EFFECTS OF DESIGN-BASED SCIENCE INSTRUCTION ON SCIENCE PROBLEM-SOLVING COMPETENCY AMONG DIFFERENT GROUPS OF HIGH-SCHOOL TRADITIONAL CHEMISTRY STUDENTS

by

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Effects of Design-Based Science Instruction on the Science Problem-Solving Skills among Different Groups of High-School Traditional Chemistry Students

Thesis directed by Associate Professor, Geeta Verma

ABSTRACT

Recent trends indicate a significant decline in the number of students graduating from Science, Technology, Engineering and Math (STEM) programs in the US. The under-representation of students of color, females and low income students in STEM programs has also been documented. Design Based Science (DBS) instruction has been suggested to improve the problem solving skills of students of color.

The present study employed a quasi-experimental pre-post-test research study. Four equivalent parallel high school traditional Chemistry classes of eighty two (82) 10th and 11th grade students was invited to participate in this study. The treatment group comprised of 36 students while the control group was made up of 46 students.

The purpose of this study was to investigate whether DBS affects student problem solving competency and chemistry achievement across student demographics (gender, race and SES). The research questions were: 1) Does DBS have any effect on the problem solving competencies of students in a high school traditional chemistry class? 2) Does the effect of DBS on problem solving competency depend on gender? 3) Does the effect of DBS on problem solving competency depend on race? 4) Does the effect of DBS on problem solving competency depend on SES? 5) Does DBS have any effect on the chemistry achievement of students in a high school traditional chemistry class? 6) Does the effect of DBS on chemistry achievement vary depending on gender? 7) Does
the effect of DBS on chemistry achievement vary depending on race? 8) Does the effect of DBS on chemistry achievement vary depending on SES? 9) Is the problem solving competency of students in a traditional chemistry class predictive of their chemistry achievement?

The findings are as follow: a) DBS significantly improved the problem solving competency of students in the study, b) DBS significantly improves the problem solving competency of both males and females, with a slight urge among females, c) the differences in the effects of DBS in improving problem solving competency among Black and Hispanic students in this study was not statistically significant, however, Black students and Hispanic female students showed significant improvement in problem solving competency after the DBS instruction, d) DBS did not statistically significantly improve the problem solving competency of students of particularly SES group(s), and e) Problem solving competency is a strong predictor of higher chemistry concepts score among students in both treatment and control groups.

The form and content of this abstract are approved. I recommend its publication.

Approved: Geeta Verma
DEDICATION

I dedicate this work to loving memory of my parents, Alexander Lartson and Charlotte Love Lartson, who are still very much a part of my life; and to my lovely wife, Angela Lartson and my children Alexander Lartson, Charlotte Lartson and Mary Street Awura Abena Lartson.
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CHAPTER I

INTRODUCTION

The total number of students graduating from math, engineering and physical science majors has been on the decline since the mid-1980s (Mooney and Laubach, 2002). Recent trends suggest a significant decline in the number of students interested in Science, Technology, Engineering and Mathematics (STEM) careers (van Langen and Dekkers, 2005) in K–12. The under representation of STEM Bachelor degrees earned by targeted minority student groups, namely, African Americans, Latino/as, South East Asians and Native Americans (ALANAS) (The Center for Education and Work, 2008) and girls (Fadigan & Hammrich, 2004; Gilbert & Calvert, 2003; Scantlebury & Baker, 2007) has also been reported. Despite the similarity in the intentions of ALANA and White students to major in STEM fields the former are less likely to major and more likely to drop out of STEM programs (The Center for Education and Work, 2008). A number of factors have been identified as accounting for these findings.

One of the reasons advance for the decline in the number of US students participating in STEM programs, in general and in particular among female and minority students is the view among these students that science and technology is uninteresting, difficult and closed off to them (President’s Council of Advisors on Science and Technology – PCAST, 2010). Hanushek & Rivkin, (2003) also point to teacher quality and effectiveness as important factors determining students’ performance in STEM classrooms. The results of the PISA 2003 problem solving competency assessment (OECD, 2003) suggest a strong correlation between problem solving competency and socioeconomic status (SES). With a high proportion of ALANAS falling within low SES
in the United States, the PISA 2003 problem solving assessment results also suggest low problem solving competency among this group of students. The current study focuses on problem solving ability since problem solving has been identified as a 21st century skill needed for students to be successful in and out of school (Partnership for 21st Century Skills, 2009). Problem solving is a focus of the current study also because problem solving through scientific reasoning (as proposed by John Dewey) remains a primary goal of science education (Atkins & Black, 2003).

Various related pedagogies such as Problem-based learning (PBL), Project-based learning (PjBL), Design-Based Science (DBS) and Inquiry-based learning (IBL) have been used in an attempt to improve problem solving skills. These pedagogies contextualize learning by making content relevant to student life experiences. Such modes of teaching have a potential of closing the achievement gap (Wisely, 2009). During Problem-Based Learning students are presented with an “ill-structured” problem intended to help students build skills and content knowledge. PjBL is similar to PBL except that student projects involve a culminating artifact in the problem solving lesson. DBS is a type of PjBL, which incorporates inquiry (the use of the scientific method in problem solving).

In his review of research on PjBL, Thomas (2000) notes that most of the research on PjBL took place between 1995 and 2000. Thomas (2000) references a number of studies such as those by the Expeditionary Learning Outward Bound (ELOB), Co-nect schools and the Academy for Educational Development (AED), relating PjBL and student achievement. Although significant improvements in student achievement were reported by the studies for students in PjBL programs, Thomas (2002) points out that the
results may be attributable in part to features other than those of PjBL (e.g. portfolios, flexible block scheduling for ELOB; technology in the case of Co-nect schools). He also posits that since technology and expeditions do not target basic skills (reading, writing and computation), the reported effects of these PjBL-programs on student’s basic skills achievement may be the result of a generalized effect associated with the whole school reform effort or, perhaps, the motivational effect of project-based instruction may lead to increased student attendance, attention, and engagement during the (non-project) periods students spend learning basic skills. Also, only one study of PjBL effectiveness was found that used a longitudinal experimental design, with pre-post assessments. As far as the effects of PjBL on problem solving skills, studies conducted between 1995 and 2000 relate primarily to PjBL (not PjBL) (Thomas, 2000). Furthermore, there are improved methods for assessing problem solving capabilities (OECD, 2003). Recent empirical studies suggest that middle school students, particularly African-American students, involved in DBS improve both in their science content knowledge and problem solving skills (Fortus, Dershimer, Krajcik, Marx and Mamlok-Naaman, 2005; Mehalik, Doppelt and Schuun, 2008). It is clear from the preceding overview that while more research is needed in the effectiveness of PjBL (and consequently DBS) in improving student achievement and problem solving capacities, more of this work is needed at the high school level, where achievement gaps, particularly that between genders widen (Ingels & Dalton, 2008; Bacharach, Baumeister & Furr, 2003; Jones, Mullis, Raizen, Weiss, &Weston, 1992). Also, in the last ten years, just a few studies have been conducted comparing the effectiveness of DBS in improving science achievement across race/ethnicity. The focus of this study is thus to investigate the relationships between
DBS on the one hand, and problem solving competency and science knowledge gain on the other, among different genders, race and socioeconomic groups.

The interactions between DBS problem solving skills, science achievement and race-ethnicity, elicited from some of the above referenced studies, are summarized in Figure I below. Mehalik, Doppelt and Schunn 2008; Fortus, Dershimer, Krajcik, Marx and Mamlok-Naaman, 2004, 2005 and Chang, 2001a, 2001b) posit that different modes of problem-solving associated instruction such as DBS can improve students’ problem-solving ability and consequently science achievement. The strong correlation between problem solving ability and science achievement reported by OECD (2003) also speaks to the latter relationship. DBS is one of such science pedagogies that has been found to show promising results in science education, by improving both science achievement (Kolodner, Camp, Crismond, Fasse, Gray, Holbrool, Puntambekar, Ryan, 2003; Mehalik,

Figure I. Interactions between DBS, Science Knowledge and problem-solving skills
Doppelt and Schunn, 2008; Fortus, Dershimer, Krajcik, Marx and Mamlok-Naaman, 2004, 2005; Silk, Schunn & Cary (2009). DBS has also been described as pedagogy in which scientific knowledge and problem-solving skills are constructed.

The extent to which the achievement gap contributes to the potential loss of the United State’s global competitive edge as well as maintenance of a robust national economy cannot be overlooked. The McKinsey consulting firm released a report on the economic impact of the achievement gap in America’s Schools in 2009. The implications of the report revealed a national decline in productivity and jobs. According to the report, if the U.S. had been able to close the gap in science and math achievement between 1983 and 1998 and raised its performance to the level of such nations as Canada, Finland and South Korea, the U.S. Gross Domestic Product (GDP) in 1998 would have been approximately $2 trillion higher. If the achievement gap had been closed between Black and Hispanic students on the one hand and white and Asian students by 1998, the GDP in 2008 would have been about $400 to $500 billion higher. If the gap between America’s low-income students and the remaining students had been similarly narrowed, GDP in 2008 would have been $400 to $670 billion higher. In terms of PISA math and science output and the amount of money the U.S. spends on each student, which is among the highest in the world, the report concludes that the United States gets 60% less for its education dollars in terms of average test score results than do other wealthy [industrialized] nations.

This chapter presents the trend of declining science achievement among U.S. students as well as the potential of DBS in the construction of new scientific knowledge. It also reviews the potential of DBS in the development of problem solving skills in
secondary science education. It describes the need for a study of the effects of DBS on different groups of students, vis-à-vis the over-a-decade long decline in the number of US students in STEM programs (particularly girls, and minority students) as well as poor problem solving abilities. This decline is presented not only as a national issue but also in relation to other industrialized countries with its implications for the U.S. economy. A number of contributory factors to the decline are discussed, with emphasis on the problem-solving abilities of students across gender, racial-ethnic and socioeconomic groups both in the U.S. and on the international scene. Also, findings from empirical studies are presented in exploring the benefits of innovative science pedagogies on the development of problem-solving skills. The relationships between such pedagogies as DBS, PBL, project-based learning, and inquiry that highlight problem-solving and the development of problem-solving skills are presented. The goal of this chapter is therefore to propose the need to study the effects of DBS (an integration of project-based learning and inquiry-based learning) on high-school students’ problem solving skills and science knowledge. Problem-solving skills must be studied across gender, racial-ethnic and SES in an attempt to meaningfully contribute to efforts aimed at closing the achievement gap in science. Closing the achievement gap has become increasingly important in a struggling U.S. education system in which racial-ethnic and socio-economic differences are becoming more and more pronounced.

**Trends in the Performance of U.S. Students in Science**

The decline in U.S. education has been attributed to inadequate preparation and experiences in math and sciences (ACT, 2006), family characteristics and educational support variables, attitudes toward math and science, differences in aptitude (Benbow &
Arjmand, 1990) and inadequate problem-solving skills (Ornstein, 2010). Although the United States can identify individual schools and school districts that have been successful, the U.S. education system as a whole has been on the decline for at least a couple of decades nationally and internationally. The Department of Education (2004) and Helpman (2004) reported that several indicators of the performance of U.S. students in science and mathematics education at the pre-college level reveal a mixed picture of successes and shortcomings. A discussion of data from the National Assessment of Educational Progress (NAEP), the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) will elucidate the performance of students in high stakes science assessments.

On NAEP, less than one-third of U.S. eighth graders show proficiency in mathematics and science, and science test scores have improved although very little over the past few decades. According to the US Department of Education (2012), the overall average score for the nation at grade 8 was 2 points higher in 2011 than in 2009. Score gaps between White and Black students and White and Hispanic students narrowed from 2009 to 2011. Sixty-five percent of eighth-graders performed at or above the in 2011, 32 percent performed at or above Proficient, and 2 percent performed at the Advanced level. The percentages of students at or above Basic and at or above Proficient were higher in 2011 than in 2009. Of the 47 states/jurisdictions that participated in 2009 and 2011, public-school students in 16 states scored higher in 2011 than in 2009. In 2011, students in 29 states scored higher than the national average, and in 16 states they scored lower. The NAEP 2005 science assessments revealed that 12th graders, showed no change in performance from the administration of the assessment in 2000. However, the 2005
average scores were lower than those in 1996. Also, at this grade level, the percentage of students performing at or above the basic level, at or above the proficient level, and at the advanced level all declined compared to 1996 data. In addition, the number of students who scored below basic increased since 1996 (Department of Education, 2006). In the U.S., achievement gaps in science and math between white or Asian/Pacific Islander students and minorities (traditionally underrepresented in STEM) exist at all levels, including significant gaps among the highest-performing students. For example, a recent analysis of both NAEP and state assessment data shows that large achievement gaps in mathematics performance continue to persist between white and underrepresented minority high achievers (Plucker, Burroughs & Song, 2010).

