attributes of middle school students.</td>
<td>40%</td>
</tr>
<tr>
<td>The curriculum is geared toward the education of African American students. Therefore, the curriculum contains the cultural learning styles of African Americans.</td>
<td>60%</td>
</tr>
<tr>
<td>The curriculum supports the K-12 American Society of Engineering Education (ASEE) vision of improving the knowledge of engineering concepts for students by presenting engaging, hands-on, minds-on engineering activities that are of high interest to African American middle school students.</td>
<td>100%</td>
</tr>
</tbody>
</table>

engineering, received a perfect rating score of four. Evaluators saw room from improvement in two categories: the curriculum contains the important concept of cultural capital and is geared toward the education of African American students. Although there rating averages were a 3.4, the teachers expressed concern that the cultural connection was not strong enough. Evaluators were also asked to provide additional comments on the electronic survey and during phone interviews regarding their rating choices.
Evaluators Three, Four, and Five all had similar comments regarding the cultural learning themes in the curriculum. They believed that the curriculum could be made stronger by possibly using the Interactive Historical Vignette (IHV) in all three curriculum units. Evaluator Five stated “the IHVs that you use are very similar but different than your normal skit. They allow students to take on different roles, but also force them to take a strong and in-depth look in the scientific nature of the scientists in question.”

Evaluators Three and Four believe that the underlying tones of cultural awareness may not be vivid enough for teachers to relay properly. “It is obvious to me that your curriculum has the student’s culture in each unit through studying urban infrastructure, potential role models that explore space, helping their homes to be green, and also some teamwork techniques used, but you may want to think about using obvious markers of direct cultural awareness,” said Evaluator Three. Evaluator Four suggested that the curriculum be accompanied by a guide that directly points out theoretical themes the researcher incorporated.

Evaluators Three, Four, and Five all asked if it would be possible to use the researcher’s curriculum in the near future. Evaluator One stated “the curriculum is very well written. It does an excellent job of integrating culture and real-world projects. Students can see that others like them have been successful in the field of science and engineering and as students matriculate through the program they can even see themselves as engineers (which is most important).”

Evaluator Two relayed her joy is reading the visual spatial learning aspects the researcher displayed in the curriculum. When contacted about her responses, Evaluator Two thanked the researcher for showing the importance of visualizing the world in the curriculum. “We focus so much on teaching our children how to use computers for 3-D learning, we forget to teach them the basic steps of learning how to draw in 3-D” said Evaluator Two. Evaluator One suggested the
use of concept maps more frequently. “Your students can use them during their design process as a brainstorming technique. You would really be able to see if they learned how to apply the concepts if they self generated concept maps at various stages.”

Evaluator Five reminisced about learning and using a computer aided drawing system during the beginning of her engineering career. “As engineering undergraduate students, our professors didn’t teach us how to draw the world by hand. My classmates and I knew that computers weren’t always around, but when we asked about previous techniques we were often told that it was best we use new methods. You would think I would use my negative experiences and teach our students to learn to see the world by using their natural mind. But most of us fall victim to the cloning that takes place.” The researcher asked Evaluator Five to elaborate on what she meant by “cloning,” and she responded that she believes “engineering faculty are making clones of themselves. The typical engineering faculty believes that culture has no place in the classroom, and they teach their students to solve equations, but not to solve cultural engineering problems. Therefore, they believe all engineers should think and act alike.”

Evaluators gave the researcher valuable insight into understanding how the curriculum can be improved and strengthen to accomplish the main goal. At this point in the survey, the overall impression of the interviewed evaluators is that three unit curriculum can make a great impact on the lives of those it intends to target.

The evaluators were also asked by the researcher to use their education and experiences to determine whether or not the theoretical components used could be effective and successful methods in the “real-world” by rating statements. Evaluators were also asked to provide additional comments on the electronic survey and during phone interviews regarding their rating choices. The evaluators used a 5-point Likert Scale to rate statements. Evaluators ranked each
statement with either a 4 for agree or 5 for strongly agree. All of the statements had a rating average of 4.6 or higher. Out of eight statements, four received a rating average of five for strongly agree. Table 8 summarizes the rating results for each statement.

Evaluator Four stated, “I believe this curriculum takes the basic concepts of similar programs and has developed a more in-depth program based on the national standards” when asked about the innovation of the curriculum. He further affirmed that the researcher’s curriculum does an “excellent job of introducing engineering to the impressionable minds of middle-school students.” Evaluator One acknowledged the use of real-world activities throughout the entire curriculum stating, “The real-world activities are excellent and will help students see that science is something that they experience on a daily basis, not just in the classroom, so hopefully they can truly see themselves as engineers through your work.”

Evaluator Three compared the researcher’s curriculum to the science curriculum in the traditional classroom. “As a former teacher in a public school system, it was very difficult to implement new concepts that would help our students experience science and engineering in a way the students can really learn how to become engineers and scientist. I believe your approach and real-world activities you are suggesting will help them become engineers. This is what I love about summer programs; they are flexible to implement what our students truly need,” said Evaluator Three. Evaluator Two added that “from my experience, middle school students need more interaction with students and they need to be put into situations that allow them to think like professional scientist and engineers. Your curriculum does and has all of the above.”

The responses to the rating statements of the evaluation survey revealed to the researcher that the evaluators enjoyed reading about a different approach to teaching STEM and various components to middle school African Americans. It also revealed that the expert evaluators
Table 8. Rating results for the statements of the proposed curriculum evaluation survey

<table>
<thead>
<tr>
<th>Statements</th>
<th>1 (Strongly Disagree)</th>
<th>2 (Disagree)</th>
<th>3 (Not Sure)</th>
<th>4 (Agree)</th>
<th>5 (Strongly Agree)</th>
<th>Rating average</th>
</tr>
</thead>
<tbody>
<tr>
<td>The proposed curriculum has relevant activities that will interest underrepresented students in engineering.</td>
<td>20%</td>
<td>80%</td>
<td></td>
<td></td>
<td></td>
<td>4.8</td>
</tr>
<tr>
<td>The proposed curriculum is written at a level appropriate for a middle school audience.</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>The proposed curriculum addressed the expectations of the national standards.</td>
<td>20%</td>
<td>80%</td>
<td></td>
<td></td>
<td></td>
<td>4.8</td>
</tr>
<tr>
<td>The proposed curriculum has relevant learning theories that will interest underrepresented students in engineering.</td>
<td>20%</td>
<td>80%</td>
<td></td>
<td></td>
<td></td>
<td>4.8</td>
</tr>
<tr>
<td>The proposed curriculum will help students &quot;see themselves as future engineers.&quot;</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>The proposed curriculum differs from existing summer engineering programs' curricula.</td>
<td>40%</td>
<td>60%</td>
<td></td>
<td></td>
<td></td>
<td>4.6</td>
</tr>
<tr>
<td>When implemented, the proposed curriculum has the ability to achieve its objectives.</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Would you use this curriculum in its entirety?</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

When asked “What do you like most of about the proposed curriculum,” the evaluators gave the following responses:

1. The real-world application of the concepts because it is important that students are able to apply what they learn in the classroom.

2. The aspect of the curriculum that I like most is the fact that it incorporates different aspects of engineering. Most middle school students do not comprehend what engineering actually entails or they believe that engineers only do one specific type of work.
3. I like the variety of activities that are included in this curriculum. Students will experience the breadth of the field of STEM which will hopefully allow them to make more informed decisions about what STEM field they will pursue in the future. It is refreshing to see a different approach to teaching engineering. We all get stuck in the traditional learning and teaching techniques, and because of the repetition, our students are not receiving the appropriate strategies.

4. African American middle school students will be able to gain the confidence they need to excel in a field they do not see every day. Your curriculum will put them in a different learning environment, therefore in a different world.

When asked, “What do you dislike about the proposed curriculum,” several of the evaluators provided the following responses:

1. Some areas may require more background information.

2. There were no aspects of the curriculum that I particularly disliked. I would personally institute the curriculum into a summer program for middle school students.

3. In the building a green home activity I would have preferred if students could use more real-world materials versus the materials listed in the current curriculum.

When asked, “What suggestions do you have for improvement,” several of the evaluators provided the following responses:

1. More background for those who may want to use the curriculum but not familiar with all engineering terminology.

2. The only suggestion I would have for the curriculum developer is the possibility of offering a workshop to train potential users of the curriculum. Often programs adopt
curriculums, but do not institute the curriculum in the manner in which it was intended.

3. The only concern I have with the proposed curriculum is the length of time allotted for each activity. Students have different prior knowledge and experience and may need more remedial work in the beginning of each activity to help them be successful in the end. On the other hand, if you have an advanced group of students then the time allotted may be too much and additional activities may need to be created to further challenge the students. These activities could be based on the same activities but require students to use higher order thinking skills to evaluate what they have done and transfer that knowledge to other situations.

Several themes emerged from evaluators’ comments regarding the strengths and weaknesses of the curriculum: increase cultural content instruction, consideration for students on different levels, in-depth real world view of engineering, effective visual techniques, summer engineering program as a change agent, innovative and different approach to teach engineering to the target population, and role-playing is an effective tool for middle school student learning and confidence building. The evaluators were also asked to assign a grade to the overall quality of the curriculum by using a 5-point Likert scale, one for low quality and five for high quality. All five evaluators gave a perfect rating of five.

Overall, the survey responses were proven to aid the researcher in determining the innovation and effectiveness of the curriculum. The potential effect the curriculum will have on middle school African American students will be endless because each evaluator has expressed a need for new techniques to be used to inspire and ignite STEM learning in the middle school underrepresented students. The evaluator’s input was extremely important because it will further
help the researcher to improve and shape the growth of future endeavors. At the end of evaluating existing programs, all of the administrators expressed interest in the researcher’s findings to hopefully improve their work and learn about other programs success.

**Researcher’s Reflections**

The evaluation of each existing program gave the researcher great insight into current programs and their practices. The ability to discuss older theories and ideas about educating an underrepresented group of students and generate new ideas with future colleagues was an exceptional experience for the researcher. The researcher was able to reflect on previous work to ensure the developed curriculum was innovative and effective.

The researcher thought that some of the existing program administrators were not completely honest in sharing their complete curriculum design principles and found inconsistencies on their website and in their reported results. The researcher found the program administrators to be hesitant to participate in the study for reasons that were not completely clear. On several occasions, the researcher stressed to each administrator the importance and value in showcasing the strides that are being made to decrease the achievement gap between the underrepresented and introduce engineering to people who may not have access to it but they still declined to participate in the study.

The process of creating the innovative curriculum was especially phenomenal and personal for the researcher. The researcher had the opportunity of creating a piece of work that she thought about while crossing a university campus at least seven years prior to beginning the formal research process. Many secondary education, higher education and professional experiences shaped the researcher’s final product. While serving as a tutor to underrepresented students in an introduction to engineering program for incoming college freshman, the researcher
began to reflect on her own elementary and secondary education background and came to the realization that engineering was a goal placed out of the reach of most underrepresented students. She wanted to change that fact. When she received the evaluators’ comments and rating scores, the researcher was overwhelmed with joy that her peers could see her vision and approved.
CHAPTER 5. SUMMARY, CONCLUSIONS, AND IMPLICATIONS

Summary

The scientific education community has focused an immense amount of effort in trying to increase the interest, participation, understanding, and academic achievement of science, technology, engineering, and mathematics (STEM), especially with underrepresented minorities. In order to accomplish the effort, educators are attempting to develop new ways of presenting STEM concept and theories. In an attempt to support the scientific education communities’ efforts, this research focused on devising a new strategy and curriculum for urban middle school minorities to maximize STEM interest and achievement with predetermined theoretical concepts. The following primary research question was the epicenter of this study that led the methods and implementation: What theoretical learning impact will a proposed innovative summer engineering program and its integrated components have upon underrepresented middle school students’ interest in and understanding of real world engineering? This research was carried out in two phases: evaluation of existing summer engineering programs curricula and development and evaluation of researcher’s innovative curriculum for a summer engineering program.

Investigating three successful existing programs’ curriculum for best practices helped to guide the researcher on determining what current curriculum components are being effectively used and why program administrators chose to use those particular methods. The programs were chosen by using criterion and convenience sampling strategies after the researcher identified the programs with the use of several summer pre-engineering programs and education databases, as well as thorough searches on the Internet. The researcher developed a curriculum for an underrepresented population in the STEM disciplines based on visual learning principles, the Human Constructivism theory of learning and cultural learning styles of minority students. The
proposed innovative curriculum was evaluated by five experts in the summer engineering education program community. The curriculum evaluators were also chosen based on criterion and convenience sampling.

Conclusions

To evaluate the research, one main question and three sub-questions were answered. The answers to these questions are as follows:

Main Question

What theoretical learning impact will a proposed innovative summer engineering program and its integrated components have upon underrepresented middle school students’ interest in and understanding of real world engineering?

The proposed innovative summer engineering program was created with the intent of ensuring all of its combined, defined, and tested components and methods would have a positive and exponential impact on minority middle school students’ interest and understanding of engineering. The components of the curriculum were chosen based on the learning needs of the students and the structure and organization of cognitive and visual spatial abilities of future engineers. The curriculum included the Human Constructivist learning theory, the cognitive and social behavioral theories of middle school students, visual spatial and graphic design learning theories, cultural awareness principles, learning styles of African American, and basic engineering concepts. Additionally, a summer program was chosen as a vehicle for delivery of the components due to the ease of providing a multidimensional learning opportunity through a flexible, informal setting; informal programs make engineering accessible by providing the needed resources and avenues to explore topics of interest to the impacted community. Experts in the engineering education field, particularly with minority elementary or secondary students,
were chosen to evaluate the curriculum to support the suggested theoretical learning impact, as well as the innovativeness of the curriculum.

The evaluators predicted the new and improved curriculum developed by the researcher indeed has the capability to have a strong and positive impact on its target population. Through their experience and expertise, the evaluators believed the proposed curriculum was different from what they had previously seen and combined new and previously unused techniques to educate minority middle school students on what engineers do and who engineers are. The evaluators rated the evidence the pre-defined, theoretical components existed in the curriculum with zero (no evidence) being the lowest and four (over-whelming evidence) being the highest rating. All of the components were rated with either a three or four, with an overall rating average of 3.7. The evaluators also rated whether or not the proposed methods would be successful and effective by rating statements. All of the statements were rated from one for strongly disagree to five for strongly agree. The statements were rated with an overall average of 4.875.