International comparisons of our students’ performance in science and mathematics place the United States in the middle of the pack or lower. TIMSS measures what students know and can remember in science and math. In 2007 U.S. fourth graders and eighth graders placed about average among industrialized and rapidly industrializing countries. However, U.S. students in fourth, eighth, and twelfth grades drop progressively lower on international comparisons of science and mathematics ability as their grade level increases. The U.S. Department of Education (2009), reports that in 2007, the average science scores of both U.S. fourth-graders (539) and eighth-graders (520) were higher than the TIMSS scale average (500 at both grades). The average U.S. fourth-grade science score was higher than those of students in 25 of the 35 other countries, lower than those in 4 countries (all of them in Asia), and not measurably different from those in the remaining 6 countries. At eighth grade, the average U.S. science score was higher than the average scores of students in 35 of the 47 other countries, lower than those in 9
countries (all located in Asia or Europe), and not measurably different from those in the other 3 countries.

PISA is a triennial survey of knowledge and skills of fifteen-year old students in countries that form the Organization for Economic Co-operation and Development (OECD). The areas PISA focuses on during each six-year cycle are mathematics, science, reading and problem solving. However, within each cycle the surveys emphasize different areas. The U.S. average score in science literacy in 2009 was higher than the U.S. average in 2006, the only time point to which PISA 2009 performance can be compared in science literacy. While U.S. students scored lower than the OECD average in science literacy in 2006, the average score of U.S. students in 2009 was not measurably different from the 2009 OECD average. However, in 2009 while 1% of U.S. students were proficient at level 6 the percentage was higher (1.5%) in 2006. At Level 6, students can consistently identify, explain and apply scientific knowledge and knowledge about science in a variety of complex life situations. U.S. students scored below most other nations tested in 2006, and the U.S. standing dropped from 2000 to 2006 in both math and science.

It is generally accepted that most high school graduates do not enroll in science and mathematics courses. In fact, of all ninth graders in the United States in 2001, for example, only about 4 percent are predicted to earn college degrees in STEM fields by 2011 (PCAST, 2010). Likewise, many studies note the importance of achievement in science during high school for determining later persistence in the science pipeline through college and early career years (Carmichael, 2007; Hanson, 1996; Kaufman, 1991). Other predictors of persistence in the science pipeline include classroom climate,
classroom pedagogy, faculty attitudes and behavior and financial aid (Carmichael, 2007). Thus, pre-college years represent a critical period for encouraging students to enter the science pipeline. Indeed, the level of science preparation in secondary school, and specifically pre-college science achievement, is generally noted to be among the most consistent and best predictors of students’ interest and persistence in postsecondary STEM fields (Griffith, 2010; Hanson, 1996; Davis, Ginorio, Hollenshead, Lazarus & Rayman., 1996).

The decline in the stream of high school graduates into undergraduate science, technology, engineering and mathematics trend manifests on college campuses all over the country. In fact, the number of U.S. college students majoring in science, math and engineering is flat, and the percentage of graduates in these essential areas in Western European and especially Asian countries have increasingly outpaced the U.S. (Ornstein 2010). The achievement gaps in science and math between white or Asian/Pacific Islander students and minorities as established by NAEP and state assessment data underscore a systemic problem: the lack of opportunities and support for underrepresented minority students, inadequate teaching, and an absence of both real-life, hands-on experiences with STEM materials and positive role models of STEM professionals (Hanushek & Rivkin, 2009; Reardon, 2008; Gándara, 2005; Donovan & Cross, 2002). In addition, many students who academically qualify for postsecondary studies in science and math fields at both two- and four-year institutions don’t pursue those programs due to a number of reasons. These reasons include: dissuasion by disappointing postsecondary experiences, high tuition or demanding curricula and courses of study, relatively low salaries in STEM fields compared to other professions, or
the lack of role models with whom they can identify (American Association of State Colleges and Universities, 2005).

As varied as the causes are for a struggling U.S. education system, so must the solution. The under-representation of women, people of color, and the poor decreases not just the quantity, but the quality and breadth of the talent of persons in STEM fields (Drew, 1996). Just by their sheer numbers, women, people of color and the poor participate significantly in the struggling U.S. education system. Solutions for the declined U.S. education system must address the achievement gap in science and math between races, socio-economic classes and gender. The achievement gap between Asian and white students compared to Hispanic and black students remain alarmingly high, granted that by the year 2015 the latter group of students will represent the majority enrollments in U.S. public schools (Ornstein 2010). It is typically noted in the literature, the primary cause of attrition of minority students from scientific fields is often poor academic preparation prior to college (Oakes, 1990; Petersdorf, 1991). In addition, racial–ethnic differences in science achievement are generally larger throughout all grades than are gender differences (Hanson, 1996). Research studies show that race–ethnicity explains much more of the variance in science achievement scores than does gender, and females and males within racial–ethnic categories are much more similar with regard to achievement than are females across racial–ethnic categories (Muller, Stage & Kinzie, 2001; Clewell & Ginorio, 1996; Creswell & Houston, 1980). Research on racial–ethnic differences shows that Asian American and White students show higher science achievement scores, as well as disproportionately greater science achievement gains, during middle school and high school than their Latino/a and African American
counterparts (Bacharach, Baumeister & Furr, 2003; Scott, Rock, Pollack, Ingels, & Quinn, 1995), and are similarly overrepresented in high school and college science courses; STEM college majors; and scientific and technical careers (Peng, Wright, & Hill, 1995). In general, these racial–ethnic differences on standardized science tests appear much earlier than gender differences (Bacharach, Baumeister & Furr, 2003; Mullis, Dossey, Owen, & Phillips, 1993), and the racial–ethnic differences tend to increase with age (Bacharach, Baumeister & Furr, 2003; Gross, 1988, 1989). Although less prominent, gender gaps in science must be addressed to ensure that all students reach their potential.

**Gender Gap in STEM Education**

Over the last 30 years the gender gap in science has narrowed, however, girls and women remain underrepresented and marginalized in physics, engineering and technology (Fadigan & Hammrich, 2004; Gilbert & Calvert, 2003; Scantlebury & Baker, 2007). The gender gap favoring males does not only appear consistently across all racial–ethnic groups, but also the pattern appears to be consistent throughout middle school and high school, with the differences widening sharply by Grade 12 (Ingels & Dalton, 2008; Bacharach, Baumeister & Furr, 2003; Jones, Mullis, Raizen, Weiss, & Weston, 1992). There are a number of pointers that may explain some of these observations. Girls of all ethnic groups have negative science attitudes and fewer science experiences than boys (Catsambis, 1995). According to Miller, Blessing & Schwartz (2006) girls like biology, chose people-oriented majors, and chose science majors to help people or animals and that girls perceive science as uninteresting, passionless, or leading to an unattractive
lifestyle. This finding partly explains the under-representation of women in STEM professions.

In 2006, women earned only 28% of Ph.D.s in physical sciences, 25% in mathematics and computer science, and 20% in engineering in the United States (NSF, 2008). Although women made up 47% of the US workforce in 2009, the percentage of women in lucrative technical professions, such as “computer and mathematical occupations” and “architecture and engineering occupations,” reached only 25% and 14%, respectively (US Bureau of Labor Statistics, 2009). The gender gap in STEM disciplines goes beyond the limited representation of women. In college physics women earn lower exam grades and lower scores on standardized tests of conceptual mastery (Pollock, Finkelstein & Kost, 2007; Brewe, Sawtelle, Kramer, O’Brien, Rodriguez, & Pamela, 2010).

Various factors have been identified as accounting for the gender gap in STEM. Students’ prior background and preparation in mathematics and physics have been identified as a major contributor to performance in introductory physics (Hazari, Tai & Sadler, 2007). In their review of literature Scantlebury and Baker (2007) identified other factors such as science attitudes, classroom environments and the impact of policies such as high-stakes testing that contribute to the gender gap. Brotman & Moore (2008), in reviewing science education literature from 1995 to 2006, developed four themes underlying the gender gap a) equity and access b) curriculum and pedagogy c) the nature and culture of science and d) identity.

Strategies related to gender responsive curricula are found in PjBL (and DBS) and is therefore worth exploring. Brotman & Moore (2008) noted a variation in what different
researchers described as gender-inclusive curriculum and pedagogy. However, some common features emerged from the interventions attempted by these researchers. Specifically, a gender-inclusive science curriculum draws upon girls’ and boys’ experiences, interests, and preconceptions; prioritizes active participation; incorporates long-term, self-directed projects; includes open-ended assessments that take on diverse forms; emphasizes collaboration and communication; provides a supportive environment; uses real-life contexts; and addresses the social and societal relevance of science. It also pays attention to issues of sexism and gender bias in curriculum materials. Roychoudhur, Tippins, & Nichols (1995) found that among majority of prospective elementary teachers - most of whom were female, situated, collaborative learning and long-term, open-ended projects in a physical science class triggered feelings of empowerment, competence, ownership, and an appreciation for the connection between science and their lives. The implications of the achievement gap to the United States make it imperative for serious systemic corrective actions. Gender-inclusive science curricula are in many ways consistent with recommendations made by science education reform efforts in general, which attempt to improve science education for all students through constructivist approaches (American Association for the Advancement of Science [AAAS, 1993]; National Research Council [NRC, 1996]) promoted by John Dewey, for example, DBS.

**John Dewey and Problem Solving**

In 1910 Dewey proposed problem-solving through scientific reasoning as a goal of science education. A review of science education reform in the U.S. and other developed nations (Atkin and Black 2003) clearly indicate that this goal was never really abandoned. Dewey’s goal of science education was punctuated in the 1950s by the goal
of teaching science for science’s sake, led by the University of Illinois. However, by the late 1980s the Deweyan problem-solving approach to science education, revived in the U.S., was evident in other developed nations such as France, Japan, Scotland, Canada, Australia, Germany and Spain. As the 20th century drew to a close the Deweyan goal of science education was broadened to include inquiry. During the last fifteen years inquiry activities have become increasingly integrated with the design process, which is also a problem-solving process (Fortus, Dershimer, Krajcik, Marx & Mamlok-Naaman (2004). This is in line with recommendations by the International Technology Education Association (ITEA) (ITEA, 2002).

The development of problem-solving skills as a long-standing goal of science education is well documented (Atkin and Black 2003, Stewart, 1982; Wavering, 1980; Champagne and Klopfer, 1977). In furtherance of this goal however, school science has traditionally been taught around well-defined problems, such as predicting an ideal projectile’s trajectory or calculating how much water is generated by the ignition of given amounts of hydrogen and oxygen. On the other hand, real-world scientific inquiry focuses on ill-defined problems as aptly described by the American Association for the Advancement of Science (AAAS, 1990),

“There simply is no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge” (p. 4).

Many school curricula and teaching practices have been criticized because they do not give students experience in real-world problems, in situations where decisions are not clear-cut, where requirements can conflict, and optimization rather than ‘proof’ is needed.
A number of researchers and organizations have recommended restructuring school science so that science, in the classroom is taught around real-world problems relevant to students’ lives. Thus design activities or lessons, that involve real-world problem solving, should be incorporated into education in general and in science education in particular (AAAS, 1990; Chiapetta, Koballa, Jr., & Collette, 2002; Davis, 1998; ITEA, 2002; Layton, 1993; NRC, 2002). These recommendations have led to crucial actions by various stakeholders including the U.S. federal government, industry and foundations to improve science, technology, engineering and mathematics (STEM) education. Real-world problems are ill-defined, lacking some required information, and not necessarily having a known correct or the best solution (Nickerson, 1994; Roberts, 1995).

The Government Accountability Office (GAO, 2005) catalogued and assessed the impact of federal programs designed to improve educational programs, particularly STEM curricula. The analysis also included the impact of such programs on the number of students pursuing STEM careers. Industries and firms dependent upon a strong science and math workforce pipeline have launched a variety of programs that target K-12 students and undergraduate and graduate students in STEM fields. Industry associations that include the Society for Manufacturing Engineers, the American Chemical Society, the American Physical Society, the National Association of Manufacturers, and the National Science and Technology Education Partnership invest in STEM education initiatives that involve curricular improvements, career-focused websites, mentoring programs, scholarships, and other incentives and supports. Individual firms and their corporate foundations, including Raytheon, Bayer, and General Electric, have created
outreach efforts of their own (Delaware Valley Industrial Resource Center and National Council for Advanced Manufacturing, 2006). Project Lead the Way (PLTW) operates in over 4,000 middle and high schools in the 2011/12 school year in all 50 states of the U.S., bringing them STEM programs (PLTW, 2011). For instance, The PLTW Gateway To Technology (GTT) program features a project-based curriculum designed to challenge and engage the natural curiosity and imagination of middle school students (http://www.pltw.org/our-programs/middle-school-engineering-program). Another example is Raytheon’s MathMovesU program, which among others showcases math (and) in action as students design and experience their own thrill ride using math fundamentals (http://mathalive.com/raytheon-mathmovesu/#raytheon). STEM Education attempts to transform the typical teacher-centered classroom by encouraging a curriculum that is driven by problem-solving, discovery, exploratory learning, and require students to actively engage a situation in order to find its solution (Fioriello, 2010). The above initiatives, though worthwhile, they are optional to schools and not available to schools nation-wide. The Next Generation Science Standards to be released in April 2013 sets the stage for the application of engineering design in K-12 science lesson nationwide. Draft II (http://www.nextgenscience.org) of the Next Generation Standards incorporates engineering design in science lessons in K-12 classrooms. Some of the well-known STEM approaches are PBL, inquiry, problem-based learning and DBS. These approaches are however similar and intertwined.

**Relationship between PBL, PjBL, DBS and Inquiry**

Problem-based learning, as it is generally known today, evolved from innovative health sciences curricula introduced in North America over 30 years ago at McMaster
University in Canada and became an accepted instructional approach in medical institutions across North America and in Europe in the 1990s (Boud and Feletti, 1997). Hmelo-Silver (2004) described Problem-based learning as an instructional method in which students learn through facilitated problem solving that centers on a complex problem, which does not have a single correct answer. Torp and Sage (2002) described Problem-based learning as focused, experiential learning organized around the investigation and resolution of messy, real-world problems. They described students in a Problem-based learning classroom as engaged problem solvers, seeking to identify the root problem and the conditions needed for a good solution and in the process becoming self-directed learners. Savery (2006) described problem-based learning as a learner-centered instructional approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem. The Problem-based Learning Institute has developed curricular materials and teacher-training programs for all core disciplines in high school (Barrows & Kelson, 1993). Problem-based learning is now used in multiple domains such as pre-service teacher education (Hmelo-Silver, 2004) and chemical engineering (Woods, 1994).

Project-Based Learning (PjBL) has a long historical background (Grant, 2002). It was first discussed in W. Kilpatrick’s article “The Project Method”, published in 1918 (Wrigley, 1998). Since, John Dewey’s “problem solving” method began to resemble the traditional teaching method, W. Kilpatrick began to spread “The Project Method” (Oguzkan, 1989). PIBL can thus be said to have emerged as a synthesis of John Dewey’s and Kilpatrick’s views on learning. According to the definitions found in PjBL handbooks for teachers, PjBL involves complex tasks, based on challenging questions or
problems, that involve students in design, problem-solving, decision making, or investigative activities; give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentations (Jones, Rasmussen, & Moffitt, 1997; Thomas, Mergendoller, & Michaelson, 1999).

Inquiry-based learning, just like PjBL is grounded in the philosophy of John Dewey, who believed that education begun with the curiosity of the learner. Inquiry-based learning is a student-centered, active learning approach focused on questioning, critical thinking, and problem solving (Savery, 2006). Inquiry-based learning activities begin with a question followed by investigating solutions, creating new knowledge as information is gathered and understood, discussing discoveries and experiences, and reflecting on new-found knowledge. Inquiry-based learning is frequently used in science education and encourages a hands-on approach where students practice the scientific method on authentic problems (or questions).

DBS was designed around a stepwise description of the design process (Davis, Hawley, McMullan, & Spilka, 1997) and a social constructivist perspective of learning (Blumenfeld, Marx, Patrick, Krajcik, & Soloway, 1997). Silk, Schunn & Cary (2009) define design-based learning in general as a type of project based learning, which engages students in the process of developing, building, and evaluating a product they have designed. According to Krajcik, Blumenfeld, Marx, Bass, Fredricks, & Soloway (1998) DBS is an inquiry-based pedagogy that grew out of Project-Based Science, which is similar to Problem-based learning. Design-based science (DBS) is a science pedagogy that aligned with the goals of STEM education and inquiry-based science education. DBS, according to Fortus, Dershimer, Krajcik, Marx and Mamlok-Naaman (2005) is an
inquiry-based science pedagogy in which new scientific knowledge and problem-solving skills are constructed in the context of designing artifacts. In a PjBL environment learners are usually provided with specifications of a desired end product achieved by following correct procedure. However, learners are likely to encounter several problems that generate “teachable moments” (Lehman, George, Buchanan, & Rush, 2006).

The relationship between PlbL, PjBL, DBS and IBL are presented in Figure 2. The primary difference between PlbL and inquiry-based learning relates to the role of the

![Figure II. Relationship between PjBL, PlbL, DBS and IBL](image-url)
tutor (Savery, 2006). In an inquiry-based approach the tutor is both a facilitator of learning (encouraging/expecting higher-order thinking) and a provider of information. In a PjBL approach the tutor supports the process and expects learners to make their thinking clear, but the tutor does not provide information related to the problem - that is the responsibility of the learners. DBS, however, incorporates inquiry and the design process. Common to these three approaches is certainly the presence a problem to be solved with the learner as an active player and the teacher as a facilitator, hence their inter-relatedness. It must be noted that the choice of DBS for the current study was made due to the promising results reported in previous research efforts in the areas of Learning by Design (Kolodner, Camp, Crismond, Fasse, Gray, Holbrool, Puntambekar, & Ryan, 2003), project-based learning (Prince, 2004; Thomas, 2000) and problem-based learning (Akınoglu and Tandoğan, 2007). The choice of DBS over other approaches was influenced by the fact that it combines inquiry and project-based approaches, both of which are consistent with problem solving as a goal of science education.

Potential of DBS for Low-SES and Low-Performing Students

The results of preliminary studies by Fortus, Dershimer, Krajcik, Marx and Mamlok-Naaman, (2005) and Puntambekar & Kolodner, 2005 imply that DBS and other inquiry-based pedagogies have the potential of helping students develop science knowledge. Engaging students in design-based learning or problem-based learning within a science classroom has the potential of helping students develop problem solving skills and scientific inquiry skills (Kolodner, Camp, Crismond, Fasse, Gray, Holbrool, Puntambekar, and Ryan, 2003; Silk, Schunn and Strand, 2007). In their study of the effects of DBS on science achievement among middle school students by gender, socio
economic status (SES) and race-ethnicity, Mehalik, Doppelt and Schuun (2008) reported that low-achieving African American students benefited the most from DBS. The above findings provide an excellent opportunity to study the effects of innovative pedagogies such as DBS on the improvement of science achievement gaps in secondary education. This is because they are primarily focused on middle schools. More research is thus needed in subjects such as Physics, Chemistry and Biology in high-school settings. Efforts to draw attention to the importance of problem solving in science are exemplified not only by the increasing number of project-/problem-solving programs but also by PISA. The potential of DBS in improving student achievement and problem solving competencies in science may emanate not only from its student-centered, hands-on approach but also from its contextualization of science.

The effects of contextualization, such as provided by DBS were studied by Wisely (2009). He investigated the hypothesis that low-skilled students can learn more effectively and advance to college-level programs more readily through contextualization of basic skills instruction. The results of his study, which was however not in science, showed that participation in contextualization was associated with the completion of developmental education courses and the speed of entry into, and performance and completion of, college level courses. These positive effects were however, limited to non-white students: no effects for contextualization were found for white students. There is an interesting overlap between this and Bernstein’s (1975) and Holland’s (1981), finding that contextualizing science problems through real-world problem-based instruction, aligned with lower class students’ preferred ways of thinking. This overlap is the relationship between race and socio-economic status: the idea that low skilled and lower-
class students benefited more from contextualization. Indeed, LaVeist (2005) describes the correlation between race and SES as substantial, with Whites and Pacific Asians having a high SES while African Americans and Hispanics tend to belong to the low SES group. According to Baker, Hope, and Karandjeff (2009), contextualization has been defined in numerous ways. For the purposes of this study I refer to the proposal by Mazzeo, Rab, and Alssid (2003) that,

“Contextualization is a diverse family of instructional strategies designed to more seamlessly link the learning of foundational skills and academic or occupational content by focusing teaching and learning squarely on concrete applications in a specific context that is of interest to the student” (p. 3).

The above findings therefore present another opportunity to investigate the effects of DBS on the development of problem-solving skills among various groups of students. If the relationship between DBS and science achievement among low-class African American students and the correlation between science literacy and problem solving skills are real then DBS may contribute to fighting the downward trend of minority students’ involvement in STEM courses.

**PISA and Problem Solving**

In 2003, PISA measured students’ problem solving capabilities. Problem solving will next be measured in 2012. The PISA 2003 problem-solving assessment measured the capability of fifteen year olds to apply knowledge to solving cross-disciplinary tasks, which approximate real-life situations. While U.S. students showed improved science results between 1995 and 2003 on their TIMSS average science score, their 2003 PISA average score in science and problem solving were below the international average
(National Science Board, 2006). This confirms the observation by OEDC (2004) that U.S. students solved problems at the basic level (http://www.oecd.org/dataoecd/25/12/34009000.pdf). These students were consistently able to understand the nature of a problem and the relevant data associated with a problem’s major features. However, most of these students were generally incapable of dealing with multi-faceted problems involving multiple data sources or requiring analytical reasoning with the information provided. Data from the PISA 2003 also reveals a high correlation of 0.8 between problem solving competency and science achievement.

The PISA 2003 data also describe the relationship between international socio-economic index (largely determined by parental occupational status) and problem solving capabilities. Fifty percent of the variance in problem solving performance in the U.S. results was explained by international socio-economic index. The disparity in problem solving performance between the top and bottom socio-economic index for the U.S. is approximately 90 score points, close to one proficiency level in problem-solving performance (OECD, 2003). Improving this relationship between problem-solving performance and socio-economic status may therefore contribute significantly to closing the achievement gap between socio-economic classes.

Earlier research studies by Clewell & Ginorio (1996); Creswell & Houston (1980) suggest that race–ethnicity and gender explain a significant portion of the variance in science achievement scores to varying degrees. If problem solving is significantly correlated to science achievement and SES, then any instructional approach that improves the problem solving competencies of students could provide leverage in closing achievement gaps between genders, SES and race. Also, on the premise that almost
everyone naturally engages in problem-solving (Nickerson, 1994) and design activities (Roberts, 1995; Baynes, 1994) it can be inferred that design-based lessons have the potential to address the basic capacity of all students. The current study therefore attempts to ascertain the impact of DBS on the development of problem-solving skills among students across gender, racial-ethnic and socio-economic status (SES).

The integration of science, mathematics, and technology has been a common expectation in science education reform, to encourage problem solving, particularly in Project 2061. According to Project 2061,

“Some important themes pervade science, mathematics, and technology . . . They are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design” (AAAS, 1989, p. 155).

It is therefore anticipated that science education will help students learn to integrate cross disciplinary principles and knowledge in solving problems. Numerous documents stress the importance of technology in science learning. Some of these efforts include: The National Science Education Standards [NSES] (National Research Council [NRC], 1996), and Project 2061 (American Association for the Advancement of Science [AAAS], 1989, 1993). Technology is quite often used in a wide variety of meanings. However, among many definitions of technology, the above documents consistently use technology to refer to engineering, design, or engineering and design interchangeably (Raizen, Sellwood, Todd, & Vickers, 1995; Roth, 1998). The component of technology most closely allied to scientific inquiry and mathematical modeling is engineering. In its broadest sense, engineering consists of construing a problem and designing a solution for it. According to NSES,
“The central distinguishing characteristic between science and technology is a difference in goal: The goal of science is to understand the natural world, and the goal of technology is to make modifications in the world to meet human needs” (NRC, 1996, p. 24).

The integration of science and technology thus allows students to use scientific knowledge to design and solve real-world problems. Despite its importance in making science relevant and practical in everyday life, technology as engineering and design has been largely ignored in school science (Raizen, Sellwood, Todd, & Vickers, 1995). However, the situation is changing. There have been increasing efforts by corporate bodies and the U.S. government to improve STEM programs in schools (Delaware Valley Industrial Resource Center and National Council for Advanced Manufacturing, 2006; PLTW, 2011; GAO, 2005). The result is an increasing popularity of pedagogies such as DBS, PIBL and PjBL, all of which have problem solving in common. These science instructional pedagogies (in science) enable the transfer of science knowledge to solving real-world problems. A number of empirical studies link real-world problem-solving associated pedagogies to science achievement.