The evaluators were able to identify each component in the curriculum with great confidence. The evaluators stated the combined curriculum components would help the students to understand the topics and strongly agreed that it contained relevant activities that will interest minority students. The evaluators also stated the three unit curriculum provided a meaningful experience that would help the students to connect their world and a previously unknown world to engineering. They especially agreed with the use and amount of visual spatial learning the curriculum will accomplish, suggesting that the curriculum could possibly enhance the students’ graphical design and visual spatial ability.
Most importantly, the evaluators supported the curriculum to consider and help middle school students to perform analytical reasoning and other behavioral abilities that are age appropriate. All five evaluators concluded that although cultural awareness existed. However, the evaluators have suggested that the researcher make an even stronger connection to the students’ cultural awareness. When implemented, the evaluators strongly agreed that the proposed curriculum has the ability to achieve its objects, and have all suggested that they would use the curriculum in its entirety. From the evaluation survey results, the researcher concluded that the curriculum’s theoretical learning impact would be substantial due to the combination of the components. The proposed curriculum theoretical components were evident in several areas of the curriculum (see Appendices A, B, and C).

Additional sub-questions were asked to support the primary research questions. The additional sub-questions were also raised to ensure the innovative curriculum was indeed innovative with its various components, different from current programs’ curricula and capable of increasing interest and ultimately the United States STEM workforce.

1. What set of relevant learning/visual design theories and innovative practices seems best suited to design the curriculum of such a STEM workforce-oriented summer engineering education program, and how does the proposed innovative program differ from existing programs currently serving similar populations?

The researcher proposed the curriculum for middle school students because they are considered a forgotten group in the American educational society (Hurd, 1978). Researchers concluded that middle school students, in the traditional educational settings, are not enriched with the necessary strategies and environment to ensure proper learning. Early adolescence thinking includes changes in several cognitive processes: deductive reasoning, decision making,
and memory processes (Byrnes, 2003; Byrnes & Overton, 1986; Keating, 2004; Klaczynski, 1993; Ward & Overton, 1990). Johnson (1978) concluded that the curriculum should emphasize the utilization of knowledge, not just the mastery. Hurd (1978) and Barr (1978) also concluded early adolescences should be placed in different roles.

These changes and recommendations need to be reflected in curricula in order to properly educate middle school students. The proposed curriculum contains several activities that allow students to experience the necessary strategies. Units One, Two, and Three allows each student, in a group setting, to assume the defined roles of engineers to accomplish various engineering tasks. For example, in Units One and Two, students must become a civil or mechanical or electrical engineering project manager, researcher, designer, surveyor or technical writer in order to design a method that helped to build a better bridge for their community. Units One and Two allow students to draw conclusions from conditional premises by challenging them to build replicas of infrastructure based on decisions they make with knowledge they acquire during the experiments or research. Each activity is a prerequisite for the final project and they enrich the students with knowledge for problem solving. Each unit builds upon the students’ spatial working memory ability by reinforcing and allowing students to use visual semantics and language to understand and complete the tasks. These activities were constructed to help students become good decision makers because it will guide them to believe in their own thinking and perspective (Byrnes, 2003; Miller & Byrnes, 2001).

Infusing cultural learning styles into curriculums is essential to the academic and creative achievement of African Americans (Anderson, 1988; Boykin & Bailey, 2000; Delpit, 2006, 2008; Gay, 2000; Nobles, 1980; Shade, 1982, 1986). Boykin (1986, 1994a) and Shade (1983, 1984) identified several African American learning preferences which were used in the
curriculum: kinesthetic processing, verve, oral tradition, visualization, and communalism. All of the activities involve students using their hands and visual ability to design and build the knowledge to become engineers and create the products engineers are responsible for creating. Students will be immersed in an energetic and colorful atmosphere of engineering through a constant and consistent display of engineering through presentations, researching, and building. Oral tradition and communalism are also experienced when students have to participate in group work and present group findings all throughout the curriculum.

Gay (2000) and Delpit (2006, 2008) also suggested that the curriculum should contain information about the history, culture, contribution, and experiences of their respective ethnic group. The students get an opportunity to explore the history and scientific influence of African Americans who aided in space exploration through performing Interactive Historical Vignettes. Cultural awareness or capital was further strengthened in the curriculum with the addition of students’ community into the activities. Cultural capital includes material artifacts that surround the students’ community. Each unit helps the student to learn more about their surroundings and the importance of science and engineering in their community. Unit One introduces them to the importance of America’s aging and failing infrastructure and how engineers apply force and motion theories to build safe bridges; Unit Two helps the student to understand the value of Earth, as well as space and why we explore it; Unit Three teaches about energy, its use and the importance of conserving energy for the safety, and livelihood of the community. All three units incorporate the importance of stewardship, the present and future impact the students can have in their communities.

The Human Constructivist learning theory strengthened the curriculum by supporting the fact that students are meaning makers. Using the students assumed existing knowledge, the
researcher developed the curriculum upon the STEM topics addressed in the National Science Education Standards (1996) for middle school students. The curriculum also supports the Human Constructivist learning theory by allowing students to bring their own personal experiences into their group dynamics. The curriculum uses three Human Constructivist activities: concept mapping, hypermedia and Interactive Historical Vignettes. The students create a concept map in each unit; unit one is on force, two on the solar system and three on energy. The students complete a hypermedia activity during their solar system WebQuest activity. They are also introduced to the human side of space exploration by way of Interactive Historical Vignettes.

Visual spatial and graphic design learning theories were embedded throughout the entire curriculum. Visual spatial ability is the ability to solve engineering problems by use of 2-D and 3-D perception and the understanding of the perceived relations (Sera et al., 2002, p. 19). Tufte’s (1990, 1997, 2001, 2007) graphic design learning theory aids with the proper quantitative and qualitative depiction of engineering problems and solutions. Unit One teaches students the fundamentals of visualizing and then how to translate that into sketching the world. Students use 2-D and 3-D freehand sketching techniques in all three units, especially through problem solving in the engineering design process. Free-hand sketching allows students to kinesthetically learn about visualizing the solutions to engineering problems. The graphic design theory is applied when students are responsible for presenting their design process and ultimately, their final product to the panel of experts. Introducing these very important engineering principles early in the students’ education will hopefully ensure proper techniques will be mastered when students enter their STEM undergraduate careers.

The innovative curriculum differs from existing programs because it appears to be inclusive. The evaluated programs seem to focus heavily on academic coursework instead of
engineering. The programs also typically use hands-on or inquiry-based learning theories, which are more traditional. Currently, program administrators also rely on computer software for visual spatial learning but only if their programs have specialized computer software usage in the activities. Programs have yet to see the importance of traditional visual spatial enhancement. Although the evaluated programs catered to middle school students, there was no evidence that supported techniques to enhance the cognition of middle school students. Some programs have mentorship as a focus, which could be used for the students to have access to adult role models. The innovated curriculum does not have mentorship as a direct focus. Most programs do have students work in groups. None of the programs evaluated focused on the cultural components of the students; instead they focused on the cultural components of engineers. Unlike the existing programs, the innovated curriculum encompasses a strong system of components to help minority middle school students become interested and chose engineering as a career.

2. Why is there an emergent need to increase the USA’s STEM workforce, especially with underrepresented members of the community, and how is the proposed program designed to help these students “see themselves as future engineers?”

There is an emergent need to increase the USA’s STEM workforce because there is a technology and achievement gap between the young citizens of the United States and other countries. The STEM educational community is pushing to achieve scientific literacy for all through reforms and various strategies. Over the past decade, more specialized STEM schools have been established, STEM career and technical education have been strengthened and monetary incentives have been offered (“The Push to Improve STEM Education,” 2008). NACME’s (2008) research has shown that minorities has an even greater achievement gap between other races in the United States. Particularly, the engineering workforce has a shortage
of engineers. The field especially has a low percentage of minorities currently participating and pursuing a degree in engineering. It is important to increase the diversity of the engineering workforce because the United States needs talent that looks very different from the past, and the engineering workforce should reflect the culture and the people it serves (Chubin et al., 2005; NACME, 2008; Wulf, 1998).

The innovative curriculum is designed to help minority middle school students see themselves as future engineers by having them use engineering science and engineering concepts and techniques to become engineers. The researcher developed the curriculum so the students could have opportunities to learn engineering through action and experience, and not solely by lecture and individualized experiments. The curriculum also helps the minority students see how engineering plays a large role in their own community. Using the students’ cultural capital will theoretically increase the interest of STEM, therefore, showing the students how engineers invent, design and build to help improve their world.

3. What is the STEM socialization value and significance of such supplemental summer programs for teaching selected core engineering concepts and projects to the underrepresented members of the community in a visual and experiential way?

Supplemental or informal programs are an invaluable resource in the science, technology, engineering and mathematics reform movement. They are used as venues to increase high school graduation rates, raise in-school and standardized test scores, introduce STEM to students who do not have access, increase the interest in STEM, increase STEM understanding, and more. Higher education institutions, philanthropic organizations, government agencies, private industry and other educational sources have begun to implement varying types of informal programs to either promote their STEM research efforts or recruit students into STEM. Informal programs
give educational administrators flexibility and control to use many learning strategies and
techniques without being bound by the often political word of the public school system.

Informal programs have known to have much success in increasing scientific knowledge,
interest, attitudes, and confidence the students’ ability to do science (Rahm et al., 2005).
Programs have also been documented to have an added value in guiding many of their
participants into STEM careers (Bouillion & Gomez; 2001; Rahm et al., 2005). Unfortunately,
many programs are very vague about how they derived their success outcomes and methods of
achieving their added value (Fadigan & Hammrich, 2004; Hofstein, Maoz & Rishpon, 1990; U.

The underrepresented communities usually reside and attend schools that are in crisis.
Urban schools are typically riddled with deplorable conditions, both in building structure and
learning tools. Textbooks are outdated; funding is limited for quality STEM materials and
resources; certified and qualified STEM teachers are also limited. Most public schools also
attempt to reflect the norm or upper-middle-class values and ideas. Urban middle schools are
typically far from what is deemed the cultural norm. Informal programs are a great vehicle to
open the STEM door to students who maybe disenfranchised.

The researcher developed the innovative engineering curriculum to provide the necessary
visual and practical tools to underrepresented students to become successful future engineers and
learn how engineering influences their world. A major goal of the program is to impart everyday
knowledge to underrepresented students and illustrate how their lives, and more importantly their
ideas, can influence their community. The researcher chose to develop a curriculum for an
informal program so students can experience a classroom with a multitude of resources and
learning strategies that are boundless and especially designed for them. The curriculum allows the students to have ownership of their learning.

**Limitations of the Study**

This research has limited transferability issues due to a small sample size in the exploratory phase. Originally, the researcher identified 11 programs but only 3 programs volunteered to participate in the study. The conclusions drawn from the existing programs research are only transferable to similar programs. The research was also limited due to the credibility of existing program administrator survey answers. Although the administrators may have answered that their program contained a certain element, the researcher at times could not clearly verify those elements in the documents provided.

Limitations also existed in the confirmatory phase of the study. The researcher developed a curriculum based on separately tested theoretical components. The assumption was made that combining those pre-defined components would strengthen STEM access and learning with a particular community. Expert evaluators concluded that the curriculum would definitely have an impact, but the curriculum would definitely have to be fully implemented to test the practical impact. Unfortunately, STEM programs are very expensive to implement. The program cost could range from $5,000 to $50,000 due to the amount of students, staffing, materials, length of program and other necessary costs.

The curriculum is also limited because it does not fully address all STEM components. Although used sparingly throughout the curriculum, technology and mathematics are not acknowledged in depth to demonstrate how they are heavily incorporated, used and needed within science and engineering. Strong mathematic skills have been proven to be a positive indicator for success in engineering disciplines.
**Recommendations for Further Research**

There are many opportunities for this research to be further validated. Due to the theoretical nature of this research, the curriculum could be implemented to further test its validity. The researcher hopes this study could be converted into a National Science Foundation grant proposal to fund a summer engineering program for middle school students. Upon implementation, the researcher can apply pre- and post-knowledge tests, confidence and interest surveys to gauge the effectiveness, and practical impact the curriculum has on the participants’ lives. Focus groups, observations, and other intrusive observation methods could be used to further validate the proposed curriculum. The researcher can also track the progress the students make after participating in the program and determine if the program had an impact on the STEM career choice the students make.

This study focused on students in the middle school years. Future research and curriculum development could be applied to students in the elementary and high school grades. Each level of the curriculum could be used as a building block to the next level. The program’s curriculum could also contain more engineering disciplines. This study only includes several engineering disciplines, but further research could include introduction and projects for all disciplines and in a more in-depth interdisciplinary manner.

Further research could also be completed on existing programs. Best practices can also be identified by studying more programs across various regions of the United States and also for different age groups and ethnicities. Evaluative studies could also be done on these programs. Although program administrators were reluctant to participate in this study, they appear to be more open to national organizations (industry, government, and nonprofit) interest in their
programs. Ethnographic and case studies could be performed on these programs in order to get a
holistic view of the programs’ success and avenues of achieving that success.

This curriculum could also be adapted to align with science and mathematics currently
being taught in the program’s feeder schools to have a better baseline of participants’ prior
knowledge before entering the program. A teacher’s training companion component could also
be developed. Community middle school teachers could be trained to implement the curriculum
during the program. They could use their professional development experience and new learned
strategies to further increase STEM awareness through the critical components identified in their
school communities with other students and teachers having a broader positive impact,
benefitting from the designed curriculum and its integrated components. The curriculum could
also be expanded to use the national technology and mathematics educational standards to be
considered a full STEM curriculum.
REFERENCES


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APPENDIX A. UNIT ONE

“May the Force be with You: Improving our Urban Infrastructure”

I. Unit Summary

America’s infrastructure is currently aging and failing. The National Academy of Engineering, commissioned by the National Science Foundation, is calling for the modernization of the fundamental structures that provide transportation and support, particularly in the urban areas where the populations are large. The purpose of this unit is to study forces and motion through learning about various bridges, especially those in the students’ community that may experience failure due to natural disasters, i.e., hurricanes, earthquakes and more. The students will study and develop ideas on how to build natural disaster-safe bridges and eco-bridges with limited resources in an urban environment. After the unit, those ideas will be presented to experts in civil engineering and urban infrastructure.

II. Curriculum Framing Questions

a. Essential Questions

i. What is the significance and current state of urban infrastructure in our community?

b. Unit Questions

i. What is involved in maintaining infrastructure?

ii. How can you improve infrastructure?

iii. How do you build better infrastructure?

c. Content Questions

i. What types of forces create stability for bridges?
ii. How does motion contribute to bridge design?

iii. What type of bridge designs exist?

iv. What are bridge characteristics?

III. STEM Subject Areas

a. Civil Engineering

b. Environmental Engineering

c. Physics

d. Technology

e. Mathematics

IV. Grade Level

a. Grades 6 – 8

V. Targeted National Science Education Frameworks

a. Content Standards B – Physical Science
   i. Motions and forces

b. Content Standards E – Science and Technology
   i. Abilities of technological design
   ii. Understandings about science and technology

VI. Student Objectives and Learning Outcomes

a. Define and identify forces

b. Learn how to correctly sketch free body diagrams

c. Identify various types of bridges

d. Learn how to use the engineering design process

VII. Length of Time
a. 1.5 weeks

VIII. Lesson Guide

a. Activity 1 – “Sketching and Visualizing the World Around You”

Since the Egyptians built the pyramids, engineers have been using forces and motion to build wonders of the world without the vast technology used today to construct buildings, transportation systems, and more. Egyptian pharaohs and the engineers that were commissioned to design and build the pyramids had to visualize those great three-dimensional wonders and sketch their ideas by hand before implementing them. Today, before engineers begin to build, they also visualize and sketch by hand to begin their process before creating designs by technology.