**Statement of the Problem**

Student achievement in science (and math) in the United States has been on the decline over the past couple of decades, both nationally and internationally (Ornstein, 2010; U. S. Department of Education 2004, 2006; NEAP, 2005), particularly in secondary education. The achievement gaps between males and females (NSF, 2008; Ornstein, 2010) and race (Ornstein, 2010; Clewell & Ginorio, 1996; Creswell & Houston, 1980) have indeed not improved. An observable direct consequence of this decline is the
decreasing of competitive edge by the United States in the global market place and the leveling of college enrollment into STEM programs while the opposite is the case in other industrialized nations (Ornstein, 2010). The decline in student academic achievement in science (and math) has been attributed to a myriad of factors including pre-college educational preparation and high-school test scores in math and science (Griffith, 2010), family characteristics and educational support variables, attitudes toward math and science, and differences in aptitude (Benbow and Arjmand, 1990) and problem solving skills (Ornstein, 2010; OECD, 2003).

Problem-solving associated science pedagogies such as DBS and PBL have the potential of improving students’ creativity/critical thinking, problem-solving ability, science-process skills and consequently science achievement (Mehalik, Doppelt and Schunn 2008; Fortus, Dershimer, Krajcik, Marx and Mamlok-Naaman, 2004, 2005; OECD, 2003; Chang, 2001a, 2001b). Other factors that have been verified to improve science achievement, particularly among African American students in particular, include their experience/conflict with science discourse (Brown, 2004; Fang, 2004; Bergin & Cooks, 2002). Systemic problems of teaching African-American students, including problems of teachers lacking science knowledge, poorly trained teachers, and poor expectations continue to exist and can be seen as a social inequity issue for African-American learners (Atwater, 2000) as well as other low-income urban students.

The current study identifies real-world problem-solving ability for study for a number of reasons, namely, a) it has been a long-standing goal of science education, b) it has been identified as one of the 21st century skills that will help students be successful in life and at their workplaces (Partnership for 21st Century Skills, 2009), c) it correlates
highly with science achievement (OECD, 2003), d) a number of studies suggest that DBS, a project-based inquiry approach can improve real-world problem-solving skills as well as improve science achievement among one of the target groups of this study, namely, African Americans (Mehalik, Doppelt and Schuun, 2008; Kolodner, 2002; Rivet & Krajcik, 2004), and that e) boys and girls tend to favor hands-on activities (such as in DBS), which result in better science attitudes (Jovanic & Steinbach King, 1998).

**Rational/Purpose of the Study**

A number of factors have been identified to account for the decline in science achievement in the U.S. locally and on the international scene. Of these factors real-world problem-solving skills will be the focus of this study for reasons explained above. While there have been signs of improvement in science scores during the last few years, achievement gaps (between race/ethnicity, gender and SES) remain a concern. Some studies have identified the direct effect of DBS on science achievement among African American students, while observing a high correlation between real-world problem-solving skills and science achievement. The direct effect of real-world problem-solving skills and science achievement needs to be studied across race/ethnicity, gender and SES. Such a study will not only confirm the efficacy of DBS in helping close the achievement gap but also in preparing students both for academics and their future workplaces.

Despite the findings stated earlier however, not enough studies have been done to demonstrate the effects of DBS on the development of real-world problem-solving skills across gender, racial-ethnic and SES and the consequent improvement in science achievement among high school students. Shepardson and Pizzini (1994), in one of a few such studies, reported that there is no significant difference in science achievement
between middle school boys and girls who learned science concepts through problem-solving approaches. There is the need to study this relationship among high school students where the gender gap widens even further. Similarly any differences in the effect of design-based learning across gender, racial-ethnic and socio-economic groups thus needs to be established and subsequently understood.

The purpose of this study is thus to investigate the differences in the real-world problem-solving abilities (and science achievement) of high school students of different gender, race and SES after treatment with DBS in Traditional Chemistry Classes. The “effects” of DBS on these students’ problem solving competency and science achievement will be described by group means, variances, correlation ratios, etc. Results from this study will contribute to responses to calls by Ault (1994) for research into the nature of learning and problem-solving in the area of science education, and by Thomas (2000) for more research on the effectiveness of PIBL.

**Research Questions**

In order to achieve the above objective the research questions this study seeks to address were:

1. Does DBS have any effect on the problem solving competencies of students in a high school traditional chemistry class?

2. Does the effect of DBS on problem solving competency depend on gender?

3. Does the effect of DBS on problem solving competency depend on race?

4. Does the effect of DBS on problem solving competency depend on SES?
5. Does DBS have any effect on the chemistry achievement of students in a high school traditional chemistry class?

6. Does the effect of DBS on chemistry achievement vary depending on gender?

7. Does the effect of DBS on chemistry achievement vary depending on race?

8. Does the effect of DBS on chemistry achievement vary depending on SES?

9. Is the problem solving competency of students in a traditional chemistry class predictive of their chemistry achievement?

**Definition of Terms**

**Problem:** A problem exists when there is an imbalance (referred to by Festinger, 1962 as “cognitive dissonance”) between the concepts inherent in the problem situation and the conceptual schema of the individual, which motivates the individual to find a solution.

**Ill-structured problem:** This is a problem that addresses complex issues and thus cannot easily be described in a concise, complete manner. Furthermore, competing factors may suggest several approaches to the problem, requiring careful analysis to determine the best approach.

**Well-defined problem:** A well-defined problem is identified by a testable goal state reachable from an initial state via one or more possible paths.

**Problem solving competency:** This is an individual’s capacity to use cognitive processes to confront and resolve real, cross-disciplinary situations where the solution path is not immediately obvious and where the literacy domains or curricular areas that might be applicable are not within a single domain of mathematics, science and other domains.
**Design-Based Science (DBS):** Design-Based Science is an inquiry-based project-based science pedagogy in which new scientific knowledge is constructed in the context of designing artifacts.

**Inquiry-based learning (IBL):** A student-centered, active learning approach focused on questioning, critical thinking, and problem solving. It involves making observations, gathering, analyzing and interpreting data in an attempt to answer a question/problem through the scientific process.

**Problem-Based Learning (PIBL):** An instructional method in which students learn through facilitated problem solving that centers on a complex problem, which does not have a single correct answer.

**Project-based Learning (PjBL):** In project-based learning learners are usually provided with specifications of a desired end product achieved by following correct problem-solving procedure.

**Contextualization:** A diverse family of instructional strategies designed to utilize particular situations or events that occur outside of science class or are of particular interest to students to motivate and guide the presentation of science ideas and concepts. Contextualizing often takes the form of real-world examples or problems that are meaningful to students personally, to the local area, or to the scientific community.

**Technology:** Technology as used in this work involves making modifications in the world to meet human needs.

**Real-world problem:** an ill-defined problem that calls on individuals to merge knowledge and strategies to confront and resolve a problem readily identifiable as arising
from real-life. It is a situation where decisions are not clear-cut, requirements can conflict, and optimization rather than ‘proof’ is needed.

**Traditional Chemistry:** This is an introductory chemistry taught to students taking chemistry for the first time and usually as a science requirement for high school graduation.
CHAPTER II

REVIEW OF THE LITERATURE

Introduction

In the following sections, a critical overview of the current state of research in the areas of design-based learning, and the development problem-solving skills are provided. The overview also includes trends in gender and race-ethnicity differences in science achievement. Another section is dedicated to an analysis of the research findings on the impact of project-based learning on students’ science performance in terms of knowledge acquisition, attitudes and metacognitive development. A brief overview of the foundations and rationale for using DBS and the models of DBS are presented. Studies of the relationship between DBS and science achievement are elucidated. Theories of problem solving are reviewed as a lens through which the results of this study will be analyzed and interpreted.

Foundations of Design-Based Learning: Constructivism

DBS was developed over the course of the 1999-2000 school year, by the Center for Highly Interactive Computing in Education (hi-ce) at the University of Michigan. DBS (like other project-based pedagogies) is a detailed instructional model rooted in inquiry and which is consistent with the principles of instruction arising from constructivism (Savery & Duff, 1995; Krajcik, Czerniak, & Berger, 2002). A review of constructivism will therefore be helpful in order to appreciate the potential impact of DBS on knowledge acquisition and the development of problem-solving skills. Constructivism is a philosophical view about how people come to understand or know. Each of us builds our own key to knowing by making sense of the world.
Constructivist theory in education comes primarily from the work of John Dewey (1938) and Jean Piaget (1977). Working from the idea that learners construct their own knowledge, both Dewey and Piaget contended that the stimulus for learning is some experience of cognitive conflict, or “puzzlement” (Savery & Duffy, 1995). Dewey argued that learning should prepare a person for life, not simply for work. He proposed that learning should therefore be organized around the interests of the learner and that learning is an active effort by learners interested in resolving particular issues. Piaget, similarly, proposed that cognitive change and learning take place when a learner’s way of thinking, or scheme, leads to puzzlement instead of producing what the learner expects. Such puzzlement then leads to accommodation (cognitive change) and a new sense of equilibrium. Learners bring their own suppositions to learning experiences based on what fits their experiences.

Dewey’s belief in competence in not only basic skills and personal qualities but also thinking skills—such as problem solving, reasoning, and knowing how to learn manifests in aspirations of recent educational policy directions (U.S. Department of Labor, 1991). During the Progressive Era, Dewey (1916) promoted the tackling of significant problems by students, as the ultimate way to engage learners in meaning-making and the development of problem solving ability. Dewey (1943) believed that learning should be situated within the context of the community. In this perception knowledge acquired is meaningful and relevant. Therefore, cognitive change often results from interactions with other learners who may hold different understandings (Volet, McGill & Pears, 1995). The associated social interactions may challenge learners’ current
views as well as allow them to test their current understandings to see how well they help
them make sense of and function in their world (Savery & Duffy, 1995).

The idea that knowledge is constructed in the minds of learners has been
extensively written about. For instance, Rorty (1991) described knowledge not as a
representation of the real world or a “match” between perception and reality, but rather as
a collection of conceptual structures that are adapted, or viable, within a person’s range of
experience. In other words, the person’s knowledge “fits” with the world, much like how
a key fits a lock (Bodner, 1986).

**Design-Based Science Framework**

The presumption associated with DBS is that students need opportunities to
construct knowledge by solving problems through asking and refining questions;
designing and conducting investigations; gathering, analyzing, and interpreting
information and data; drawing conclusions; and reporting findings (Rivet & Krajcik,
2004). In DBS, the design of the artifacts is not a culminating activity at the end of the
curriculum, but rather it is the framework around which all the learning activities are
organized. Any DBS instruction is characterized by five learning features (Singer, Marx,

These five features are a) active construction, b) situated cognition, c) community,
d) discourse, and e) cognitive tools. Students’ active construction of knowledge refers to
engaging students with the task in thought-demanding ways such as explaining, gathering
evidence, generalizing, representing, and applying ideas (Perkins, 1993). Situated
cognition refers to students making meaning through interactions between the world and
others, and their interpretations of these interactions (Lave & Wenger, 1991) within the
contexts of the discipline. These interactions engage students with a community of practitioners in the discipline (Perkins, 1993). It enables students learn ways of knowing what counts as evidence, and how ideas are shared within the culture of the discipline. Participation also brings students into the language and discourse of the community of practice (Singer, Marx, Krajcik, & Clay-Chambers, 2000). Cognitive tools can extend what students can do and learn (Solomon & Perkins, 1989), in that they provide opportunities for students to visualize and explore phenomena that would not otherwise be possible in classrooms through manipulating multiple dynamic representations (Novak & Krajcik, 2005).

The DBS learning cycle (Figure III) provides the framework for how classroom activities are structured. The cycle involves five stages. The first stage is contextualization. Context supplies significance for the tasks the students will be facing and provides trigger points for action - things the students can immediately begin to investigate (Kimbell, Stables & Green, 1996). The second stage involves background research, which can be in the form of searching and gathering relevant information,
benchmark lessons in which the teacher presents new scientific concepts, reading selected materials, sharing on a whiteboard of data collected in group experiments and then collectively analyzing the complete database, teacher-led demonstrations, computer-based simulations of relevant phenomena, and virtual expeditions to examine appropriate primary sources.

During the third stage every student generates their solution to the design problem and presents it to their group members. The group decides which of the suggested solutions they prefer or they might combine the solutions. The group then writes a justification for their decision. In the fourth stage, each design team constructs a model or modifies an existing model based upon the design solution they decided upon in the former stage. For example, they might construct a three-dimensional model of a house or a cell phone antenna shield, or a cut-away drawing of an electrochemical cell. In the final stage, students’ models are subjected to physical tests whenever possible, and they are presented to the entire class in a pin-up session (Kolodner, Stables, K., & Green, 1998; Schön, 1985). The models are laid out or hung up and the entire class moves from model to model, listening to the student-designers’ descriptions and the teacher’s comments, and offering their own critique.