Visual thinking is the foundation of engineering because it one way engineers can demonstrate how all of the components work together to address the problem. Visualizing and sketching pictures helps the researcher or designer to develop reasoning skills by having to draw conclusions from conditional premises of a mental model and/or demonstrate the sequence of task completion and how each sequence effect the other. Sketching also helps engineers to communicate their ideas effectively to others (non-engineers) in a format that is more universal than a series of equations.

Describe to the students the importance visual spatial thinking and provide 2-D and 3-D images to depict the differences and the importance of each.

Part One: Practice free-hand 2-D and 3-D sketching

Sketching arcs and lines

Explain how all sketches are made of arcs and lines. Instruct the students that they need to first practice sketching straight lines and circles correctly by simple use
of the hand and eye. A straight line should be sketched by sketching the endpoints of the line as small crosses or dots. The students should place their pencil at the starting point, and while keeping their eyes on the endpoint, use a smooth continuous stroke to draw the line between the two points.

**Sketching Circles**

The students should practice circle drawing by drawing light horizontal and vertical lines crossing at the center of the soon-to-be circle. Instruct the students that light hash marks should be created to mark the radius of the circle. Finally, the students should connect the light hash marks or radius marks with a curved line to form a circle. The students should practice drawing circles and lines with quarter square grid paper, or engineering paper (Appendix K).

**Sketching Complete Pictures**

Now that students have practiced sketching lines, circles and arcs by free-hand, introduce how to start sketches of pictures in their entirety. This will prepare them to sketch 2-D and 3-D pictures. When sketching complete pictures, students should follow the three basic steps of creative sketching. Step one: plan the sketch by visualizing it, including the size of the drawing and the orientation of the sketch on the paper. Step two: outline the sketch by using very light lines to establish a very basic drawing. Make sure the students understand that step two allows them how to determine the position, the proportion and the details of the sketch on the paper. Step three: sharpen and darken the lines and add details to develop the sketch.
Level 1 Certification: 2-D Sketching

The students are now ready to practice sketching basic 2-D sketches. Using engineering paper, the students should practice sketching of circles, squares, rectangles and triangles.

After practicing 2-D sketches of geometrical shapes, the students should create 2-D animals from shapes, letter, numbers and things by using the 2-D handout based on Ed Emberley’s Drawing Book of Animals (2006). Explain to the students that Ed Emberley’s series of books help students to draw and see how combining simple shapes could form into complex things. After successful completion of this activity, students are now ready to receive their level one certification and are now ready for level two training (Appendix L). Level one certification is met when students’ drawings are 80% accurate (Appendix M).

Level 2 Certification: 3-D Sketching

The students can now be introduced to 3-D sketching through oblique projections. Oblique projections are basic 3-D sketches in which the face of the picture is not at an angle; it is parallel to the paper. Introduce the following four steps to creating an oblique projection to students.

Oblique projection sketching begins with a 2-D representation of the front face of an object. First, draw horizontal and vertical lines, or construction lines, that outline the face of the 3-D picture. Second, sketch in the face of the picture using the construction lines as a guide. Third, sketch the construction lines that extend into the plane, or angle, of the paper. The third step helps students to block in the 3-D box enclosing the picture. Fourth, sketch in the lines of the remaining picture using the
construction lines created in step three as a guide. Remind students that it is easier to sketch the straight lines and then the arcs or half circles.

**3-D Oblique Projection Sketches**

The students are now ready to practice sketching basic 3-D oblique projection sketches. Using the engineering paper, the students should practice sketching 3-D geometrical shapes. Using the 3-D activity handout, the students should create innovative animals from 3-D geometrical shapes and things, along with numbers and letters. After completion of this activity, students are now ready to receive level two certification, for mastering oblique 3-D drawing (Appendix N). Level two certification is met when students’ drawings are 80% accurate (Appendix O).

**Part Two: Visualizing of forces and motion**

Now that the students are sketching and visualizing experts, on the next topic that will be presented to the students is visualizing and sketching forces, which act on all objects. This activity will introduce forces and motion through sketching and visualizing. It will also introduce free body diagrams and how to identify forces that act on moving and unmoving objects.

Review and discuss with the students the importance of Newton’s first, second and third laws of motion. As a review, students will participate in a brainstorming activity that will be instructor and student driven. “May the Force be With You” Concept Map with Inspiration will be created with the ideas provided by students. This activity will help the students to remember prior knowledge of and identify Newton’s laws, types of forces; it will also allow them to make personal connections with and meaning of Newton’s laws and allow for the teacher to help identify and
correct misconceptions. The instructor will discuss with the students the importance of understanding Newton’s laws and how the applications of those laws are the foundation of engineering.

Engineers and physicists use free body diagrams to analyze the forces acting upon an object. Free body diagrams are simple visual representations that show all contact and non-contact forces acting on an object in a given situation. The diagram helps to solve unknown forces and understand forces in relation to other forces.

There are two steps in construction of free body diagrams: 1) draw the object you want to analyze as a box, and 2) draw each force acting on the object as an arrow pointing in the direction the force is acting. The instructor should discuss and demonstrate examples of forces acting on objects. Using engineering paper, the students will practice drawing free body diagrams of forces in everyday situations acting on everyday objects provided by the instructor (Appendix P).

b. Activity 2 – “My Urban Infrastructure”

Using pictures of healthy and unhealthy urban infrastructure from around the world, discuss with the students the role of urban infrastructure in their lives, their community and the world. Explain how infrastructures in urban areas fail more quickly due to growing population, natural disasters, and accidents causing stress on the systems. There is an abundance of aging and failing urban infrastructure around the world and the cost to rebuild is astronomical. Engineers are challenged to provide economical solutions with limited resources.

For many years, bridges have been long regarded as works of art as well as major transport systems. During this activity, students will learn about bridges in their
communities, as well as discover other types of bridges they may have never seen before. Students will also learn about the forces that act on bridges to help maintain their stability. This activity will also introduce the engineering design process, in which the students will build model bridges, and do research on providing economic solutions to building disaster safe and eco-friendly bridges.

**Part One: Bridge my community**

Discuss with the students that before building bridges, engineers consider a number of factors in the design: shape, size, span, load, environmental factors, soil characteristics of the river banks the bridge will cross, materials used to build the bridge and the budget. Once those specifications are set into place, the engineer can choose the proper bridge for the area.

Provide the students with an informational sheet that describes the types of bridges (Appendix Q). Instruct the students to use the Internet to find pictures of historic and present day bridges that match the bridges on the informational sheet to assist in providing a real-world visual. Instruct the students to also locate pictures of bridges that failed due to aging and environmental issues; this activity should lead to the discussion of how forces and their imbalance could lead to bridge failure.

Discuss with the students the many forces that impact the design of the bridge, including load, compression, tension and shear. All of the previously mentioned forces will be demonstrated in the bridge design project. Using a wooden truss and cantilever bridge models, demonstrate the forces by adding and subtracting weights. Show students that when loads are placed on the bridges, they experience
compression, tension and shear stress. Describe these types of forces with the provided informational sheet (Appendix R).

To further strengthen the importance of rebuilding urban infrastructure and bridges, plan an industry experience with the local Army Corps of Engineers office or Civil Engineering consulting firm in which the organization will plan a field experience tour of past, present and future infrastructure projects. The field experience will allow students to get an opportunity to experience real world applications and interact with design and field engineers to learn about their experiences. After the industry tour, the students will be ready to create their own bridges.

Introduce the students to their model bridge design and testing project. One of the goals of this project is for the students to become actual engineers and use the design method throughout the entire phase of designing and testing their bridge. Most students will be familiar with the scientific method, so it is imperative that a discussion is held to talk about the differences and similarities between the two methods. Use the design method informational sheet handout to aid in the discussion (Appendix S).

The students will redesign a bridge that already exists in their community or design a new bridge that can replace a failing bridge in their community. Another goal of the project is for them to become stewards of their community. As a part of the research process, the students will research and decide on a plan to develop new construction material and methods to address economic and material challenges. Once the bridge design is complete, the students will test their prototype bridge to
determine how much weight it will hold until it fails. The students will also give a PowerPoint presentation to display their design process, knowledge and model to experts.

Divide students into groups of four to six, and assign roles to each team member. Each team should consist of a project manager, researcher(s), surveyor(s), bridge designer(s) and technical writer(s). Explain the roles of the engineering team to the students. As a team, each group should first use the design method in its entirety to ask about the problem or task. Their next step is to imagine the solution and free hand sketch the type of bridge they want to rebuild or redesign on engineering paper and include all measurements.

Once a bridge type is determined, the students should plan the design approach which includes purchasing bridge building materials and supplies from the construction store (the instructor) with the $100 dollars of fake money provided by the instructor, create the model and finally test the model with the purchased weights. The students can buy materials from the following list:

1. 2-ft Wood strips (balsa and/or basswood)
2. X-acto knife
3. Dull knife
4. Long pins
5. Wax paper (18-inch x 18-inch)
6. Masking tape
7. Glue gun
8. 1 Glue stick
9. Glue
10. Ruler
11. Foam board
12. Paper clips
13. Tape
14. Pounds of varying weights
15. Durable string
16. Dowel rods (6 inch)

Discuss with the students the rules and procedures of the project, as well as the safety issues with using some of the materials. Provide baseline rules that could include the following: span of bridge must be at least 1 foot, the width of the bridge must be at least 3 inches, only the materials purchased can be used, and the bridge must be mobile. The students should be given a WebQuest activity to guide them through the design the project, including instructions, roles, research resources and expected outcomes (Appendix T).

At the end of this design project, students should be able to describe their design, incorporating bridge forces in their description. They should be able to explain why their bridge held more or less weight than others, and why their bridge succeeded or failed.

The students should also have identified novel approaches to bridge construction through research, brainstorming and teamwork to provide economic and eco-friendly solutions to bridge construction. The students should present their novel bridge building approaches as a part of their final presentation.
The students will then complete a PowerPoint presentation to demonstrate their process and final project while using Tufte’s theory of graphic design. Using Tufte’s theory of graphic design, explain to students the relevance and importance of using the proper techniques to relay and display quantitative and qualitative information. Refer the students to the section in the WebQuest that explains the dos and don’ts of graphic design theory (Appendix U).
APPENDIX B. UNIT TWO

“Here, There and Beyond: Understanding the World Around Me”

I. Unit Summary

Many people do not understand the purpose of NASA and how it relates to their world. Students will be introduced to the components of the solar system by taking on the role of astrologer, researcher and project designer. The main focus of this unit is discussing the differences and similarities in planets, the earth’s characteristics and space exploration. Students will study the earth and what makes it different from other planets and celestial bodies. Students will also be asked to discover the personal lives, experiences and history of underrepresented astronauts to provide a historical perspective of how astronaut’s research and background has impacted the students’ lives.

II. Curriculum Framing Questions

a. Essential Questions
   i. Can we live on other planets?

b. Unit Questions
   i. What are the components of the solar system?
   ii. Why are all of the planets different?
   iii. What makes earth unique?
   iv. What is the importance of space exploration?

c. Content Questions
   i. What are the characteristics of earth?
   ii. What are the characteristics of other planets?
   iii. What technological advances have enabled the exploration of space?
iv. What type of technology do the astronauts need to survive in space?

III. STEM Subject Areas

a. Aerospace Engineering
b. Environmental Engineering
c. Mechanical Engineering
d. Electrical Engineering
e. Biomedical Engineering
f. Chemical Engineering and/or Chemistry
g. Earth Science
h. Space
i. Science
j. Technology
k. Mathematics

IV. Grade Level

a. Grades 6 – 8

V. Targeted National Science Education Frameworks

a. Content Standards D – Earth and Space Science
   i. Structure of the earth system
   ii. Earth’s history
   iii. Earth in the solar system

b. Content Standards E – Science and Technology
   i. Abilities of technological design
   ii. Understandings about science and technology
VI. Student Objectives and Learning Outcomes

a. Identify the physical characteristics of the earth

b. Differentiate among moons, asteroids, comets, meteoroids, meteors, and meteorites

c. Describe the characteristics of the planets

d. Explain rotation and revolution by using models and illustrations

e. Identify and explain advances in technology that have enabled the exploration of space

f. Develop innovative equipment to help sustain the lives of astronauts in space

VII. Length of Time

a. 2 weeks

VIII. Lesson Guide

a. Activity 1 – “Introducing the Solar System”

The first day of this unit will be spent on reviewing the components of the solar system. The students will review that the earth is part of a system called the solar system that includes many celestial bodies: sun, moons, stars, planets, asteroids, comets, meteoroids and galaxies. Students will participate in a brainstorming activity that will be completed by each group: Solar System Concept Map with Inspiration. This activity will help students remember prior knowledge of the solar system, and set up a mini-lecture on how the solar system was formed and the differences of the celestial bodies and definitions.
b. Activity 2 – “Let’s Explore the Solar System”

Discuss the earth and its characteristics with the help of a brochure made by the instructor. The instructor will use the brochure as a conversation piece to generate questions about earth and why we are able to live on it.

Part One – Virtual Tour of the Solar System

The students will take a virtual tour of the system on [www.planet-science.com/planet10/solar_preload.html](http://www.planet-science.com/planet10/solar_preload.html) with “Virtual Tour of Planet 10: An Interactive Model. This interactive model defines the celestial bodies and their characteristics. Based on the information on the tour, the students will construct a tri-fold brochure on one of the eight planets (earth will be used as an example and covered by the instructor) by using Microsoft Publisher (a brief tutorial will be given).

The students will be separated into groups named after their respective planets. Each group member will have a lead researcher, transcriber and assistants. The lead researcher will have main control of the computer, the transcriber will document the information needed for the brochure, and the assistants will be responsible for the design of the brochure. Each group has creative reign over the brochure as far as color and style, but has to use Tufte’s graphical design principles in the creation of the pictures, graphs and charts (Appendix U). Students will be instructed to cite any sources they use to create their brochure, including all images in a reference section on the brochure and/or as an attachment that they will provide to the instructor.

The following planet information needs to be in the brochure:
1. Picture (Microsoft Clip Art)
2. Diameter
3. Average distance from the Sun
4. Time to orbit the sun
5. Time to turn on axis
6. Tilt of axis in degrees
7. Speed around orbit
8. Mass
9. Density
10. Surface gravity
11. Surface temperature
12. Description of atmosphere and terrain (if possible)
13. Name of moons (if possible)
14. Existence of life (if possible)

**Part Two--“Can you make a planet from scratch?”**

One side of the brochure will be dedicated to Planet 10: World Builder.