**Review of Literature on Design-Based Science**

As the U.S. and other nations search for ways to close the achievement gap in STEM education in an effort to become more competitive in a global economy, the prospects of DBS should be seriously studied. Studies suggest that the adoption of DBS in science classrooms provide contextualized instruction, which benefits almost all students (Mehalik, Doppelt and Schuun, 2008; Rivet & Krajcik, 2004), particularly non-
white students as well as students from low SES families. The subsequent improvement in science achievement has been documented. The effect of DBS on the improvement of problem-solving skills, for the 21st century, has also been suggested although more empirical studies need to be conducted. Some of these studies are presented in the following paragraphs. The incorporation of engineering design in the “Next Generation Science Standards” (http://www.nextgenscience.org), a national initiative for new science standards, is due to the potential of DBS improving science achievement and problem solving skills.

One of the most recent studies on project-based inquiry instruction like DBS as a contextualizing instruction was conducted by Rivet & Krajcik (2004, 2008). Their study involved sixth through eighth-grade students within the Detroit Public School System, and investigated the effects of project-based curriculum materials on science achievement over a 10-week period. The curriculum materials used contextualized the learning of science in meaningful real-world problems and engage students in science inquiry. Students in these schools were representative of the district, which was over 91% African American, with over 70% of students receiving free or reduced-price lunches, and 85% of students were below grade level on standardized eighth-grade science assessment. The results show a strong and significant correlation between contextualizing score and all measures of learning. Similar suggestions have been made by other researchers, namely, calls for using “authentic tasks” (Lee & Songer, 2003), making science “relevant” (Fusco, 2001), and promoting community connections, and building from local contexts (Bouillion & Gomez, 2001). Also, Wisely (2009) investigated the hypothesis that low-skilled students can learn more effectively and advance to college-level programs more
readily through contextualization of basic skills instruction. The results of his study showed that participation in contextualization was associated with the completion of developmental education courses and the speed of entry into, and performance and completion of, college level courses. These positive effects were however, limited to non-white students; no effects for contextualization were found for white students.

Studies that are specific to DBS, but which were not focused on contextualization are consistent with the above findings. For instance, Mehalik, Doppelt and Schuun (2008) contrasted overall performances and by gender, ethnicity, and socioeconomic status (SES) for middle school students learning science through traditional scripted inquiry versus a design-based inquiry (DBS). In their study the treatment group (DBS group) had a higher proportion of students from schools in the low SES range (53 percent of 587 students versus 32 percent of 466 students in the control or scripted inquiry group). The four lowest SES schools in the district were in the DBS group. SES categories were based on the proportion of students considered by the district to be economically disadvantaged, with the low group having schools with more than 66 percent of their students economically disadvantaged. In terms of gender, the design group had a slightly higher proportion of female students (54 percent vs. 51 percent). As far as ethnicity, there was twice as much African American students (66 percent vs. 33 percent). The results suggested that the DBS approach for teaching science concepts had superior performance in terms of knowledge gain achievements in core science concepts, engagement, and retention when compared to a scripted inquiry approach. The DBS approach was most helpful to low-achieving African American students.
Since the 1970s, there has been an increasing emphasis on the use of the problem-solving approach in science teaching. Some research evidence has shown that explicit teaching of problem solving processes in science classes can improve students’ problem-solving skills, students’ cognitive development and science achievement (Huffman, 1997; Heyworth, 1998). Sternberg (1985) and Simon and Simon (1978) stressed that students meaningfully learn problem solving skills through concrete experiences. Visser (2002) compared the effects of problem based and lecture based teaching on student problem solving and attitudes in a high school genetics class. She found statistically significant differences (p<.05) in learning outcomes and motivation for students in the PBL and Lecture/Discussion treatments. Problem-solving skills remain vital to the success of students even today (Partnership for 21st Century Skills, 2009).

Teachers can help students by providing explicit strategies that are procedurally structured to encourage students to become involved in their own learning and undertake the steps necessary to solve problems in science (Pizzini, Shepardson & Abell, 1989). It is suggested that DBS (and other project-based inquiry approaches) can improve problem solving skills (Fortus, Dershimer, Krajcik, Marx and Mamlok-Naaman, 2005), however, the above studies do not show that the effects of DBS on science achievement is associated with a corresponding improvement in problem-solving skills, nor are there enough recent empirical studies to establish this relationship. In addition, majority of studies on DBS that compare student demographics have been limited to elementary and middle schools and not high schools where achievement gaps tend to be wider. The current study therefore seeks to investigate the link between DBS and real-world problem-solving skills of students in high school.
Theories of Problem Solving

Any given problem has at least three components: the givens, goal(s) and operations. The Givens are the facts or pieces of information presented to describe the problem. The Goal(s) is the desired end state of the problem, while the Operations are the actions to be performed in order to reach the desired goal (Newell and Simon, 1972). To successfully solve a problem the problem solver’s previous knowledge is important. Conceptually, there are two kinds of problem-solving knowledge (Gagné, Yekovich, and Yekovich, 1993): declarative knowledge, which is knowledge that something is the case, and procedural knowledge, which is knowledge of how to do something. While declarative knowledge is knowledge of facts, theories, events, and objects, procedural knowledge includes motor skills, cognitive skills, and cognitive strategies. Both declarative and procedural knowledge are activated in working memory as problem solving occurs. Declarative and procedural knowledge interact in a variety of ways during problem solving (Gagné, Yekovich, and Yekovich, 1993).

There isn’t only one way of solving problems. As a result there are a number of theories that may be used to explain how different problems may be solved. An overview of some of these theories and how they relate to the current study may provide some insight in understanding and perhaps explaining differences that may be observed between the different groups of students being investigated in this study. These theories include the a) constructivism, b) expert-novice theory, and c) cognitive theory.

Constructivism

Learners bring their own suppositions to learning experiences based on what fits their experiences. Thus, constructivism philosophy explains that knowledge is actively
constructed by an individual by comparing new ideas and concepts with their current knowledge (schema or mental models). Constructivist theory in education comes primarily from the work of John Dewey (1938) and Jean Piaget (1977). Dewey and Piaget contended that the stimulus for learning is some experience of cognitive conflict, or “puzzlement” (Savery & Duffy, 1995). Even the motivation to resolve the cognitive conflict may be spurred among others, by curiosity and personal or community needs. Hence, Dewey argued that learning should prepare a person for life, not simply for work. He proposed that learning should therefore be organized around the interests of the learner and that learning is an active effort by learners interested in resolving particular issues.

During the Progressive Era, Dewey (1916) promoted the tackling of significant problems by students, as the ultimate way to engage learners in meaning-making and the development of problem solving ability. Dewey (1943) believed that learning should be situated within the context of the community. In this perception knowledge acquired is meaningful and relevant. Therefore, cognitive change often results from interactions with other learners who may hold different understandings (Volet, McGill & Pears, 1995) of a given situation. The associated social interactions may challenge learners’ current views as well as allow them to test their current understandings to see how well they help them make sense of and function in their world (Savery & Duffy, 1995). Dewey’s belief in competence in not only basic skills and personal qualities but also thinking skills—such as problem solving, reasoning, and knowing how to learn are encouraged by recent educational policy directions (U.S. Department of Labor, 1991).
In the current study students had to overcome specific constraints in order to meet needs that they had identified as relevant to their lives. In solving their problem, if the science concepts students were expected to learn were new to them, it was anticipated that students would tap into their prior knowledge (misconceptions or otherwise). If the problems were indeed relevant to their lives (as was the case), students would have the motivation to actively construct new knowledge as they solve the problem.

**Expert-Novice Theory**

A review of the differences between expert and novice problem solvers may help understand differences that may be observed during the current study. Three attributes are commonly used to differentiate expert from novice problem-solving characteristics (Muller, 1996). These attributes are a) conceptual understanding, b) basic, automated skills and c) domain-specific strategies. Conceptual understanding refers to both the actual information in memory and the organization of that information in memory. Conceptual understanding is closely related to schema theory, in which information is considered to be stored in memory as frameworks or structures that, once instantiated, provide a lens through which to view new information. Having a conceptual understanding of a domain means that an individual can make meaning of domain-specific situations or problems, based on prior knowledge of that domain. Students may approach a problem with this attribute already acquired or should develop it during the second or third stages of the DBS learning cycle: background research and the development of personal and group ideas.

Basic, automated skills in any domain are those that allow an individual to perform necessary and routine operations without much thought. These skills are learned
to the extent that they become habitual and even unconscious, enabling individuals to operate quickly and accurately without over-burdening their short-term memories. This form of automaticity allows individuals to focus their attention on the more complex tasks associated with a specific domain and is a general attribute associated with experts in a domain. Automaticity supports the expert’s speed and skill of execution. During a DBS unit students who do not already have such skills will need sufficient time to develop some automaticity, hence the importance of project duration.

Unlike basic, automated skills, which occur unconsciously and thus do not tax short-term memory, domain-specific strategies remain under conscious control. They are the processes and procedures in a domain that an individual, even an expert, must consciously think about in order to solve a problem. They are, in other words, the procedural knowledge associated with a domain. Expert–novice differences have been studied and described within the context of these three attributes: Experts (a) exhibit better conceptual understanding of their domain; (b) use more automated skills and domain-specific strategies; and (c) have a conceptual understanding that is declarative, while basic skills and strategies are procedural (Miller, 1996).

During the current study, in following the DBS framework, students are expected to develop conceptual understanding of the problem they intend to solve. It is also anticipated that students will develop an appreciation for the power of eliciting both declarative and automated skills in order to resolve a problem. In other words beyond the problem being resolved in the current study, students would recognize the need to look inward and elicit knowledge and skills required to solve any problem on hand. These students would move toward becoming expert problem solvers.
Cognitive Theory

The cognitive theory is consistent with constructivism, in proposing that an inconsistency between behavior and beliefs motivates change. Cognitive psychologists, Wallas and Poly, separately developed four-stage models of problem solving. The four stages of problem solving identified by Wallas were: a) preparation - defining the problem and gathering information relevant to it, b) incubation - thinking about the problem at a subconscious level, c) inspiration - having a sudden insight into the solution of the problem, and d) verification - checking to be certain that the solution was correct (Ormrod, 1987). Poly’s four steps in the problem-solving process included: a) understand the problem, b) devise a plan, c) carry out the plan, and (d) look backward (Ormrod, 1987). These two processes are very similar to each other and consistent with the five steps of the DBS learning cycle. Hence, assuming that the design challenge provides ample cognitive dissonance, the DBS learning cycle will provide the necessary paths needed by students in the current study to solve their problem of interest. It can therefore be anticipated that students who go through a unit by following the DBS learning cycle would ultimately become better problem solvers.

Models of Problem Solving Instruction and Problem-Solving Skills

Whether or not students’ problem-solving skills will improve after a treatment such as the use of DBS units depends on students’ basic knowledge of problem solving processes. In other words if a student does not have a clue how to approach the solution of real-world problems even a strategy that has a potential of improving problem-solving skills may not have a fair chance of successfully solving the problem. The selection of a problem solving model of instruction is however one of the critical choices a teacher
must make as s/he prepares students for real-world problem solving. Since the current study includes the provision of basic instruction in problem-solving strategies, a review of problem solving instruction models will provide a great reference for the model chosen and why. Three models commonly used are: a) Parnes’ (1967) and Osborn’s (1963) Creative Problem Solving (CPS) process, b) Bransford and Stein’s (1984) Identify, Define, Explore, Act, and Look (IDEAL) model and, c) the Search, Solve, Create, and Share (SSCS) model created by Edward Pizzini (1987), and Pizzini, Abell, & Shepardson (1988). The CPS model is a hierarchical process, with each step depending on the preceding step. The five steps of the CPS model are: a) fact-finding, b) problem-finding, c) idea-finding, d) solution-finding, and e) acceptance-finding.

The IDEAL and SSCS Models of Teaching Problem Solving

The IDEAL model is also a five-step hierarchical model which involves: a) identifying the problem, b) defining and representing the problem, c) exploring alternative strategies, d) acting on the strategies, and e) looking back and evaluating the effects. The SSCS model on the other hand is a four step cyclical model allowing for re-entry into the various states of the model during the problem solving process (Figure IV). The SSCS model reduces the other problem

Figure IV. The SSCS Problem Solving Cycle.
solving models into fewer steps; thereby, simplifying the process (Figure IV).