World Builder is a part of the interactive guide. The student is guided and directed to build a new world from the beginning and launch it into orbit. This part of the brochure will explain the physical characteristics, chemical and biological make-up, position in orbit and name.

The groups will then present their brochures, which will include their designed planet, using Tufte’s graphical design theory, to the class (Appendix U).
Each member will take a role, to be decided amongst themselves, during the presentation.

c. **Activity 4 – “Exploring the Universe”**

**Part One – Why We Explore**

The instructor gives a brief overview of the history of space travel and answers the question, “Why we Explore?”

The instructor will use three video clips to show examples of space travel and purpose:

i. **Moon, Mars and Beyond: “Why We Explore”**  
   [www.nasa.gov/multimedia/videogallery/Video_Gallery_Archives.html](http://www.nasa.gov/multimedia/videogallery/Video_Gallery_Archives.html)

ii. **First Steps on the Moon**  
   [www.bbc.co.uk/science/space/exploration/missiontimeline/](http://www.bbc.co.uk/science/space/exploration/missiontimeline/)

iii. **STS-31: Launch of the Hubble Space Telescope**  

The students will be directed to use several websites to research a space launch or mission (past, present or future but not including the International Space Station or other examples used in class) and make a 3-slide PowerPoint presentation on their findings. The space launch or mission chosen will have to be approved by the instructor to ensure there are no duplications. A rubric will be provided for the slides and presentation (Appendix V).

The websites are:

i. [www.solarview.com/eng/history.htm](http://www.solarview.com/eng/history.htm)

ii. [www.aero.org/education/primers/space/history.html](http://www.aero.org/education/primers/space/history.html)
iii.  http://spaceflight.nasa.gov/history/

iv.  www.bbc.co.uk/science/space/exploration/missiontimeline/

Part Two--“Build Your Own International Space Station (ISS) WebQuest”

The instructor will provide a brief overview of one of the main missions occurring in space travel today, the ISS.

The students will be given a WebQuest activity to study and research the ISS (Appendix W). The purpose of this activity is for them to learn more about space travel technology and what direction it is going in. The WebQuest also includes the students designing their own ISS based upon the information they have learned and determine what research will be conducted in their ISS and why. The students also have to justify their reasons for the choices they made and answer several questions on the WebQuest.

d. **Activity 3 – “NASA History and You”**

This activity will introduce the students to the human side of space exploration, astronauts. The instructor will begin the activity by asking students if they know the names of any astronaut who has travelled to space and/or preparing to travel to space, especially minority astronauts.

Students will be introduced to Interactive Historical Vignettes, and assigned to research a minority astronaut of their choice and demonstrate their life through performing a interactive skit of their life that demonstrates a scientific decision/discovery being made, a love for the STEM discipline, or a humorous or dramatic fact of their life that helped them to decide to be in the STEM discipline and an astronaut. The students will be asked to be very creative in designing props,
costumes and more for their presentation. Provide students the Interactive Historical Vignette Activity booklet and example compliment paper to guide them during their planning (Appendix X).

This activity will help students to make connections to scientists, engineers, doctors and more who like them and may have grown up in similar situations, serving as role models.
APPENDIX C. UNIT THREE

“Go Green!”

I. Unit Summary

With the current use of personal or at-home technology at an all time high, it is imperative for students of all ages to understand how the electronics they use actually operate, and how the use or misuse of energy affects their everyday lives. The purpose of this unit is to look at the transfer and conservation of energy through the use of electricity, heat and light of everyday household items such as, cell phones, games consoles, iPods and more. After students learn about energy, they will devise a strategy that their families could adopt that would help save energy. Students will present their plans to experts in the energy field, which will consist of parents, scientist, teachers and energy executives.

II. Curriculum Framing Questions

a. Essential Questions
   i. How can I help create a safe, healthy and eco-friendly energy environment to help my community?

b. Unit Questions
   i. What are current energy sources?
   ii. How do circuits work?
   iii. What are alternative energy sources?
   iv. How can I conserve energy in my home to be more energy efficient?

c. Content Questions
   i. What are the different components of circuits?
ii. How do you calculate at-home energy use?

iii. How does insulation play a role in efficient energy?

iv. How does proper window shading play a role in efficient energy?

III. **STEM Subject Areas**

a. Environmental Engineering

b. Mechanical Engineering

c. Electrical Engineering

d. Physics

e. Chemistry

f. Technology

g. Mathematics

IV. **Grade Level**

a. Grades 6 – 8

V. **Targeted National Science Education Frameworks**

a. Content Standards D – Physical Science

   i. Properties and Changes of Matter

   ii. Transfer of Energy

b. Content Standards E – Science and Technology

   i. Abilities of technological design

   ii. Understandings about science and technology

VI. **Student Objectives and Learning Outcomes**

a. Define and identify energy sources

b. Learn how to identify potential misuse of energy
c. Define renewable energy sources

VII. Length of Time
a. 2 weeks

VIII. Lesson Guide
a. Activity 1 – “We’ve got the power!”

This activity is designed to help students understand how energy moves, changes and operates in their lives. Students will experience how energy affects their lives, raising their awareness and ultimately gaining a great appreciation for its use. Students should be asked “What is energy?” recalling the students’ prior knowledge and current understanding. Instructors should also ask students to provide examples of their energy ideas, as well as reassuring that the students know meaning of energy.

Instructors should distinguish between potential and kinetic energy and give examples of each. The instructor can use the energy and energy resources concept maps to guide the conversation with the students (Appendix Y).

Part One – Energy Safari

Place students in teams of 2-3, and have them identify all the energy sources currently being used in their home and community. The students should identify their everyday uses for those sources, as well as how their community uses the energy sources. The students will present their ideas to the class.

The students will also take industrial field trips to local power plants, sewerage and water plants and oil refineries to tour the facilities and meet industrial engineers who help to make the power sources viable. It is imperative that students get first-hand experience of engineers at work so that they may visualize their
potential career opportunities. Students should also discover how our current energy sources are depleting.

**Part Two – Is your circuit open or closed?**

The students now discovered that they mostly use electric energy to power their lives. But what they may not know is that their house, phones, games and more cannot operate without electrical circuits and the currents that flow through them. During this portion of the activity, further increase the awareness of the importance of electricity in everyday life by demonstrating electric currents and circuitry.

Take a moment to reintroduce basic electrical terms by using illustrations demonstrating how electricity moves in series and in parallel. Use examples of everyday series and parallel circuits to describe their use. Place all the materials of circuits on a table and review each component with the student. Using Blobz Guide to Electric Circuits (http://www.andythelwell.com/blobz/), an interactive web game consisting of informational sessions, activity sessions and quizzes, to further visually demonstrate and assist the students in understanding the definition of circuits, how circuits work, the components of a circuit and circuit diagrams. The web game will show how switches control the flow of electricity through a circuit. Verify that the students understand that if switches are off, the current does not flow.

Using the materials below, have each student construct a simple circuit in parallel and series that illuminates a light bulb, rings a buzzer and/or generates a small motor. The following materials should be available for each student: toggle switch, push switch, insulated copper wire, 1.5 volt dry battery, battery holder, 1.5 volt bulbs, fasteners, paper clips, mini motor and buzzer. This activity will
demonstrate how the use of different types of switches activates the circuit to allow current to move through the circuit.

Part Three – Calculate your personal use of energy

After discovering current energy sources and how electricity flows, students should discover how much energy they possibly use a day with using household items, cell phones, game consoles, iPods and more. Ask students to make a personal list of their daily energy activity, from the time they wake up until the time they go to sleep.

For example, they should document if they use an alarm clock to wake up, the radio and how much TV they watch. The students should complete the activity sheet to calculate their energy usage (Appendix Z). Calculating their energy usage or misuse will help the students become stewards of their environment. They can determine how their possible misuse is minimally contributing to the energy source depletion, causing their parents to pay large electric and gas bills. This is also an activity they can share with their family members to help their family also become stewards and become more cost efficient by identifying opportunities for energy savings. Students should be able to discuss the effect of energy has on their lives and their communities.

As the students identify the appliances and materials they use, they can use the web to research the amount of watts that each appliance uses. Using the following formula, the students can estimate the amount of energy consumption used by that appliance.

\[ \text{Wattage} \times \text{Hours Used Per Day} = \text{Daily Wattage hour (Wh) consumption} \]
The students will then multiply the above number by the number of days per year that the appliance is used to determine how many watts the appliance uses in the year. After multiplying the days, please remind the students that they must convert watts hour to kilowatts hour because energy rates are charged by the kilowatt hour (kWh). Once Wh is converted into kWh, multiply the number by the current kWh rate which can be found on recent energy bill or on the local energy company’s website to calculate the annual cost to run an appliance.

\[
\text{Wh x days used per year ÷ 1,000 x kWh rate = cost per year}
\]

Explain to the students that many appliances continue to draw a small amount of power when they are switched off. The phenomenon is called “leakage current” or “phantom loads” because they are drawing electricity being remained plugged into the wall sockets. The loads or extra currents could be avoided by unplugging the appliance or using a surge protector or power strip and switching the power off.

**Part Four – Potential Alternative Energy Sources**

Once students have determined historic energy sources and information regarding their depletion, students should discover new energy techniques currently being developed by scientists and engineers. This portion of the activity should be completed as a mini-research project. The students will be placed in groups and gather information to ultimately introduce their new information to the entire group by participating in a research symposium. Explain to the students that undergraduate and graduate students and professional engineers participate in research symposiums to showcase their innovative ideas and work during conferences and meetings to other colleagues in the STEM community.
Students should research the following alternative energy sources: solar, wind, biomass and nuclear. Throughout the research, the students should discover and provide the following information in their research poster: description of the sources, the pros and cons, if they are renewable or nonrenewable, if they are available in your state, and the environmental impact the sources have.

The research poster must contain all of the above information and include graphics and pictures to visually display their findings. Provide the students with a 2’x3’ poster template, and instruct them to follow the Tufte graphical theory design principles. Although the students are receiving a poster template, remind them that they have creative freedom with color, font and layout but must adhere to the Tufte guidelines.

b. Activity 2 – “Building a Green Home”

After learning about various types of energy, students are now ready to build model energy efficient homes. Using the engineering design process, the students should design and build an energy efficient home and present their design to a panel of energy professionals.

Divide students into groups of four to six, and assign roles to each team member. Each team should consist of a project manager, researcher(s), designer(s) and technical writer(s). Explain the roles of the engineering team to the students. Discuss with the students the rules and procedures of the project. Provide them with a student activity booklet describing the project, their roles and expected outcomes (Appendix AA).
Parts one and two of the “Building a Green Home” activity will provide the information and necessary tools for the students to construct their new homes.

**Part One – Testing Insulation Materials**

Ask the students if they have ever seen the “pink stuff” or fiberglass in the attics or in walls when new homes are being built. Explain that fiberglass is one of several types of insulation that helps to save energy by providing a cooling and heating system when protecting homes from weather conditions. Proper insulation in the ceilings, walls and floors could minimize the amount of hot air from outside that enters the home during the summer and minimizes the amount of cold air that enters the home during the winter.

Discuss with students that insulation is rated by the R-value and the greater the R-value the more effective the insulation, but different R-values could be used in different parts of the home. According to the State of Texas Energy Conservation Office, the ceilings should have the greatest R-value, then the walls followed by the floor.

Using the “Insulation is the Key” activity guide, adopted from the State of Texas Energy Conservation Office, have the students determine the effectiveness of various kinds of materials used as insulations (Appendix AA). The activity guide will instruct students on how to test commercial insulation pieces, Styrofoam, cotton balls, fabrics, packing peanuts, paper towels, newspaper and bubble wrap to determine which item is a more efficient insulator.
Part Two – “Do you have Shady Windows?”

Energy efficient architects and home builders decide where to locate homes on a piece of land according to the position of the sun so the home can make the most of the sun’s heart during winter but still remain cooler during the summer. In this activity, students will determine the position of the sun during noon altitude and design window overhangs and awnings for shade so the windows facing the sun during midday will receive shade in the summer and sunlight during the winter.

Discuss with the students how the sun’s position in the sky is due to tilt of the earth, therefore, during the winter the sun passes lower in the sky than during the summer. According to their geographic location, the students need to determine in which direction the sun rises and sets (east, southeast, northeast, etc.). After discovering this information, the students will determine the variation in noon altitude of the sun and design an overhang or awning so the windows of their home will receive adequate shading in the summer and sunlight in the winter.

Provide the students with the following materials: meter stick, protractor, pencil, poster paper, and toilet plunger to be used as a gnomon. Using the “Shady Windows” Activity Guide (Appendix AA), the students should follow the instructed steps to determine the length and size of their overhang. The students should repeat this activity for at least three days to determine the most accurate sun altitude.

Part Three – “Build your home”

Using the information discovered in parts one and two, the groups of students are now ready to build their energy efficient homes. The students should first construct free-hand sketches of their homes on engineering paper. Using boxes of
their choice (cardboard or shoe boxes), the students should construct their homes using the insulation they found most efficient and the type of overhang they discovered to properly protect their home from heat and cold.

After the students have completely constructed their homes, they will use temperature probes to measure the effect of their energy efficient home design’s ability to maintain proper temperatures in the home. Provide the students with the “Build Your Home” instructional guide to ensure they are following the correct steps in regards to rules and procedures (Appendix AA).

At the end of this design project, students should be able to describe their design. They should be able to explain why their home is considered energy efficient. The students will also prepare a newsletter to distribute to their parents and the energy community documenting their process and persuading their constituents to consider their energy efficient home design. The student must follow Tufte’s graphic theory design principles when designing and completing their newsletter.
APPENDIX D. IRB APPROVAL

Application for Exemption from Institutional Oversight

Unless qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/projects using living humans as subjects, or samples or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This Form helps determine if a project may be exempted, and is to be used to request an exemption.

- Applicant, please fill out the application in its entirety and include the completed application as well as parts A-E, listed below, when submitting to the IRB. Once the application is completed, please submit two copies of the completed application to the IRB Office or to a member of the Human Subjects Screening Committee. Members of this committee can be found at http://www.lsu.edu/irb/screeningmembers.shtml

- A Complete Application Includes All of the Following:
  (A) Two copies of this completed form and two copies of parts B thru E.
  (B) A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 1 & 2)
  (C) Copies of all instruments to be used.
    - If this proposal is part of a grant proposal, include a copy of the proposal and all recruitment materials.
  (D) The consent form that you will use in the study (see part 3 for more information)
  (E) Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB.

  Training link: (http://hprp.nihtraining.com/users/login.php)

1) Principal Investigator: Vanesahette T. Henderson | Rank: Doctoral Candidate

   Dept.: ETP | Ph: 504-704-9467 | E-mail: vhende1@lsu.edu

2) Co Investigator(s): please include department, rank, phone and e-mail for each

   Supervising Professor: Dr. James Wandersee, Professor; 578-2348; jwandersee@lsu.edu

3) Project Title: "The Theoretical Learning Impact of a Summer Engineering Program Curriculum for Underrepresented Middle School Students"

4) LSU Proposal? (yes or no): No
   If Yes, LSU Proposal Number: ______
   Also, if YES, either ______ This application completely matches the scope of work in the grant
   OR ______ More IRB Applications will be filed later

5) Subject pool (e.g. Psychology Students) & Educational Programs

   • Circle any "vulnerable populations" to be used: (children <18, the mentally impaired, pregnant women, the aged, other)
   Projects with incarcerated persons cannot be exempted.

6) PI Signature: ___________________________ Date: 01/15/09 (no per signatures)
   "I certify my responses are accurate and complete. If the project scope or design is later changed, I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted. I also understand that it is my responsibility to maintain copies of all consent forms at LSU for three years after completion of the study. If I leave LSU before that time the consent forms should be preserved in the Departmental Office.

   Screening Committee Action: Exempted
   Reviewer: _______ Signature: ______________________ Date: 01/15/09
Engineering Education Faculty/Administrator Interview Consent Form
Louisiana State University – Baton Rouge Campus
Department of Educational Theory, Policy and Practice

Study Title: “The Theoretical Learning Impact of a Summer Engineering Program Curriculum for Underrepresented Middle School Students”

Performance Site: Louisiana State University and Agricultural and Mechanical College
Library and Archival Research and Internet Survey

Investigators: The following investigators are available for questions about this study,
M-F, 8:00 a.m.–4:30 p.m.: Vaneshette T. Henderson, PhD Candidate (504)704-9467

Purpose of Study: This study attempts to compose a curriculum for an urban middle school summer engineering program. The curriculum is based on visual thinking principles, Human Constructivism, cultural learning styles of African Americans and more. This study will also analyze four top urban middle school curriculums to investigate their learning theories and approaches and look to them for best practices of an effective summer engineering program. The benefit of participating in this study will provide valuable information and insight into the benefit of a minority engineering program and its curriculum.

Subject Inclusion: Individuals between the ages of 18 and 65 who do not report psychological or neurological conditions

Number of Subjects: 6

Study Procedures: This proposed study has two phases. The first phase consists of examining top-rated minority middle school summer engineering programs through library and archival research, and interviews. Phase two consists of synthesizing an innovative curriculum with pre-defined theoretical and principled sources and having the curriculum analyzed by experts in the engineering education field.

Risks: Any discomforts or risks that may result from participation are minimal.

Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

Privacy: Results of the study may be published, but no names or identifying information will be included in the publication. Subjects’ identity will remain confidential unless disclosure is required by law.

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have any questions about subjects’ rights or other concerns, I can contact Robert C. Matthews, Institutional Review Board, (225) 578-8692.

I agree to participate in the study described above and acknowledge the investigator’s obligation to provide me with a signed copy of the consent form.

_________________________           ___________________________
Print Name                              Date

_________________________           ___________________________
Signature                             Date

Study Exempted By:
Dr. Robert C. Matthews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 / www.lsu.edu/irb
Exemption Expires: 12-18-2012
APPENDIX E. ENGINEERING EDUCATION FACULTY/ADMINISTRATOR INTERVIEW CONSENT FORM

Engineering Education Faculty/Administrator Interview Consent Form

Louisiana State University – Baton Rouge Campus
Department of Educational Theory, Policy and Practice

Study Title: “The Theoretical Learning Impact of a Summer Engineering Program Curriculum for Underrepresented Middle School Students”

Performance Site: Louisiana State University and Agricultural and Mechanical College
Library and Archival Research and Internet Survey

Investigators: The following investigators are available for questions about this study,
M-F, 8:00 a.m. – 4:30 p.m.: Vaneshette T. Henderson, PhD Candidate (504)704-9467

Purpose of Study: This study attempts to compose a curriculum for an urban middle school summer engineering program. The curriculum is based on visual thinking principles, Human Constructivism, cultural learning styles of African Americans and more. This study will also analyze four top urban middle school summer curriculums to investigate their learning theories and approaches and look to them for best practices of an effective summer engineering program. The benefit of participating in this study will provide valuable information and insight into the benefit of a minority engineering program and its curriculum.

Subject Inclusion: Individuals between the ages of 18 and 65 who do not report psychological or neurological conditions

Number of Subjects: 6

Study Procedures: This proposed study has two phases. The first phase consists of examining top-rated minority middle school summer engineering programs through library and archival research, and interviews. Phase two consists of synthesizing an innovative curriculum with pre-defined theoretical and principled sources and having the curriculum analyzed by experts in the engineering education field.

Risks: Any discomforts or risks that may result from participation are minimal.

Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

Privacy: Results of the study may be published, but no names or identifying information will be included in the publication. Subjects’ identity will remain confidential unless disclosure is required by law.

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have any questions about subjects’ rights or other concerns, I can contact Robert C. Matthews, Institutional Review Board, (225) 578-8692.

I agree to participate in the study described above and acknowledge the investigator’s obligation to provide me with a signed copy of the consent form.

_______________________________________________                       _________________________
Print Name         Date

_______________________________________________                       _________________________
Signature         Date
APPENDIX F. EXISTING PROGRAM ADMINISTRATOR INTERVIEW CONSENT FORM

Existing Program Administrator Interview Consent Form
Louisiana State University – Baton Rouge Campus
Department of Educational Theory, Policy and Practice

Study Title: “The Theoretical Learning Impact of a Summer Engineering Program Curriculum for Underrepresented Middle School Students”

Performance Site: Louisiana State University and Agricultural and Mechanical College
Library and Archival Research and Internet Survey

Investigators: The following investigators are available for questions about this study,
M-F, 8:00 a.m. – 4:30 p.m.: Vaneshette T. Henderson, PhD Candidate (504)704-9467

Purpose of Study: This study attempts to compose a curriculum for an urban middle school summer engineering program. The curriculum is based on visual thinking principles, Human Constructivism, cultural learning styles of African Americans and more. This study will also analyze four top urban middle school summer curriculums to investigate their learning theories and approaches and look to them for best practices of an effective summer engineering program. The benefit of participating in this study will provide valuable information and insight into the benefit of a minority engineering program and its curriculum.

Subject Inclusion: Individuals between the ages of 18 and 65 who do not report psychological or neurological conditions

Number of Subjects: 4

Study Procedures: This proposed study has two phases. The first phase consists of examining top-rated minority middle school summer engineering programs through library and archival research, and interviews. Phase two consists of synthesizing an innovative curriculum with pre-defined theoretical and principled sources and having the curriculum analyzed by experts in the engineering education field.

Risks: Any discomforts or risks that may result from participation are minimal.

Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

Privacy: Results of the study may be published, but no names or identifying information will be included in the publication. Subjects’ identity will remain confidential unless disclosure is required by law.

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have any questions about subjects’ rights or other concerns, I can contact Robert C. Matthews, Institutional Review Board, (225) 578-8692.

I agree to participate in the study described above and acknowledge the investigator’s obligation to provide me with a signed copy of the consent form.

______________________________                       _________________________
Print Name         Date

______________________________                       _________________________
Signature         Date
APPENDIX G. ONLINE ENGINEERING EDUCATION FACULTY/ADMINISTRATOR ASSESSMENT OF PROPOSED CURRICULUM

1. Curriculum Assessment

1. Please complete the following.

Please complete the following.
Name: 
Company: 
City/Town: 
State: 
Email Address: 

2. For each category/definition below, please rate the level of evidence each category/definition exists in the proposed curriculum. Please include additional comments regarding each category.

<table>
<thead>
<tr>
<th>No Evidence</th>
<th>Moderate Evidence</th>
<th>Overwhelming Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>The curriculum contains activities to help students gain/increase spatial visualization or the ability to mentally manipulate 2-D and 3-D figures.</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>The curriculum contains activities that enhance meaningful learning. Are the activities relevant to the learner? Do they have the potential to be meaningful.</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>The curriculum contains activities</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Evidence Level</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>No Evidence</td>
<td>That enhance students’ graphical design ability, focusing on the role of visualization and drawings as tools to properly understand and convey engineering principles. The curriculum contains the important concept of cultural capital (i.e., factors that constitute a cohesive, recognized group’s cultural identity). The curriculum contains activities and concepts that take into consideration the cognitive abilities of middle school students in grades 7 and 8 to perform analytical reasoning. The curriculum contains activities and concepts that take into consideration the behavioral attributes of middle school</td>
<td></td>
</tr>
<tr>
<td>Moderate Evidence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overwhelming Evidence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evidence Level</td>
<td>No Evidence</td>
<td>Moderate Evidence</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>students.</td>
<td></td>
<td></td>
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<tr>
<td>The curriculum is</td>
<td></td>
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<tr>
<td>geared toward the</td>
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<tr>
<td>education of African</td>
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<td></td>
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<tr>
<td>American students.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Therefore, the</td>
<td></td>
<td></td>
</tr>
<tr>
<td>curriculum contains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the cultural learning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>styles of African</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Americans. The</td>
<td></td>
<td></td>
</tr>
<tr>
<td>curriculum supports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the K-12 American</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Society of Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education vision of</td>
<td></td>
<td></td>
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<tr>
<td>improving the</td>
<td></td>
<td></td>
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<tr>
<td>knowledge of</td>
<td></td>
<td></td>
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<tr>
<td>engineering concepts</td>
<td></td>
<td></td>
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<tr>
<td>for students by</td>
<td></td>
<td></td>
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<tr>
<td>presenting engaging,</td>
<td></td>
<td></td>
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<tr>
<td>hands-on, minds-on</td>
<td></td>
<td></td>
</tr>
<tr>
<td>engineering activities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>that are of high interest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>to African American</td>
<td></td>
<td></td>
</tr>
<tr>
<td>middle school students.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Rate the proposed curriculum in terms of overall quality.

Low Quality

High Quality

Rating Scale

Please explain your response and include suggestions to improve the quality.

4. Rate the following statements.

<table>
<thead>
<tr>
<th>The proposed curriculum has relevant activities that will interest under-represented students in engineering.</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Not Sure</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The proposed curriculum is written at a level</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Not Sure</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
appropriate for a middle school audience. The proposed curriculum addressed the expectations of the national standards.

The proposed curriculum has relevant learning theories that will interest under-represented students in engineering. The proposed curriculum will help students "see themselves as future engineers.”

The proposed curriculum differs from existing summer engineering programs' curricula. When implemented, the proposed curriculum has the ability to achieve its objectives. Would you use this curriculum in its entirety?

Please explain response.
5. What do you like most about the proposed curriculum?

6. What do you dislike about the proposed curriculum?
7. What suggestions do you have for improvement?
### APPENDIX H. TABLE 2 DATA COLLECTION PROCEDURES AND VARIABLES FOR EACH RESEARCH QUESTION

Table 2. Data collection procedures and variables for each research question

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Variables</th>
<th>Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUAL: What are the similarities/differences in curriculum?</td>
<td>Curriculum concepts and reasons for</td>
<td>Documents, reports, teaching modules provided by the program and open- and closed-ended interviews</td>
</tr>
<tr>
<td>QUAL: What is the curriculum based upon (e.g. state and/or national education standards)? Why?</td>
<td>Curriculum standards</td>
<td>Documents, reports, teaching modules provided by the program and open- and closed-ended interviews</td>
</tr>
<tr>
<td>QUAL: What are the similarities/differences in pedagogical approaches?</td>
<td>Pedagogical approaches</td>
<td>Documents, reports, teaching modules provided by the program and open- and closed-ended interviews</td>
</tr>
<tr>
<td>QUAL: Do these programs use tested cognitive learning theories to justify their methods? Why or Why not?</td>
<td>Learning theories and reasons for</td>
<td>Documents, reports, teaching modules provided by the program and open- and closed-ended interviews</td>
</tr>
</tbody>
</table>
APPENDIX I. ONLINE EXISTING PROGRAMS ASSESSMENT SURVEY

Existing Programs Survey--Henderson PhD Research
Please complete the following questions regarding your program.

1. What is the name of your program?

2. What is the name of your school?

3. What is your affiliation to the program?

4. How many years has your program existed?
   - 0 to 2 years
   - 2 years to 4 years
   - 4 years to 6 years
   - 6 years or more
   - Other, please specify

5. What is the target audience for your program? Please check all that apply.
   - Females
   - African Americans
   - Hispanics
   - Asian-Pacific Islanders
   - Caucasians
   - Elementary School Students
   - Middle School Students
   - High School Students
   - Other, please specify
How many students participate in your program on average each year?

- 10 to 15
- 15 to 20
- 20 to 25
- 25 to 30
- 30 or more
- Other, please specify

Please complete the follow questions regarding the components of your program.

Please select the major components of your program/curriculum. Check all that apply.

- Mentorship
- Urban Education
- Real-World Applications
- Career Preview
- Academic Coursework
- Residential--Introduction to College Life

Please provide a brief description as to why these components were chosen.

Does your program/curriculum contain any defined learning theories, i.e., inquiry based learning, discovery learning, hands-on learning, problem based learning? If so, what? Please provide an example. If not, why?

What teaching method approach is used with your students, i.e., learner centered, teacher centered, community centered? Please provide an example.
Does your program/curriculum contain activities to help students gain/increase spatial visualization or the ability to mentally manipulate 2-D and 3-D figures, i.e., do they practice modeling, learn a computer program similar to AutoCAD? If so, please provide an example.

Does your program/curriculum and its associated activities have potential meaning, allowing the participants to create new knowledge with the use of existing knowledge? If so, please provide an example.

Does your program/curriculum include cultural components to aid in the participants learning? Why or why not? If so, please provide an example.

Does your program/curriculum contain activities and concepts that take into consideration the cognitive abilities of middle school students to perform analytical reasoning? Why or why not? If so, please provide an example.

How are the science, technology and engineering activities chosen for your program?

Does the program/curriculum support the K-12 American Society of Engineering Education vision of improving the knowledge of engineering concepts for students by presenting engaging, hands-on, interdisciplinary engineering activities? Please provide an example of an activity.
Does your program have a record/history of increasing the level of engineering college major/career interest in the participants of your program?

If so, by what percentage?

- 0%--5%
- 5%--10%
- 10%--20%
- 20%--30%
- 30%--40%
- 40%--50%
- 50%--60%
- 60% or more
- Other, please specify

What type of funding does your program receive? Check all that apply.

- NSF
- NIH
- NASA
- Corporations
- Non-profit organizations
- Private Foundations
- Other, please specify

Does your program produce annual reports?