Additionally, the SSCS model provides students with an opportunity to communicate their results (Figure V), something that is missing in other problem solving models of instruction. Although the SSCS model is not a pre-packaged curriculum, it can easily be incorporated into science instruction, providing a successful and creative way for students to learn science concepts and problem solving skills in science (Pizzini, Shepardson & Abell, 1989). The use of problem solving models in instruction calls for purposefulness on the part of the teacher and student.

In any problem solving model of instruction the first level of learning includes problem recognition, the determination of information needed to solve the problem and where to obtain the information (Presseisen, 1985). Johnson, Ahlgren, Blout & Petit (1981) stressed the importance of how students search for an idea (concepts within the problem) that will assist them in understanding the problem. Glatthorn and Baron (1985) emphasized the importance of the search process, as well as setting goals, searching for possibilities, and evaluating evidence. Zoller (1987) suggested that the students’ question-asking ability is an essential aspect of problem solving. Through the above processes, students derive meaning from the problem (Anderson & Smith, 1981; Winne & Mark, 1977) and can take ownership of the problem. Pizzini, Shepardson & Abel (1989) found that student ownership of the problem is one of the most essential variables resulting in successful problem solving. Providing students with the opportunity to select and pursue problems of concern and interest to them increases their motivation, persistence, and intensity to learn.
The SSCS model was developed on the premise that students meaningfully learn problem solving skills and science concepts through concrete experiences in solving problems in science, as evidenced by the literature. The SSCS model requires students to utilize various problem solving thinking skills identified by Stemberg (1985) and Pizzini, Shepardson & Abell (1988).

<table>
<thead>
<tr>
<th>PROBLEM SOLVING MODELS</th>
<th>QUESTIONS/TASKS/ APPROACHES</th>
<th>PROCESSES/SKILLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>(SSCS)</td>
<td>(IDEAL)</td>
<td>(CPS)</td>
</tr>
<tr>
<td>IDENTIFY</td>
<td>Identify</td>
<td>Brainstorming, Observing, Deciding, Defining</td>
</tr>
<tr>
<td>FACT FINDING</td>
<td>Identify</td>
<td>Analyzing, Classifying, Creating, Applying, Designing</td>
</tr>
<tr>
<td>SEARCH</td>
<td>Search</td>
<td>Measuring and Describing, Evaluating, Synthesizing, Testing and Verifying</td>
</tr>
<tr>
<td>DEFINE</td>
<td>Define</td>
<td>Questioning, Searching literature and Inquiring, Predicting, Evaluating, Testing and Questioning</td>
</tr>
<tr>
<td>PROBLEM FINDING</td>
<td>Identify</td>
<td>Brainstorming, Hypothesizing, Deciding, Defining</td>
</tr>
<tr>
<td>EXPLORE</td>
<td>Explore</td>
<td>Predicting, Evaluating, Testing and Questioning</td>
</tr>
<tr>
<td>IDEA FINDING</td>
<td>Identify</td>
<td>Brainstorming, Focusing, Deciding, Defining</td>
</tr>
<tr>
<td>ACT</td>
<td>Solution</td>
<td>Inquiring, Comparing, Combing and Analyzing</td>
</tr>
<tr>
<td>SOLVE</td>
<td>Finding</td>
<td></td>
</tr>
<tr>
<td>LOOK</td>
<td>Acceptance</td>
<td></td>
</tr>
<tr>
<td>ACCEPTANCE FINDING</td>
<td>Finding</td>
<td></td>
</tr>
<tr>
<td>CREATE</td>
<td></td>
<td>Accepting, Rejecting, Modifying, Refining, Completing, Troubleshooting</td>
</tr>
<tr>
<td>SHARE</td>
<td></td>
<td>Communicating, Displaying, Displaying, Promoting and Evaluating,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evaluating, Promoting, Displaying, Reporting, Verbalizing, Questioning, Reviewing and verifying</td>
</tr>
</tbody>
</table>

Figure V. The SSCS Model as Related to the IDEAL and CPS Models (Pizzini, Shepardson & Abell, 1989)

Presseisen (1985) (Figure VI). The four phases of the SSCS model according to Pizzini, Abell, & Shepardson (1988) are explained as follows. The Search phase of the SSCS
model involves brainstorming and other idea-generating techniques that facilitate the identification and development of researchable questions or problems in science. Demonstrations, magazines and newspaper articles, field trips, and science textbooks can lead students to the identification of researchable questions. In addition to identifying and developing questions and problems during the Search phase, students identify criteria for problem selection and state the question or problem in a researchable format. The Search phase assists students in relating the science concepts inherent in the problem to the relevant, existing science concepts embedded in their schema. This initiates the development of the problem space or mental representation of the problem. The problem then is identified and defined by the student, based on his/her existing conceptual schemata.

The Solve phase requires students to generate and implement their plans for finding a solution to the problem they identified in the Search phase. During the Solve phase, the student reorganizes the concepts derived from the Search phase into a new "higher-order" that identifies the method for solving the problem and the desired solution, completing the development of the problem space. It is during the Solve phase that students apply operator(s) to solve the problem. If the operation is unable to solve the problem or creates an intermediate state, the student may re-enter the Search phase or continue to implement their plan (apply additional operators). The application of science concepts in the Solve phase provides meaning to the concepts as the student experiences the relationship between the concepts inherent in the problem, the concepts of the solved
### Table: Problem Solving/Thinking Skills within the SSCS Model

<table>
<thead>
<tr>
<th>SEARCH</th>
<th>SOLVE</th>
<th>CREATE</th>
<th>SHARE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognizing the problem</td>
<td>Selecting Problem Solving Procedure</td>
<td>Selecting Method Monitoring</td>
<td>Selecting Method Using Solved Problem</td>
</tr>
<tr>
<td>Defining the problem</td>
<td>Allocating Time and Resources</td>
<td>Monitoring</td>
<td>Using Solved Problem</td>
</tr>
<tr>
<td>Forming Mental Representation</td>
<td>Forming Mental Representation</td>
<td>Using Solved Problem Feedback</td>
<td>Feedback</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance Components</th>
<th>C</th>
<th>P</th>
<th>M</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deductive Reasoning</td>
<td>Inferring Alternative Solutions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selective Encoding</td>
<td>Selective Comparison</td>
<td>Selective Combination</td>
<td>Selective Combination</td>
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<tr>
<td>Selective Comparison</td>
<td>Selective Combination</td>
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<tr>
<td>Selective Combination</td>
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</tbody>
</table>

Figure VI. Problem Solving/Thinking Skills within the SSCS Model (based on Sternberg, 1985 and Presseisen, 1985)
problem, and the concepts applied to the problem, which are all linked to the students’ conceptual schema.

The Create phase requires students to create a product that relates to the problem/solution, compare the data to the problem, draw generalizations, and if necessary modify. Students employ skills such as reducing data to simpler levels of explanation or eliminating discrepancies. The Create phase enables students to evaluate their own thinking processes. The outcome of the Create phase is the development of an innovative product, which communicates the results of the Search and/or Solve phase to others. Self-evaluation (thinking about one’s thinking) is the dominant activity throughout the Create phase.

The basis of the Share phase is to involve students in communicating their problem solutions or question answers. The product created becomes the focus of the Share phase. The Share phase goes beyond simply communicating to students and others. Students articulate thinking through their communication and interaction, receive and process feedback, reflect on and evaluate solutions and answers, and generate potential Search questions. The generation of new potential Search questions occurs when an accepted solution creates a new problem, or when faulty reasoning or errors in the problem solving plan are discovered through external evaluation of the shared product. This enables the problem solver to identify problem solving skills which are in need of refinement, as well as initiate new Search questions.

**Framework for Assessing Problem Solving Skills**

The development of a problem-solving framework for assessing student performance is not easy. One of the reasons for this is that both individual and
collaborative problem solving are important for future learning, effective participation in society and for conducting personal activities. However, while measurement of individual problem solving competency may be achieved with greater ease, measurement of collaborative problem-solving competency is beset with numerous challenges (Reeff, Zabal & Blech, 2006). Foremost among these challenges are: how to a) assign credit to individual group members if this is required, b) account for differences across groups that may bias individual performance, and c) account for cultural differences in group dynamics. Most researchers who study problem solving in practice or research-based settings agree that in describing student problem solving, the major focus is on describing the cognitive acts students make in addressing, solving and reporting solutions (OECD 2003). Cognitive acts therefore form the cornerstone of the PISA 2003 problem-solving assessment framework.

Based on the definition of problem solving advanced earlier, the task to be performed by the student is shaped by its context(s), domain-specific knowledge and

Figure VII. PISA 2003 Problem Solving Assessment Framework (OECD, 2003)
strategies or skills required for solution. The PISA 2003 problem-solving assessment
framework (Figure VII) adopted for the current study, include the following components:
a) problem types, b) problem context, c) disciplines involved, d) problem solving processes
and e) reasoning skills.

PISA 2003 chose to assess decision making, system analysis and design, and
trouble-shooting as problem types because they are generic problem-solving structures
that capture important aspects of everyday, real life analytical reasoning. They provide
the structure within which problem solving is assessed without necessarily placing
emphasis on domain knowledge but rather on the process and skills. Sample problems are
provided in appendix B. Decision making problems enable one to determine whether a
student understands different alternatives and constraints in a problem situation and if the
student’s decision satisfies the imposed constraints. A system analysis and design
problem is different from a decision-making problem in the sense that the former, a)
requires a student to analyze a system or design a solution to a problem instead of
selecting from a set of alternatives, b) involves a complex system of interrelated variables
and a solution is not clear-cut. Solution of system analysis and design problems requires
the ability to identify the different variables and how they affect each other. In the case of
designs such relationships must be considered in optimizing the desired goal. Trouble-
shooting tasks on the other hand involve diagnosing, proposing a solution and sometimes
executing this solution. Trouble-shooting requires a) an understanding of how a device or
procedure works and b) the ability to identify the relevant features for the task and to
create or apply a representation in order to successfully solve the problem at hand. In all
the three types of problems a student’s ability to evaluate, justify and communicate their
solution to another person(s), form integral aspects of the problem-solving competency. The PISA 2003 problem solving assessment involved problems embedded in real-life settings associated with personal life, work and leisure or community and society.

While it may be necessary to identify the processes used by students as they solve problems the endeavor can be cumbersome if all problem types are considered. In the PISA 2003 framework problem solving processes considered are those based on cognitive analysis of the three types of problems assessed. The selection of these processes was informed by the work of cognitive psychologist such as Mayer & Wittrock (1996), Baxter & Glaser (1997) and Bransford, Brown & Cocking (1999) as well as by the seminal work of Polya (1945). These problem-solving processes include: a) understanding the problem, b) characterizing the problem, c) representing the problem, d) solving the problem, e) reflecting on the solution, and f) communicating the problem solution. The framework does not assume that these processes are hierarchical or even necessary for the solution of any problem. Indeed it recognizes that a student may solve a problem in a way that transcends the narrow linearity of the above model. In characterizing the problem students identify the variables in the problem and their interrelationships; decide relevant and irrelevant variables; construct hypotheses; and retrieve, organize, consider and critically evaluate contextual information. Representing the problem involves tabular, graphical, symbolic or verbal representation. Solving the problems, however, involves finding a solution that meets or exceeds the constraints and goals of the problem. Reflection involves examination and evaluation of the solution from different perspectives in an attempt to make it more acceptable as well as justifying these solutions.
The ability of a student to effectively use a given problem solving process does not only depend on his/her domain knowledge but also on the reasoning skills s/he possesses. In the PISA 2003 framework four reasoning skills are identified as being related to the problem types assessed. These skills include: a) analytical reasoning, which includes the application of principles from formal logic in determining cause-and-effect relations in order to select strategies, b) quantitative reasoning, which involve the ability to apply principles related to number sense and number operations, c) analogical reasoning, which involves the ability of the student to tap into his/her previous knowledge in order to venture into the unfamiliar, and d) combinatorial reasoning, which enables a problem solver to identify or rank all combinations of factors in order to achieve a set goal. The above mentioned skills are all expected to be demonstrated in SSCS, CPS and IDEAL framework (Figures IV and V).

In summary, the PISA 2003 problem-solving assessment framework measures student problem-solving competency, using three types of problem: decision making, system analysis and design, and trouble shooting. The problems are cross-disciplinary and drawn from contexts that relate to student’s personal life, work and leisure as well as to the community and society. Solution of a given problem may require the use of problem solving processes each of which depends of the reasoning skills of students. The problems are presented so that problem solving and not knowledge is being assessed and the problem solving processes don’t necessarily have to be demonstrated at all and if demonstrated, not necessarily in any specific order.
CHAPTER III
MATERIALS AND METHODS

Introduction

Chapter three presents the research methodology of the present study. It begins by summarizing the problem and restating the research questions. This is followed by a description of the subjects of the study and an overview of the research design. The chapter ends with data collection and data analysis procedures and statement of the hypotheses.