Why or why not?
How does your program recruit participants?
### APPENDIX J. TABLE 3 DATA COLLECTION PROCEDURES, VARIABLES AND ANALYSIS FOR EACH RESEARCH QUESTION

Table 3. Data collection procedures, variables and analysis for each research question

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Variables</th>
<th>Instruments</th>
<th>Data Analyses Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUAL: What are the similarities/differences in curriculum?</td>
<td>Curriculum concepts and reasons for</td>
<td>Documents, reports, teaching modules provided by the program and open- and closed-ended interviews</td>
<td>Constant comparative analysis; descriptive methods</td>
</tr>
<tr>
<td>QUAL: What is the curriculum based upon (e.g. state and/or national education standards)? Why?</td>
<td>Curriculum standards and reasons for</td>
<td>Documents, reports, teaching modules provided by the program and open- and closed-ended interviews</td>
<td>Constant comparative analysis; descriptive methods</td>
</tr>
<tr>
<td>QUAL: What are the similarities/differences in pedagogical approaches?</td>
<td>Pedagogical approaches and reasons for</td>
<td>Documents, reports, teaching modules provided by the program and open- and closed-ended interviews</td>
<td>Constant comparative analysis; descriptive methods</td>
</tr>
<tr>
<td>QUAL: Do these programs use tested cognitive learning theories to justify their methods? Why or Why not?</td>
<td>Learning theories and reasons for</td>
<td>Documents, reports, teaching modules provided by the program and open- and closed-ended interviews</td>
<td>Constant comparative analysis; descriptive methods</td>
</tr>
</tbody>
</table>
APPENDIX L. 2-D LEVEL ONE SKETCHING ACTIVITY

2-D Level One Sketching Activity

From Ed Emberley’s Drawing Book of Animals (2006), use the following shapes, letters, numbers and things to create at least 5 animals in 2-D, on the provided engineering paper. You can also use colored pencils to decorate your animals. Refer to the attached rubric for rules and more details on how to complete.
APPENDIX M. 2-D LEVEL ONE CERTIFICATION RUBRIC

## 2-D Level One Certification Rubric

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Novice 1</th>
<th>Competent 2</th>
<th>Proficient 3</th>
<th>Expert 4</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Number of animals created and completed</td>
<td>One animal was created and completely drawn</td>
<td>Two animals were created and completely drawn</td>
<td>3 animals were created and completely drawn</td>
<td>5 animals were created and completely drawn</td>
<td></td>
</tr>
<tr>
<td>2. Evidence that steps of creative sketching was used</td>
<td>No steps were used to complete animals</td>
<td>1 out 3 steps were used to complete animals</td>
<td>2 out of 3 steps were used to complete animals</td>
<td>All three steps were used to complete animals</td>
<td></td>
</tr>
<tr>
<td>3. Craftsmanship</td>
<td>Sketches are messy and shows marks, folds or tears</td>
<td>Sketches are somewhat messy and show either marks, folds or tears</td>
<td>Sketches are neat and show very little evidence of marks, folds, or tears</td>
<td>Sketches are very neat and show no evidence of marks, folds or tears.</td>
<td></td>
</tr>
<tr>
<td>4. Creativity</td>
<td>Sketches show little or no evidence of original thought with no color used. Same symbols were used for each animal.</td>
<td>Sketches lack sincere originality. Animals were sketched using 3 to 5 different symbols.</td>
<td>Sketches demonstrate originality. Animals were sketched using 5 to 7 different symbols.</td>
<td>Sketches demonstrate a unique level of originality and color using different symbols for all animals.</td>
<td></td>
</tr>
<tr>
<td>5. Sketches</td>
<td>Sketches are not in 2-D</td>
<td>2-D was used in at least 2 sketches</td>
<td>2-D was used in at least 4 sketches</td>
<td>All sketches are in 2-D</td>
<td></td>
</tr>
</tbody>
</table>

Points Justification:

<table>
<thead>
<tr>
<th>Criteria 1</th>
<th>Criteria 2</th>
<th>Criteria 3</th>
<th>Criteria 4</th>
<th>Criteria 5</th>
</tr>
</thead>
</table>
3-D Sketching Activity

From Ed Emberley’s Drawing Book of Animals (2006), use the following shapes, letters, numbers and things to create at least 6 animals in 3-D, on the provided engineering paper. You can also use colored pencils to decorate your animals.
APPENDIX O. 3-D LEVEL ONE CERTIFICATION RUBRIC

3-D Level One Certification Rubric

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Novice 1</th>
<th>Competent 2</th>
<th>Proficient 3</th>
<th>Expert 4</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Number of animals created and completed</td>
<td>One animal was created and completely drawn</td>
<td>Two animals were created and completely drawn</td>
<td>3 animals were created and completely drawn</td>
<td>5 animals were created and completely drawn</td>
<td></td>
</tr>
<tr>
<td>7. Evidence that steps of creative sketching was used</td>
<td>No steps were used to complete animals</td>
<td>1 out 3 steps were used to complete animals</td>
<td>2 out of 3 steps were used to complete animals</td>
<td>All three steps were used to complete animals</td>
<td></td>
</tr>
<tr>
<td>8. Craftsmanship</td>
<td>Sketches are messy and shows marks, folds or tears</td>
<td>Sketches are somewhat messy and show either marks, folds or tears</td>
<td>Sketches are neat and show very little evidence of marks, folds, or tears.</td>
<td>Sketches are very neat and show no evidence of marks, folds or tears.</td>
<td></td>
</tr>
<tr>
<td>9. Creativity</td>
<td>Sketches show little or no evidence of original thought with no color used. Same symbols were used for each animal.</td>
<td>Sketches lack sincere originality. Animals were sketched using 3 to 5 different symbols.</td>
<td>Sketches demonstrate originality. Animals were sketched using 5 to 7 different symbols.</td>
<td>Sketches demonstrate a unique level or originality and color using different symbols for all animals.</td>
<td></td>
</tr>
<tr>
<td>10. Sketches</td>
<td>Sketches are not in 3-D but 2-D.</td>
<td>3-D was evident in at least 2 sketches.</td>
<td>3-D was evident in at least 4 sketches.</td>
<td>All sketches are in 3-D.</td>
<td></td>
</tr>
</tbody>
</table>

Points Justification:
Criteria 1
Criteria 2
Criteria 3
Criteria 4
Criteria 5
APPENDIX P. FREE BODY DIAGRAM ACTIVITY SHEET

Free Body Diagram Activity Sheet

Using the engineering paper provided, complete the free body diagrams of the objects in the following situations below. Please remember to complete the following steps:

1. Draw the object you want to analyze as a box
2. Draw each force acting on the object as a arrow pointing in the direction the force is acting

A. Determine the forces acting on the apple
B. Determine the forces acting on the dresser drawer while sitting the the table.

C. Determine the forces acting the sleigh
D. Determine the forces acting on the football.
APPENDIX Q. TYPES OF BRIDGES INFORMATIONAL SHEET

Types of Bridges Informational Sheet

Arch Bridges

“Arch bridges are one of the oldest types of bridges and have great natural strength. Instead of pushing straight down, the weight of an arch bridge is carried outward along the curve of the arch to the supports at each end. These supports, called the abutments, carry the load and keep the ends of the bridge from spreading out.” www.pbs.org

Beam

“A beam or "girder" bridge is the simplest and most inexpensive kind of bridge. In its most basic form, a beam bridge consists of a horizontal beam that is supported at each end by piers. The weight of the beam pushes straight down on the piers. The beam itself must be strong so that it doesn't bend under its own weight and the added weight of crossing traffic. When a load pushes down on the beam, the beam's top edge is pushed together (compression) while the bottom edge is stretched (tension).” www.pbs.org

Cable-Stayed

“Cable-stayed bridges may look similar to suspension bridges—both have roadways that hang from cables and both have towers. But the two bridges support the load of the roadway in very different ways. The difference lies in how the cables are connected to the towers. In suspension bridges, the cables ride freely across the towers, transmitting the load to the anchorages at either end. In cable-stayed bridges, the cables are attached to the towers, which alone bear the load.” www.pbs.org
Cantilever

“A cantilever bridge is a form of bridge whereby the structure is supported using the technique of cantilevers. Unlike suspension bridges where the load is supported at either end of the bridge, the strength of a cantilever bridge comes.” [pbs.org](http://www.pbs.org)

Suspension

“Aesthetic, light, and strong, suspension bridges can span distances from 2,000 to 7,000 feet—far longer than any other kind of bridge. They also tend to be the most expensive to build. True to its name, a suspension bridge suspends the roadway from huge main cables, which extend from one end of the bridge to the other. These cables rest on top of high towers and are secured at each end by anchorages.” [pbs.org](http://www.pbs.org)

Truss

“Trusses are composed of straight members connected at their ends by hinged connections to form a stable configuration. When loads are applied to a truss only at the joints, forces are transmitted only in the direction of each of its members. That is, the members experience tension or compression forces, but not bending forces. Trusses have a high strength to weight ratio and consequently are used in many structures, from bridges, to roof supports, to space stations.” [jhu.edu](http://www.jhu.edu)

[blog.wolfram.com](http://www.blog.wolfram.com)
Facts in Bridge Design: Load, Compression, Tension and Shear Forces

The number of design possibilities for bridges are abundant. However, certain facts about the process in bridge design are necessary to ensure the design is strong and durable. Engineers consider many forces when designing a bridge. Bridges have to be built carry weight or loads which includes its own weight. When a load is placed on the bridge, compression, tension and shear forces all have to remain stable in order for the bridge to stay strong. The picture below will help you to visualize forces affecting bridges, as well as provide definitions for those forces. In order for a bridge to maintain its stability, the forces have to remain constant.

Load is composed of live, dead and dynamic loads. Live lad consists of the weight of the cars, trucks and people expected to use the bridge. Dead load is the weight of the bridge itself. Dynamic loads present a special problem. They are the unusual forces of unexpected magnitude, i.e., earthquakes, hurricanes, etc.

Compression is a pushing force. When a load is placed on the beam, it tries to compress the beam. Compression acts to shorten the beam.

Tension is a pulling force. When a load is placed on the beam, it also tries to pull apart the beam at the bottom, causing tension. Tension acts to expand or lengthen the beam.

Shear occurs when two opposing forces act on the same point of the bridge. Shear force is an internal force and acts perpendicular to the beam, causing it to strain or shear.
## APPENDIX S. ENGINEERING DESIGN METHOD

### Engineering Design Method

<table>
<thead>
<tr>
<th>ASK</th>
<th>CREATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the problem?</td>
<td>Build the model.</td>
</tr>
<tr>
<td>What have others done?</td>
<td></td>
</tr>
<tr>
<td>What are the constraints?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PLAN</th>
<th>TEST</th>
<th>IMAGINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sketch a diagram of the solution.</td>
<td>Test your design model.</td>
<td>Brainstorm solutions/ideas to the problem.</td>
</tr>
<tr>
<td>List all materials.</td>
<td>Modify your design to make it better</td>
<td>Visualize the solution.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Choose the best one.</td>
</tr>
</tbody>
</table>

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APPENDIX T. BUILD YOUR OWN BRIDGE WEBQUEST

Build Your Own Bridge WebQuest!

Introduction:

There are millions of bridges in the United States of all shapes and sizes. Bridges are a fundamental system in our infrastructure, but unfortunately, they are aging and failing and in need of restoration. Your engineering mission is to gather information about the current state of bridges in your community, bridge design and forces, and information about restoring and improving infrastructure.

After all the research is complete, become a true engineer by designing your own bridge to replace a failing bridge in your community or redesigning an existing bridge in the community. Use the engineering design method to inquire about the problem, imagine your new design, and plan how you will complete the bridge model, create and test your bridge.

The purpose of this assignment is to help you understand how to complete the engineering design method, learn about the infrastructure in your community, learn how to restore and improve the infrastructure with new construction materials and methods, and more.

Each group is responsible for their own work. The rules and regulations are below. Several websites are provided for you to browse and provide the answers to your problem.

HAVE FUN AND HAPPY BUILDING!
PROCEDURE

Each group will include 4 to 6 group members. Each group member will be assigned a role decided by the program instructor.

Each team must use the design process to address the issues discussed in the introduction to complete this assignment.

After the design of the bridge, each group’s bridge will be tested by program personnel and experts to determine whose bridge can hold the most weight.

At the end of this project, you should be able to describe your design, incorporating bridge forces in your description. You should also be able to explain why your bridge held more or less weight than others, and why your bridge succeeded or failed.

You should also identify novel approaches to bridge construction through research and brainstorming to provide economic and eco-friendly solutions to bridge construction. The approaches you identified will be a part of your final presentation. Presentation rules discussed below.

ROLES OF GROUP MEMBERS

1. Project Manager – Group member/leader who is the overseer of the entire project. He/she is responsible for planning, execution, and closing of any project. The Project Manager is responsible for creating clear and attainable project objectives, building the project requirements, and managing the cost, time and quality of the project.

2. Researcher(s) – Group member(s) who performs most of the research needed for the project. He/she is responsible for much of the “Ask” phase of the design method and must find answers to the proposed question.

3. Surveyor(s) – Group member(s) who serve as surveyors must accurately gather information about the earth’s surface in the area the bridge will be built and then graphically displaying the various levels of the land on a drawing.

4. Bridge Designer(s) – Group member(s) who is responsible for the design of the bridge based on the criteria set by the researcher and surveyor. The bridge designer will sketch and build the bridge with the help of the other group members.

5. Technical Writer(s) – Group member(s) who is responsible for all of the written finished products, which includes the engineering design notebook, the presentation, and assisting the researcher(s).
Resources

The following websites are to be used in your research. If you have any questions, ask your instructor.

Building Big: Bridges
http://www.pbs.org/wgbh/buildingbig/bridge

Promoting Land Surveying in Our Schools
http://www.lsrp.com/lseducation.html

American Society of Civil Engineers
http://www.asce.org/reportcard/2005/page.cfm?id=203

Grand Challenges for Engineering
http://www.engineeringchallenges.org/

Washington State Bridge Design Manual
http://www.wsdot.wa.gov/eesc/bridge/bdm/

Super Bridge
http://www.pbs.org/wgbh/nova/bridge/build.html

Bridge Engineering
http://www.scsolutions.com/bridge/

Bridge Engineering

Bridge Engineering

Green Infrastructure
www.pennet.com/display_article/297781/41/ARTCL/none/Green-Infrastructure-BMPs-for-Treating-Urban-Storm-Runoff:-Multiple-Benefit-Approaches
Rules and Regulations

1. The bridge must span a distance of 1 foot.
2. The width of the bridge must be at least 3 inches.
3. Only the materials purchased can be used.
4. The bridge must be mobile.
5. The bridge must be designed to test.
6. Some of the materials you will use have safety concerns. Please be careful when you are using the X-acto knife, the glue gun and the weights.
7. Each team will be given only $100 to purchase the materials from the list below.

Materials List

1. 2-ft Wood strips (balsa and/or basswood)
2. X-acto knife
3. Dull knife
4. Long pins
5. Wax paper (18-inch x 18-inch)
6. Masking tape
7. Glue gun
8. 1 Glue stick
9. Glue
10. Ruler
11. Foam board
12. Paper clips
13. Tape
14. Pounds of varying weights
15. Durable string
16. Dowel rods (6 inch)

Presentation

Each group will present their design method and final bridge product by giving a PowerPoint presentation to the program staff, bridge design experts, and their fellow program members.

The PowerPoint Presentation has to include at least 10 slides that contain a description of each step of the design method, as well as pictures that document the process.

Groups must use the Tufte’s Theory of Design Graphic Handout as a guide to creating a proper visual display of information.

HAVE FUN!
(this will be placed on the class program website.)
Tufte’s Graphical Design Theory Dos and Don’ts

Much of science and engineering entails learning, designing and presenting quantitative information from design projects and world changing research to prove a theory or cause-effect relationship. Edward Tufte, statistician and Princeton University professor, developed a 4-volume theory of graphical information design complete with the do’s and do not’s on properly depicting data to provide explanations and make critical decisions, while maintaining graphical integrity. Tufte seeks out to make one a better quantitative storyteller.

<table>
<thead>
<tr>
<th>Dos</th>
<th>Don’ts</th>
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<tbody>
<tr>
<td>Maximize data to ink ratio</td>
<td>Abstain from using moiré effects – distracting material</td>
</tr>
<tr>
<td>Erase non-data ink – if it doesn’t depict information it is not necessary</td>
<td>Abstain from using gridlines – gridlines clutter up data</td>
</tr>
<tr>
<td>Erase redundant data-ink – information that depicts the same information over and over</td>
<td>Abstain from using “the duck” – too much decoration that hides the meaningful data</td>
</tr>
<tr>
<td>Use the data to create your when possible. Use multifunctional elements, called mapped pictures, which combine scales, diagrams, numbers, words and images.</td>
<td>Do not use color to hide the nature of the graphic</td>
</tr>
<tr>
<td>Use realistic detail as much as possible</td>
<td>If the information is not important to the project, do not include it in your presentation</td>
</tr>
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<td>Use color to only imitate reality</td>
<td></td>
</tr>
<tr>
<td>Visuels need to be clear and concise in illustrating the evidence</td>
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APPENDIX U. TUFTE’S GRAPHICAL DESIGN THEORY

Tuftes Graphical Design Theory Dos and Don’ts

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# APPENDIX V. SPACE LAUNCH AND MISSION PRESENTATION RUBRIC

## Space Launch and Mission Presentation Rubric

<table>
<thead>
<tr>
<th>Subject Knowledge</th>
<th>Maximum Points</th>
<th>Maximum Point Description</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
<td>Students demonstrate full knowledge (more than required) by providing a great deal of factual information about the launch/mission; All facts in the presentation are accurate and appropriately cited.</td>
<td></td>
</tr>
</tbody>
</table>

| Organization      | 10             | Each slide presents information in logical sequence which audience can follow. Each slide has a clear beginning, middle, and end. |               |

| Design/Graphics    | 10             | Appropriate graphics are used to enhance the space launch/mission chosen; they are clearly visible on each page; they are cited. They reinforce screen text. |               |

| Appearance/Mechanics | 10             | No spelling/grammar errors; easy to read; appropriately sized; text and formatting consistent; variety of symbols or shapes; color used effectively for emphasis. |               |

| Length             | 5              | The presentation contains the appropriate number of slides (3). |               |

| Eye Contact        | 5              | Students maintain eye contact with audience. |               |

| Elocution          | 5              | Student uses clear voice with correct pronunciation so that all audience members can hear and understand presentation. |               |

**TOTAL POINTS EARNED**

**Points Justification:**
APPENDIX W. THE INTERNATIONAL SPACE STATION WEBQUEST

The International Space Station: Build Your Own Station WebQuest!

Introduction:

Since the beginning, man has wondered what the bright stars are in the sky and wishing someday the chance to visit and research these far off places. Now it is your turn! Your mission is to gather information about the International Space Station, and with that information, Design Your Own with a drawing! The purpose of this assignment is to help you understand the technological advances in space research and travel. Each group is responsible for their own work. The questions you have to answer are below. I have provided you with four websites to browse and find those answers. Your design should be drawn be neatly drawn free-hand with the use of engineering paper. Along with the design, you are to write a one page description on why you chose to design you ISS that particular way, “What is the purpose of your ISS?” HAVE FUN AND HAPPY HUNTING!
**Questions to be answered**

1. What is the purpose of the International Space Station?
2. Who are the partners?
3. Where is the ISS located?
4. When was it started and when is it expected to be completed?
5. How much does the entire ISS (construction and maintenance) cost?
6. What will be the entire components upon completion of the ISS?
7. How many expeditions will it take to complete the ISS?
8. What is the process of building the ISS?
9. Does the ISS have to be occupied at all times? If yes, why and who occupies it now?
10. What are the current components of the ISS?

**Resources**

The following websites are to be used to research your planet:

**National Aeronautics Space Center**
http://spaceflight1.nasa.gov/station/

**Discovery**
http://www.discovery.com/stories/science/iss/iss.html

**European Space Agency**
http://www.esa.int/esaHS/iss.html

**Wikipedia, the Free Encyclopedia**
http://en.wikipedia.org/wiki/International_Space_Station
Evaluation

The entire assignment is worth 100 points. You will be graded in the following areas:

1. Your answers to the questions will be graded on completeness and content information. Your answers are to be factual and cited. Your answers must be written in well thought and complete sentences. (Each question is worth 5 points)

2. You will be given a grade on the design of your International Space Station. Your free-hand sketch of your ISS has to be neatly drawn and colored. Please do not draw one square and claim it to be your station. This picture should be detailed and be feasible. (25 points)

3. You will be given a grade for your one page explanation on the purpose of your ISS. In order to get an “A,” you need to give detailed information on why you used the components you chose and their purpose. (25 points)

HAVE FUN!
APPENDIX X. CONSTRUCTING AN INTERACTIVE HISTORICAL VIGNETTE

EXTRA! EXTRA!
READ ALL ABOUT IT!

HOW TO LESSONS:
CONSTRUCTING A
INTERACTIVE HISTORICAL VIGNETTE

Step One: Read the history of science about the life of the chosen astronaut.
Step Two: Choose a pivotal incident, intellectual or behavioral action, in the life.
Step Three: Decide what attributes of the nature of science is conveyed.
Step Four: Write a IHV using the following format:
  - Introduce the scientist
  - Describe the context of the incident
  - Provide options in the story
  - Describe the final outcome of the incident
Step Five: Write the vignette in docudrama style with a presentation time of 10
  minutes or less.
Step Six: Present the IHV with the use of costumes, props and more!

Each group must also submit a at least a 3 page paper along with the presentation
of the IHV. The paper must include an introduction, script of the docudrama, list
of group members and the roles they played, and pictures to compliment the
IHV, as well as a list of references. Please see attached paper as an example!
EXAMPLE: INSULIN: THE DRUG THAT SAVED MANY LIVES

This Interactive Historical Vignette could be used in biology and anatomy and physiology courses.

If you want to be a scientist, who is interested in health and medicine, it is imperative to learn as much as you can about the body and its functions. This is a little story about the pancreas, diabetes and the hormone that controls it all, insulin.

Does anyone know where their pancreas is? What does the pancreas do and can we live without it? So if our pancreas is damaged, what will happen to our bodies? What is the name of the disease that you will get if your pancreas is damaged? How many students know what diabetes is?

The pancreas was one of the most difficult organs to figure out especially during the late 1800s. The pancreas is an organ that functions in the digestive and endocrine systems. The pancreas secretes hormones that regulate blood glucose levels and it produces enzymes that break down digestible foods. In 1869, a medical student in Berlin, Germany, Paul Langerhans, was studying the pancreas under a microscope and noticed previously unrecognized clumps of tissue scattered throughout the pancreas. Paul Langerhans called his discovery The Islets of Langerhans. He did not know their function, but it was assumed that they played a role in digestion.

In 1889, Dr. Oscar Minkowski, in collaboration with Joseph von Mehring removed the pancreas from a healthy dog to test its assumed role in digestion. Several days after the dog's pancreas was removed, the animal keeper noticed a swarm of flies feeding on the dog's urine. On testing the urine they found that there was sugar in the dog's urine, establishing for the first time a relationship between the pancreas and diabetes. Just a few short years later, another major step was taken by Dr. Eugene Opie, when he clearly established the link between the Islets of Langerhans and diabetes. Opie discovered that diabetes mellitus was caused by destruction of the islets of Langerhans and occurs only when these bodies are in part or wholly destroyed. Before Opie’s work, the link between the pancreas and diabetes was clear, but not the specific role of the islets.

Over the next several decades, many attempts were made to isolate whatever it was the islets were making that was causing diabetes. In October 1920, Frederick Banting was reading one of Minkowski’s papers and concluded that whatever the islets were producing was being broken down and it needed to be isolated; Banting set out to be the first to isolate the secretions and treat
diabetes. In 1921, Banting travelled to the University of Toronto and met with Dr. J.J.R. Macleod, to discuss his ideas regarding the islets secretions.

Dr. Macleod, a professor of physiology, gave Banting laboratory facilities and an assistant who was in medical school, Charles Best. Banting and Best started the work which led to the discovery of insulin.

Banting and Best worked many hours on the isolation of insulin for use of treating diabetes. Let’s listen in on one of their conversations that led to the miracle discovery and subsequent first treatment.

Best: How are we going to do this Frederick? What is the best approach you have figured out so far to isolate the islets.

Banting: Ok, Charles… (Rubbing his chin) How many dogs do we have?

Best: I believe Dr. Macleod gave us 10 dogs to work with? I know that look on your face Fred, what kind of ideas are floating around head in that foam board shaped head of yours?

Banting: I was thinking that we take 5 dogs and remove their pancreas completely causing them to have diabetes, and we take the other 5 dogs and tie off their pancreatic ducts to the digestive system.

Best: If we tie off their ducts, what will that do to the pancreas?

Banting: When we tie off the pancreatic ducts, the cells on the pancreas that produces the enzymes should eventually die since they travel through the ducts and islets should be isolated on the pancreas while the pancreatic digestive cells should be consumed by the immune system.

Best: That sounds kind of basic or your sure this will work?

Banting: That’s why it’s called an experiment Charles, you’re not sure until you get the finished product.

How many people think the experiment worked? Those of you who didn’t work, why do you think Banting’s theory was wrong? Do you have any ideas about what should have been done? Let’s see who is right and who is wrong.

After several weeks, Banting and Best removed the shriveled pancreas from the dogs whose ducts had been tied off. During the weeks prior to this, blood and urine tests were taken from the diabetic and digestive enzyme deprived dogs to monitor the dogs’ health status. Banting and Best prepared an extract from the excised pancreas by chopping the pancreas into small pieces, grinding it in a chilled mortar with salt water, and filtering the mixture through cheesecloth.

Best: I am going to inject the islet extract into Diabetic Dog #1.
Banting: Let’s pray for a miracle Best because I sure want to win a Noble Prize!

After two injections of the extract, the dog’s blood sugar level dropped by half. Banting and Best were excited by what they had done although the dog had died the next day from they deemed an infection. They called the extract isletin. They continued to test their experiment to confirm and explain their results, perfecting the extract technique more easily and obtaining pancreases from a nearby slaughter house. By the end of the summer of 1921, they were able to revive a dog from a diabetic coma and prevent its death.

Banting: I think we are now ready to test our insulin on a human. What do you think Charles?

Best: Fred, if we can save a human our work will be truly worth the blood sweat and tears. Let’s test it on ourselves first to see if there are any adverse reactions in humans?

Banting: I would have never thought I would be a lab dog, but you are right we have to make sure...

After injecting the insulin in themselves and having no adverse reactions, they searched for their first diabetic human patient in January 1922. Leonard Thompson, a 14 year old boy admitted into Toronto General Hospital for severe diabetic symptoms, was given insulin on January 11, 1922. Leonard had a severe allergic reaction, so Banting and Best improved the extract by making a purer form with the help of a biochemist. On January 23rd, Leonard received his second injection which was a complete success, eliminating his diabetic symptoms.

Banting: Well Charles, if we make a whole bunch of this stuff we can make a killing, no pun intended! I am just so thrilled that we are able to save millions of people who are dying from diabetes. Thank goodness the pharmaceutical company Eli Lilly has offered to assist us in producing large quantities after our paper was published a few months ago.

Best: Thanks for allowing me to work with you Fred! Now I can graduate from medical school, published, rich and famous!

In 1923 Frederick Banting and J.R.R. Macleod received Nobel Prizes in Physiology of Medicine for discovering insulin. Because Banting was so upset about Charles Best being left out of the honor, he split his award money with him. Dr. Banting was truly noble.

References

www.pbs.org
www.wikipedia.org
www.nobelprize.org
APPENDIX Y. CONCEPT MAPS
Energy Concept Map

Energy

Potential

Is known as

stored energy

forms

ENERGY

forms

Kinetic

Is known as

energy in motion

May be

May be

Gravitational

May be

Chemical

Electrical

Elastic

Heat

Sound

Light

Motion
Energy Concept Map

Energy Resources

Are described as

Renewable
- Wind
- Solar
- Water
- Geothermal
- Biomass

Nonrenewable
- Oil
- Natural Gas
- Nuclear
- Coal
### APPENDIX Z. CALCULATING PERSONAL ENERGY USE

#### How to Calculate Personal Energy Use Activity Sheet

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Watts</th>
<th>X</th>
<th>Hours per day</th>
<th>X</th>
<th>Days per year</th>
<th>Convert to kWh</th>
<th>X</th>
<th>kWh Rate</th>
<th>=</th>
<th>Cost per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling Fan</td>
<td>200</td>
<td></td>
<td>4</td>
<td></td>
<td>120</td>
<td>1,000</td>
<td></td>
<td>.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radio</td>
<td>350</td>
<td></td>
<td>8</td>
<td></td>
<td>260</td>
<td>1,000</td>
<td></td>
<td>.75</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX AA. BUILDING A GREEN HOME ACTIVITY BOOKLET

“Building a Green Home”
Activity Booklet

Introduction:

After learning about various types of energy, your depletion and your personal energy usage, you are now ready to build model energy efficient homes. Using the engineering design process, you should design and build an energy efficient home and present your design to a panel of energy professionals.

You will be divided into groups of four to six, and assigned roles to each team member. Each team should consist of a project manager, researcher(s), designer(s) and technical writer(s). This activity booklet describes the project, your roles and expected outcomes.