Restatement of the Problem

The purpose of this study is to investigate whether DBS affects student problem solving skills and science achievement across student demographics in a high school in Denver, Colorado. Effects of DBS will be studied across gender, race/ethnicity and SES among students in a traditional chemistry class. A strong correlation between problem-solving skills and science achievement has been reported (OECD, 2003). The effects of pedagogies such as project-based learning on science achievement and problem solving skills have not been extensively studied among different groups of students. For example, studies show that the use of pedagogies such as project-based learning, such as DBS, is associated with higher achievement in science in middle schools. However, more studies need to be conducted to investigate whether these pedagogies directly improve problem solving skills, with a consequent improvement in science achievement. With the achievement gaps in science not getting any better especially in high schools it will be helpful to establish the benefits of these pedagogies to high school students of different gender, race and SES. For the scope of this study DBS is chosen because of its potential
in improving science achievement among non-white students and its increasing presence in recent science education studies.

The current study tries to achieve its purpose by attempting to answer the following research questions:

1. Does DBS have any effect on the problem solving competencies of students in a high school traditional chemistry class?

2. Does the effect of DBS on problem solving competency depend on gender?

3. Does the effect of DBS on problem solving competency depend on race?

4. Does the effect of DBS on problem solving competency depend on SES?

5. Does DBS have any effect on the chemistry achievement of students in a high school traditional chemistry class?

6. Does the effect of DBS on chemistry achievement vary depending on gender?

7. Does the effect of DBS on chemistry achievement vary depending on race?

8. Does the effect of DBS on chemistry achievement vary depending on SES?

9. Is the problem solving competency of students in a traditional chemistry class predictive of their chemistry achievement?

**Hypothesis as Null Hypothesis**

The reformulation of the research questions as null hypotheses will facilitate the examination of the statistical analyses and are indicated as follows:
1. DBS has no effect on the problem solving competencies of students in a high school traditional chemistry class?

2. The effect of DBS on problem solving competency does not depend on gender?

3. The effect of DBS on problem solving competency does not depend on race?

4. The effect of DBS on problem solving competency does not depend on SES?

5. DBS has no effect on the chemistry achievement of students in a high school traditional chemistry class?

6. The effect of DBS on chemistry achievement does not vary depending on gender?

7. The effect of DBS on chemistry achievement does not vary depending on race?

8. The effect of DBS on chemistry achievement does not vary depending on SES?

9. Problem solving competency of students in a traditional chemistry class is not predictive of their chemistry achievement?

**Participants**

For the purposes of the current study, the treatment and control groups were derived through the non-probability means of purposive sampling. Krathwohl (2004) describes non-probable purposive sampling as a technique that is convenient to the researcher but which lessens questions about the representativeness of the sample. The subjects for this study included students in four traditional Chemistry classes in an urban high school in the State of Colorado. Majority of the students in these classes were low performing students, with a high proportion of African-American and Hispanic students.
Based on state tests (CSAP) these students were a fair representation of the African-American and Hispanic high-school student population in the state of Colorado. The Colorado Department of Education reports that in 2011 60.4% of students from this high school in grades 9 and 10 were below proficient in science. Among the Black students while 89% were below proficient in math the number was 72% among Hispanics. Also, while 62% of Black students were below proficient in reading this number was 50% among Hispanic students. Only 23% of Black students were proficient in writing while 30% of Hispanic students were proficient. With a student population of 1610 in 2011, this school was 41.7% Black, 29.3% White, 23.3% Hispanic, 4.8% Asian and 0.9% American Indian. The percentage of students that was eligible for free and reduced lunch was 51.8%. In contrast to the preceding statistics 67% of Asian students and 72% of White students in the school were at or above proficient in math. In reading 84% of White and Asian students were at or above proficient while in writing 81% Asian students and 78% of White students were at or above proficient. Four equivalent parallel traditional chemistry classes of ninety five (95) 10th and 11th grade students were invited to participate in the study. Eighty two (82) students participated in this study.

The treatment group comprised of 36 students (16 females and 20 males) while the control group was made up of 46 students (23 females and 23 males). The composition of the treatment group by race was as follows: Asians - 1; Black - 19; Hispanic - 14; Native American - 2; White - 0. The control group however consisted of: Asians - 1; Black - 21; Hispanic - 20; Native American - 1; White - 3.
Research Design

A quasi-experimental pre/posttest research study with non-randomized sampling was conducted. Non-randomized assignment of participants to groups deals with intact groups and thus does not disrupt the existing research setting. This reduces the reactive effects of the experimental procedure and, therefore, improves the external validity of the design (Dimitrov & Rumrill, 2003). In order to ensure that any treatment and control group created were similar in their chemistry knowledge, district chemistry assessment data were reviewed before these groups were formed. The Denver Public Schools District chemistry assessment class average scores (ranging from 20% to 30%) showed that all four classes were similar. Subsequently two of the classes were randomly assigned to the treatment group while the other two classes are assigned to the control group. The treatment group learned anticipated chemistry concepts through DBS instruction (treatment) while the control group was expected to learn the chemistry concepts but through traditional methods of instruction. Pretests and posttests on problem solving competency and chemistry achievement were given to both groups to determine the effect of the treatment on problem solving competency and chemistry achievement.

Problem solving competency was measured for both groups using the PISA 2003 problem solving assessment protocol. After 2003 the next focus on PISA problem solving was 2012, after science in 2006 and reading in 2009 (OECD, 2003). At the time of this study the PISA 2012 problem solving items were not available, hence the use of the 2003 problem solving items. Students’ knowledge of chemistry concepts expected to be learned from the chemical energy/heating and cooling unit was also assessed before and after treatment. The unit included the three core chemical concepts: atomic interactions,
reactions and energy changes during reactions. In this design the method of instruction (DBS) was the independent variable. The dependent variables on the other hand were problem solving competency and knowledge of chemistry concepts (appendix F). Sample questions for the assessment of knowledge of chemistry concepts are shown in appendix E. Weekly assessment data were collected only as a way of monitoring student progress and to keep students focused. This is because DBS, like other forms of PjBL is self-directed and students are likely to be at different stages of learning during the project.

**Procedures**

**The Treatment**

Before the implementation of the unit in both groups the teacher elicited ideas and understanding currently held by students about the chemistry and design of heating and cooling systems. For meaningful learning to occur, instruction should begin with an exploration of learners’ interpretations and understandings of the science concepts to be addressed (Taber 2003). The treatment provided opportunities for students to learn about the design process and presented the problem that needed to be resolved through scientific principles from the heating/cooling unit and the design process. The control group was neither engaged in the design process nor required to solve a design challenge problem.

The treatment was the DBS-Heating/Cooling System (Chemical Energy) unit used by Apedoe, Reynolds, Ellefson and Schunn (2008). As a first step, the treatment group watched the video clips “Engineering Design Process” by NASA and “Bombing Hitler’s Dams”. As they watched the latter video, they were expected to document what they learned about the researcher’s processes, personal qualities and why they thought he
was successful in establishing how Hitler’s Dams were successfully destroyed during World War II by allied forces. They were expected to discuss if and how he used the engineering design process as described in the first video. This activity enabled students to become familiar with key design ideas such as needs, requirements and functional decomposition. It also provided a context for student work during the 12-week unit as well as helped students see how scientific principles and engineering design go hand-in-hand during the search for solution to a problem. Students in the control group did not watch the video on engineering design. However, they watched the video on bombing Hitler’s dams and were required to write an essay on how science contributed to ending World War II.

The second main step involved students in the treatment groups working in groups to brainstorm their needs for a heating and cooling system in their own lives. This opportunity was expected to create a personal motivation for the design work and made the topic relevant across ethnicity, gender, and other micro-cultures and helped students see the relevance of science and technology in their daily lives (Apedoe, Reynolds, Ellefson and Schunn, 2008). When groups had identified their needs they were then required to design a heating or cooling system that relies on chemical energy to meet the need(s), using concepts/knowledge from the unit. For example, they could create systems that would a) help keep them cool in the summer when they are playing sports, b) prevent them from having to sit on a cold toilet seat during cold weather and c) keep them cool when on a date and things start to “heat up”. Students also had the option of designing and building a prototype of a toy. Students’ work involved three aspects: a) planning the design, b) deciding and studying the chemical reactions that meet their specific needs as
well as how the reactions will be contained and c) making a three to five minute presentation to their classmates who represented the board of directors of a firm that was looking for ideas to invest in. During the next step students thought about other examples of heating and cooling systems from their everyday lives to consider the parts of these systems that make them work. The students did this to develop suggestions for solution to the problem on hand. Students in the control group were not assigned a design challenge. Instead, they learned chemistry concepts (appendix F) through traditional methods such as lecture, word problems and scripted inquiry.

The identification of other heating and/or cooling systems was intended to help students understand that systems are made of subsystems, which in turn can be broken down in order to understand how they function. Subsystem decomposition is critical for engineering design (Bradshaw 1992; Ulrich and Eppinger 2004). While students suggested solutions to the problem on hand the teacher ensured that students stayed with the use of required chemistry concepts (appendix F). Although actual heating and cooling systems tend to have more than two subsystems, as a result of limited time for the unit and the emphasis on science concept learning students were encouraged to work towards a two-subsystem design: the reaction subsystem where energy is produced and a container subsystem, which manages the transfer of energy in the system. Students were to spend more time on the reaction and container subsystems stage than the other two (planning the design and presenting the design) since most of the chemistry concepts will be learned during this stage.

Figure VIII summarizes the process of planning the design. To illustrate the above process one of the student projects is described as follows. After deciding to design a
toilet seat warmer the group planned their design by making drawings of their design. As part of their design they identified their reaction system, which would generate the heat for their warmer and their container system, which would comprise materials that will hold the chemical(s) and/or transfer the generated heat. During reaction I the group researched the source of chemical energy during chemical reactions. The goal was to understand the effect of molecular shape, size and bond type as well as other factors in

![Diagram of aspects of heating and cooling unit](image)

Figure VIII. Aspects of Heating and Cooling Unit (Apedoe, Reynolds, Ellefson and Schunn, 2008)

determining the amount of heat change in a chemical reaction. During reaction II the group applied knowledge gained in system I to generate chemical energy. For example,
the group investigated factors affecting the quantity of heat generated. The group then used properties of materials (metals, plastics, leather, etc.) to decide where chemicals would be stored as well as what materials to insulate and transmit heat.

According to Apedoe, Reynolds, Ellefson and Schunn (2008), the reaction subsystem (Reactions I and II) and the container subsystem address different, chemistry concepts and as a result if students went through them more times they gained a deeper understanding of the relevant chemistry concepts. As shown in appendix F, each of the subsystems indeed addresses one big idea. During each lesson students engaged in activities that challenge them to work with one or two of these key concepts as they discuss them with their teacher. The lessons build upon each other and culminate in a lesson titled “Connecting to the Big Idea”.

The Design-Science Cycle

Activities within each subsystem (Reactions I and II) are structured cyclically so that students move from design goals to science goals and back to design goals. This cycle, made room for whole class discussions, team activities, and individual activities intended to maximize the learning of science content as well as design and science processes. Thus, this cycle can be called the design-science cycle (or the learning cycle), similar to the legacy cycle (Brophy & Bransford 2001). Students started the design-science cycle (Figure IX) in the “Design” phase at the “Create Design” node by developing a design idea and trying it out in the “Evaluate Outcome” node. They discussed reasons for their outcomes as a class or in-group during “Generate Reasons”. During this stage, students addressed questions such as: a) Was our design successful? b)
What factors were important for the success of the design? c) What factors may have influenced the failed performance of the design? Students proposed ways to systematically test some of their generated reasons and conduct these tests during “Test Ideas”. Students then analyzed the results from their experiments and discussed their findings as a class/group during “Generalize Results” to uncover a pattern, theory, or trend. Finally, students arrived at “Connect to Big Idea”, where they linked their design to the key science concept(s) that can be used to improve its performance.

Overall, the Design-Science Cycle is structured to maintain a motivating design storyline while preventing students from wasting time floundering and encouraging them to focus attention on the selected core concepts. At the end of the reaction subsystem students built on their ideas developed by considering the material(s) for the container, and the properties such as density, thermal conductivity, melting point, specific heat capacity, etc. of the material. Student-groups presented their design to the class in ways...
they found convenient and effective. Appendix G summarizes the activities for the treatment and control groups. While students in the treatment group learned about heating and cooling through a DBS unit over a 12-week period (Apedoe, Reynolds, Ellefson and Schunn 2008) the control group learned about heating and cooling through lecture, word problems and scripted inquiry, where students were given steps and guidelines to follow to complete the experiments.