Parts one and two of the “Building a Green Home” activity will provide the information and necessary tools for you to construct your new homes. “Testing Insulation Materials” will allow you to discover the proper insulation to use in your home’s ceilings, walls and floors to minimize the amount of hot air and cold air from entering and leaving the home during the winter and summer. The “Shady Windows” activity will allow you to determine the best type, or size, of roof overhang so the windows of your home will receive adequate shading in the summer and sunlight in the winter.

Using the information discovered in parts one and two, each group will build an energy efficient home.

HAVE FUN AND HAPPY BUILDING!
PROCEDURE

Each group will include 4 to 6 group members. Each group member will be assigned a role decided by the program instructor.

Each team must use the design process to address the issues discussed in the introduction to complete this assignment.

After the design of the home, each group’s home will be tested by program personnel and experts to determine whose home design had the ability to maintain proper temperatures in the home.

At the end of this design project, you should be able to describe your design. You should be able to explain why your home is considered energy efficient. Each group will also prepare a newsletter to distribute to your parents and the energy community documenting your process and persuading your constituents to consider your energy efficient home design. The student must follow Tufte’s graphic theory design principles when designing and completing your newsletter.

You should also identify novel approaches to home construction through research and brainstorming to provide economic and eco-friendly solutions to home construction. The approaches you identified will be a part of your final presentation. Presentation rules discussed below.

ROLES OF GROUP MEMBERS

1. Project Manager – Group member/leader who is the overseer of the entire project. He/she is responsible for planning, execution, and closing of any project. The Project Manager is responsible for creating clear and attainable project objectives, building the project requirements, and managing the cost, time and quality of the project.

2. Researcher(s) – Group member(s) who performs most of the research needed for the project. He/she is responsible for much of the “Ask” phase of the design method and must find answers to the proposed question.

3. Home Designer(s) – Group member(s) who is responsible for the design of the home based on the criteria set by the group. The home designer will sketch and build the home with the help of the other group members.

4. Technical Writer(s) – Group member(s) who is responsible for all of the written finished products, which includes the engineering design notebook, the newsletter, and assisting the researcher(s).
Part One – “Insulation is Key”
Adapted from the State of Texas Energy Conservation Office

Introduction
The purpose of this activity is to determine the effectiveness of different kinds of materials you will possibly use as insulation. The proper insulation can save homeowner’s a lot of money. Insulation can keep your home warm in the winter and cool in the summer.

Materials
Obtain an equipment kit that contains the following materials:
• 2 Dixie cups per insulation material
• Water
• 25 mL graduated cylinder per insulation material
• Packaging tape
• Styrofoam
• Cotton balls
• Packing peanuts
• Newspaper
• Bubble wrap
• Cloth
• Ruler
• Poster board
• Marker
• Stapler

Step One: Preparation
1. Take half of the Dixie cups you are instructed to use by your teacher and make a mark 1 cm below the top edge of each cup using a marker. Label each of your cups with your group name or number
2. Fill the cup(s) to the 1 cm mark with cool water.
3. As the teacher instructs, place your cup(s) on a tray to be placed in the freezer.
4. Use the remaining half of the cups to design and construct insulated containers with the materials you choose to use for insulation. Use one of the cups as a template to draw a number of circles on the poster paper equal to the number of cups in the freezer. Carefully cut out each of the circles. The insulated container you design will hold the frozen Dixie cups. The poster paper circles will become lids for the insulating containers.
5. Choose your insulating materials, which will vary by group. You will also be testing one of the insulating materials in 3 varying degrees of thickness for comparison.
6. Wrap 1” of one the insulating materials around one container and tape or staple the materials in place.
   If you are using stiff Styrofoam, you will have to cut it in thin strips to fit around the circular cup. The packing peanuts may best be stuck to tape first and then secure the tape to the cup. Also cover the lid. Use tape sparingly, as it will add to your insulation and affect your results. Repeat this step with the other insulating materials being tested. Label each cup with your group name or number and assign numbers to each cup. Record the materials being used on Data Table 1.
7. Choose one test material and prepare 3 cups in the same manner as Step 6, except you will use 3 different measures of thickness. Record the measures of thickness on Data Table 2.
8. Store your labeled “designer insulated cups” as instructed.

Step Two: Activity
1. Place your prepared “designer insulated cups” with the 3 different test materials on the lab table.
2. Obtain the frozen cups prepared beforehand.
3. Place each frozen cup into a “designer insulated cup” and immediately place the cover on top. Do this for each of your designer cups.
4. Place your “designer insulated cups” with the frozen cup inside in the sunlight, if possible, or as instructed by your teacher. Record the time.
5. Every 4 minutes, uncover your insulated design and carefully pour out any melted water into a graduated cylinder, being sure to keep the remaining ice in the cup. Re-cover immediately and return the cup to the sunlight. Repeat for each of your insulated cups. A unique graduated cylinder should be used for each type of test material to keep each measurement separate.
6. On Data Table 1 record the amount of water melted by the designer insulated cup in a total of 20 minutes. (Do this for each different designer insulated cup you are testing.)
7. Repeat Steps 1--5 with the 3 cups of one material in 3 different thicknesses. On Data Table 2 record the amount of water melted by the insulated cups in a total of 20 minutes.

8. Complete your Data Tables (The least amount of melted liquid indicates the best insulator.)
“Insulation is Key” Student Data Sheet

Data Table 1. Amount of ice melted by type of insulating material.

<table>
<thead>
<tr>
<th>Cup#</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Insulating Material</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time interval (mins)</td>
<td>Amount of ice melted</td>
<td>Amount of ice melted</td>
<td>Amount of ice melted</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data Table 2. Amount of ice melted by thickness of insulating material

<table>
<thead>
<tr>
<th>Type of Insulating Material</th>
<th>Cup#</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of insulating material:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time interval (mins)</td>
<td>Amount of ice melted</td>
<td>Amount of ice melted</td>
<td>Amount of ice melted</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
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</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data Summary

1. Which material was the best insulator? ___________________________
2. Did the thickness of material make any difference? _____________
   If so, what was the difference?
   ____________________________________________________________
   ____________________________________________________________
   ____________________________________________________________
   ____________________________________________________________
Part Two: “Do you have Shady Windows”  
Adapted from the State of Texas Energy Conservation Office

Introduction

In this activity, students will determine the variation in noon altitude of the sun and design an overhang or shade so that south-facing windows are shaded in summer but receive sunlight in winter.

Materials

• Ruler
• Marker
• Protractor
• Toilet plunger (to be used as gnomon)
• Pencil
• Poster paper

Step One: Measuring the Altitude of the Sun

1. About 30 minutes before noon (standard time), take the poster paper, protractor, directional compass, meter stick and your gnomon outside.
2. Use the compass to locate north. Place the poster paper flat on the ground in a level, smooth, and sunny location so that the long side is oriented north and south. Use tape or small weights to hold the paper in place.
3. Set the gnomon at the south edge of the poster paper and mark the locations of the base of the gnomon and the tip of the shadow of the gnomon. Label the shadow of the tip with the time.
4. Every 15 minutes mark the new position of the tip of the gnomon and label it with the time.
5. Continue until 30 minutes after noon. You will have marked five points.
6. Draw a smooth curve through all five points.
7. Return to the classroom and find the point on the curve you have drawn that is closest to the gnomon. Estimate the time this occurred. This time is called local noon.
8. Draw a line from the point of local noon to the center of the base of the gnomon. This line should be true north and south.
9. Measure the length of the shadow, $l$, at local noon and the height of the gnomon, $h$.
10. Determine the altitude of the sun: $\text{altitude} = \tan^{-1}\left(\frac{l}{h}\right)$
11. Repeat after an interval of three days.

Step II. Daily Variation of Solar Altitude

1. On your computer, start your web browser and point it to: http://www.usno.navy.mil/USNO/astronomical-applications/data-services/alt-az-us
2. Enter your location and select the date as January 21.
3. Scan the list that is produced and pick the time and altitude closest to an azimuth of 180°. This time should be approximately the same as your calculation of local noon and the altitude should be a maximum.
4. Record the date and the maximum altitude.
5. Repeat for each month through December 21.
6. Construct a graph of the maximum altitude of the sun versus the date.
7. Draw a smooth curve through the monthly solar altitude points.
8. From the graph you just drew, read the seasonal maximum noon altitude of the sun and the seasonal minimum noon altitude and the dates on which those occur.

Step III. Constructing the Scale Model of the Wall

1. Make a scale drawing of the window to be shaded on your poster board. Include a roof with an appropriate slant.
2. Starting at the bottom of the window, draw a line upward at the angle of the maximum noon altitude of the summer sun.
3. Draw an overhang that just touches the line drawn in step 2.
4. Draw a line from the edge of the overhang to the wall at the angle of the minimum noon altitude of the winter sun.
5. The wall will be solid above the point where the line intersects the wall in step 4. The window occupies the rest of the space between where the two lines to the sun intersect the wall.
Part Two: “Do you have Shady Windows”

Part Two Data Summary

1. What was the maximum summer altitude of the sun? _______________
2. On what day did the maximum summer altitude occur? _______________
3. What was the minimum winter altitude of the sun? _______________
4. On what day did the minimum winter altitude occur? _______________
5. What is the height of your window? ____________________________
**Part Three: “Build Your Own Home”**

Using the information discovered in parts one and two, you are now ready to build your energy efficient homes. You should first construct free-hand sketches of your home using engineering paper. Using boxes of your choice (cardboard or shoe boxes), you should construct your homes using the insulation you found most efficient and the type of overhang you discovered to properly protect your home from heat and cold.

After you have completely constructed your homes, you will use temperature probes to measure the effect of your energy efficient home design’s ability to maintain proper temperatures in the home. The instructor will bring all groups outside to test your homes.

**Newsletter**

At the end of this design project, you should be able to describe your design. You should be able to explain why your home is considered energy efficient. You will prepare an “Energy Newsletter,” using Microsoft Publisher, to distribute to your parents and the energy community documenting your process and persuading your constituents to consider your energy efficient home design. You must follow Tufte’s graphic theory design principles when designing and completing your newsletter.

**HAVE FUN!**
APPENDIX AB. FIGURE COPYRIGHT PERMISSION

Permission to Use Figures 9-11

Dear Vaneshette Henderson,

Thank you for sending your pdf again.

Figure 7. The New York Times holds copyright to this image. Please contact them for permission.

Figure 10. We have no objection to your use of this image. You do have "Visual Explanations" under this image. It appears in Envisioning Information.

Figure 11. This image is in the public domain.

Figure 12. We have no objection to your use of this image.

Thank you for writing.

Carolyn Williams

From: "Vaneshette T Henderson" <vhende1@lsu.edu>
Date: 2010/02/24 Wed AM 09:27:13 EST
To: <cwilliams@graphicspress.com>
Subject: RE: Copyright permission for dissertation

Good Morning Ms. Williams,

The document is attached. Thank you.

Vaneshette T. Henderson
College of Engineering
Office for Diversity Programs
3304 Patrick F. Taylor Hall
Baton Rouge, LA 70803
O: 225.LSU.6004
F: 225.LSU.4845
diversity.eng.lsu.edu

-----Original Message-----
From: cwilliams@graphicspress.com [mailto:cwilliams@graphicspress.com]
Sent: Wednesday, February 24, 2010 8:25 AM
To: Vaneshette T Henderson  
Subject: Copyright permission for dissertation  

Dear Vaneshette Henderson,

Edward Tufte has forwarded your permission request to be for processing. I cannot open your attachment. Could you please resend this directly to me.

Thank you,

Carolyn Williams

From: Edward Tufte <et314@me.com>  
Date: 2010/02/24 Wed AM 12:34:18 EST  
To: Carolyn Williams <cwilliams@graphicspress.com>  
Subject: Fwd: Copyright permission for dissertation

Begin forwarded message:

From: Edward Tufte <edward.tufte@yale.edu>  
Date: February 23, 2010 10:05:04 PM EST  
To: Vaneshette T Henderson <vhende1@lsu.edu>  
Subject: Re: Copyright permission for dissertation

OK for the one-time use described in the email below.

Edward Tufte

On Feb 23, 2010, at 9:59 PM, Vaneshette T Henderson wrote:

Good Evening Dr. Tufte,

My name is Vaneshette Henderson and I am a PhD Candidate at Louisiana State University in the Department of Educational Theory, Policy and Practice. My dissertation is entitled "The Theoretical Learning Impact of a Summer Engineering Program Curriculum for Underrepresented Middle School Students," and visual spatial and graphic design theory is a great part of my work.

I have used your 4-volume series in support of the importance of visual spatial and graphic design theory in STEM learning. Therefore, I have used several of your images to support my
work. I need your formal permission to use your images per the Graduate School at LSU. I have
tached a copy of the section that includes your images and work to this email.

If you feel that is proper use, I would truly appreciate it if you grant me formal permission to use
your images. If you believe my use of your images violate copyright, I will remove them from
my dissertation to be submitted by April 23rd.

If you have any questions, please feel free to contact me via email or by phone at 504-704-9467.

Thank you in advance for your consideration.

Sincerely,

Vaneshette Henderson

<VHenderson Use of Tufte_2010.pdf>

Carolyn Williams
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PO Box 430
Cheshire, CT 06410
phone: 203 250-7007
fax 203 272-8600
VITA

Vaneshette Teshawn Henderson was born in Houston, Texas, and was raised in Gretna, Louisiana. She received her Bachelor of Arts degree in physics from Xavier University of Louisiana. She also received her Master of Science degree in biomedical engineering from the University of Michigan. Vaneshette was the first Xavier student to complete the Dual-Degree Physics and Biomedical Engineering Master’s Program between Xavier and the University of Michigan.

After completing her studies at the University of Michigan, Vaneshette started her professional career working as a project manager in the Applied Sciences Directorate at the National Aeronautics and Space Administration (NASA) in Stennis, Mississippi. In this position, she was able to apply her physics and biomedical engineering knowledge skills to determine the appropriate way to use NASA satellite data to benefit Mississippi and Arizona state governments’ public health systems. After two years of service to the federal government, Vaneshette believed that she could not ignore her ultimate goal, helping minority students of all ages to love and excel in engineering just as she had. In order to accomplish her ultimate goal, Vaneshette wanted to earn a Doctor of Philosophy in curriculum and instruction with a concentration on science and engineering education. Vaneshette enrolled in Louisiana State University (LSU) in the Spring of 2006 in the College of Education. She is currently the Pre-College Program Coordinator with the LSU College of Engineering’s Office for Diversity Programs.

Her research interest includes enhancing science, technology, engineering and mathematics learning and interest in elementary and secondary minority students. Her dissertation involved the enhancement of science, technology, engineering and mathematics
learning in middle school minority students via visual spatial and Human Constructivism learning. The degree of Doctor of Philosophy will be conferred at the May 2010 commencement ceremony.

Vaneshette is the daughter of Mervin A. Henderson, Jr., and Sheila A. Henderson. She is the oldest sister to Toya, Alexandra, Dominique and Angelle. She is the proud aunt of Imani, Imari and Indya Brown.