Data Sources
Student biographical information (gender, race/ethnicity, SES) was the first set of information to be collected, before the start of the unit, by means of a survey from both groups. Students’ gender and ethnicity was obtained from the school while SES was determined using the BSMSS (Appendix A). The BSMSS incorporates a student's parent's educational attainment and occupational prestige as well as his/her own educational attainment and occupational prestige (Barratt, 2006). Pretests of problem solving ability and chemistry concept knowledge in heating and cooling were administered to both the control and treatment groups. A sample of real-world PISA 2003 problem-solving items, that were used for the pre-test and post-test can be found in Appendix B. The problem solving items assess problem solving competency in the following areas: decision making, system design and analysis, and troubleshooting. The chemistry concepts inventory is a twenty two item test that assesses understanding in chemical and physical changes.

Teacher as Researcher

Whenever the teacher of a given class is also a researcher in the same class there are some advantages and disadvantages. An advantage of a teacher-as-researcher
arrangement is the fact that the research environment is kept intact. The teacher-student and student-students relationships in the room are not interfered with. Students may more likely be open to sharing their challenges and inclinations with the teacher than an outsider. Another advantage is that the teacher-researcher usually has a long-term experience of the setting being studied and therefore know the history and information needed to understand what is going on in the setting (Hammersley, 1993). On the other hand, there is a risk of the teacher-researcher being biased in his/her judgments towards students and different situations. Therefore, in order to ensure inter-rater reliability and minimize any biases that may result from the teacher as researcher two peer observers were requested to visit two class periods each. They also reviewed sample student responses (problem solving assessment and Chemistry Concepts test) graded by the class teacher (researcher).

**Instrumentation**

The independent variable to be studied is participation in DBS unit (across gender, race and SES). The instruments that were used for data collection from the treatment and control groups are described below. The socioeconomic status of students was measured using the Barratt Simplified Measure of Social Status (BSMSS) shown in Appendix A. The BSMSS is a version of the A. B. Hollingshead (1975) four-factor index of social status, with a reliability of 0.85 and demonstrated to be a valid measure of SES (Cirino, Chin, Sevcik, Wolf, Lovett & Morris, 2002). The BSMSS accounts for an individual's parent's educational attainment and occupational prestige and combines them with the individual's own educational attainment and occupational prestige (Barratt, 2006). BSMSS scores range from 8 (lowest SES) to 66 (highest SES). This measure of
SES is more likely to be accurate than student eligibility for free or reduced lunch since students living in single-parent families may have an unfair advantage of being classified as belonging to free or reduced lunch program while support from the other parent may not be considered in determining eligibility. The score that results from the BSMSS is ordinal only and is sufficient for regression analysis or for creating SES groups based on the data collected.

In order to answer the first research question, the effect of DBS on the problem solving competency of a student was measured by administering a pretest and posttest using the PISA 2003 problem solving sample problems (Appendix B). The problems that were used in assessing problem solving competency included 19 items as in PISA 2003: 7 decision making items, 7 system analysis and design items and 5 trouble shooting items. In this assessment, more emphasis is placed on decision-making followed by system design, with troubleshooting being allocated the least scores. Across the three problem types more difficult problems are scored at the middle of the scale (Appendix D). Some questions require students to construct their own responses, either by providing a brief answer from a wide range of possible answers (short-response items) or by constructing a longer response (open-constructed response items), allowing for the possibility of divergent, individual responses and opposing viewpoints. Other parts of the test are based on students constructing their own responses, but based on a very limited range of possible responses (closed-constructed response items), which are scored as either correct or incorrect. The remaining items are asked in multiple-choice format, in which students either make one choice from among four or five given alternatives (multiple-choice items) or a series of choices by circling a word or short phrase (for
example “yes” or “no”) for each point of credit (complex multiple-choice items). The reliability of these assessments is 0.87 (OECD, 2005).

The features of each problem type (goals, processes and sources of complexity) compared in Appendix C, serve as the basis for establishing a scale to describe increasing student proficiency in problem solving. The problem solving items would be scored using the rubric associated with each item (Appendix B), while the skill level of students would be determined using the PISA 2003 problem solving scale (Appendix D). The PISA problem-solving scale provides a representation of students’ capacity to understand, characterize, represent, solve, reflect on and communicate their solutions to a problem. The total student problem solving score is use to determine the student’s level (or competency) of problem solving. The three levels of proficiency in problem solving are: a) level 1 - basic problem solvers, b) level 2 - reasoning, decision-making problem solvers, and c) level 3 - reflective, communicative problem solvers.

Level 3 students score above 592 points on the PISA problem solving Scale. Typically, these students are able to analyze a situation and make decisions, as well as think about the underlying relationships in a problem and relate them to the solution. These students are systematic problem solvers and construct their own representations to help them solve problems. They verify that their solution satisfies all requirements of the problem. These students communicate their solutions using accurate written statements and other representations. Students at the top of Level 3 can cope with multiple interrelated conditions that require them to work back and forth between their solution and the conditions laid out in the problem.
Students at Level 3 are also expected to be able to successfully complete tasks located at lower levels of the PISA problem-solving scale. The Students at Level 3 therefore possess the following skills: monitoring variables, accounting for temporal restrictions, and other constraints; troubleshooting, analytical, decision making, visualization, evaluation of their solution, effective handing of the complexity of multiple interrelated conditions and effective communication. These are problem solving skills that are associated with all three levels (metacognitive, performance and knowledge acquisition) of the SSCS Model (Figure VI).

Students proficient at Level 2 score between 499 to 592 points on the problem-solving Scale. These students use reasoning and analytic processes and solve problems requiring decision making skills. They can apply various types of reasoning (inductive and deductive reasoning, reasoning about causes and effects, or reasoning with many combinations, which involves systematically comparing all possible variations in well-described situations) to analyze situations and to solve problems that require them to make a decision among well-defined alternatives. To analyze a system or make decisions, students at Level 2 combine and synthesize information from a variety of sources. They are able to combine various forms of representations (e.g. a formalized language, numerical information, and graphical information), handle unfamiliar representations (e.g. statements in a programming language or flow diagrams related to a mechanical or structural arrangement of components) and draw inferences based on two or more sources of information. Students at Level 2 are also expected to be able to successfully complete tasks located at Level 1 of the PISA problem-solving scale.
Students proficient at Level 1 score between 405 to 499 points on the problem-solving scale. They typically solve problems where they have to deal with only a single data source containing discrete, well-defined information. They understand the nature of a problem and consistently locate and retrieve information related to the major features of the problem. Students at Level 1 are able to transform the information in the problem to present the problem differently, e.g. take information from a table to create a drawing or graph. Also, students can apply information to check a limited number of well-defined conditions within the problem. However, students at Level 1 do not typically deal successfully with multi-faceted problems involving more than one data source or requiring them to reason with the information provided. Students below level 1, with scores of less than 405 points, are weak or emergent problem solvers. They consistently fail to understand even the easiest items in the assessment or fail to apply the necessary processes to characterize important features or represent the problems. At most, they can deal with straightforward problems with carefully structured tasks that require the students to give responses based on facts or to make observations with few or no inferences. They have significant difficulties in making decisions, analyzing or evaluating systems, and trouble-shooting situations.

The effects of DBS on student proficiency in the science concepts and knowledge gain intended by the Heating and Cooling System unit would be assessed by 24 questions taken from the Chemical Concept Inventory (CCI) (American Chemical Society, 2001) and the American Chemical Society’s (ACS) Test Item Bank for high school chemistry (Eubanks and Eubanks, 1993). Samples of these questions are shown in appendix E. The
reliability of CCI is 0.71 with proven validity (Krause, Birk, Bauer, Jenkins, & Pavelich, 2004).

Data Analysis

In order to answer research questions one to eight, data collected were analyzed by ANCOVA, controlling for pretest scores. ANCOVA was used because it yields more powerful results, meaning there was a higher probability of finding group differences if indeed any difference existed and is not associated with an inflated $\alpha$-level of significance (Dimitrov & Rumrill, 2003). Other analyses that could have been performed, namely: a) Analysis of variance (ANOVA) on gain scores, b) ANOVA on residual scores, or (d) Repeated measures ANOVA. The use of pretest scores in these methods helps to reduce error variance, thus producing more powerful tests than designs with no pretest data (Stevens, 1996). ANOVA on residual scores was not used because: a) when the residuals are obtained from the pooled within-group regression coefficients, ANOVA on residual scores results in an inflated $\alpha$-level of significance and b) when the regression coefficient for the total sample of all groups combined is used, ANOVA on residual scores yields an inappropriately conservative test (Maxwell, Delaney, & Manheimer, 1985). Also, repeated measures ANOVA was not used because according to Huck & McLean (1975) and Jennings (1998) the results provided by repeated measures ANOVA for pretest-posttest data can be misleading. Specifically, the $F$ test for the treatment main effect (which is of primary interest) is very conservative because the pretest scores are not affected by the treatment. Hence for the analysis of pretest-posttest designs Dimitrov & Rumrill (2003) recommend one-way ANOVA on gain scores or, even better, ANCOVA with the pretest scores as a covariate.
Analysis of Covariance (ANCOVA), was therefore performed (controlling for pretest scores) to determine if groups (including gender, race-ethnicity and SES) differed significantly in gains in problem solving competency and chemistry achievement in Chemical heating/Cooling, pursuant to the administration of the DBS instruction. For the ANCOVA procedure, the effect sizes are noted and discussed using the $\eta^2$ value. The $\eta^2$ value is the proportion of variation in the dependent variable (problem solving competency or Chemistry concept) that is attributable to the DBS instruction and other factors such as gender, race and SES. The dependent variables (within-group) in the study were: a) Problem solving competency, and b) Chemistry achievement, considered one at a time. Both of these are scale quantities. The main independent variable (between-group) is the treatment (with 2 levels - treatment and control). The other predictors are: gender, race and SES. All predictors were nominal variables.

The third research question sought to investigate whether the problem solving competency of a student was predictive of his/her achievement in chemistry. This question was answered by performing a correlation for all participants to determine if students who did well on the problem solving assessment also performed well on the chemistry concepts inventory and vice versa.

**Summary**

The research methodology of the study involved a quasi-experimental pretest/posttest design with a non-randomized sample, comprising 10th and 11th grade students in four traditional chemistry classes. Two main groups were compared, namely treatment and control groups. The treatment was DBS instruction on chemical heating/cooling unit. The study sought to investigate: a) the effects of DBS on problem
solving competency across gender, race and SES, b) the effects of DBS on chemistry achievement across gender, race and SES, and c) whether problem solving competency is predictive of chemistry achievement. Analysis of Covariance (ANCOVA) was the preferred analysis due to its reduction of systemic bias caused by group differences in pretest scores and the higher power associated with its results.

The generalizability of the findings of this study is restricted to: a) students of traditional chemistry who are taking chemistry for the first time, b) students who are generally not highly motivated to study chemistry and c) schools in an urban school district with similar student characteristics as the one used in this study. This is because testing one school makes generalization difficult since the individual school tested may generate better or worse results for students using that particular educational instruction. The students in one school may be from a completely different socioeconomic background or culture and therefore cannot be a representative sample of the population.
CHAPTER IV
DATA ANALYSIS AND RESULTS

Introduction

The purpose of this study was to investigate the effects of DBS instruction on the problem solving competency and the concepts of chemical energy among different groups of students. Student groups used in the analysis included gender and race. The relationship between SES and problem solving competency was also considered. A treatment group of 33 students were taught a twelve-week chemical energy unit through lessons in which students designed solutions to real-world problems as well as design their own investigations. The study sought to answer the following questions: “Do the effects of DBS on problem solving competencies of students in a high school Traditional Chemistry class vary depending on gender, race and/or SES?”; “Do the effects of DBS on science achievement of students in a high school Traditional Chemistry class vary depending on gender, race and/or SES?” and “Do students who show improved real-world problem solving skills also perform well on science achievement?”. A control group of 41 students studied the same unit in traditional classroom settings. This chapter presents results from the quantitative methods used in the study.

To investigate research questions one to eight an Analysis of Covariance (ANCOVA) procedure was performed, using pretest scores as covariate, to compare the means between the treatment and control groups. The analysis was conducted to ascertain group differences attributable to DBS. For the ANCOVA procedure, the effect sizes are noted and discussed using the $\eta^2$ value. The $\eta^2$ value is the proportion of variation in
the dependent variable (problem solving competency or Chemistry concept) that is attributable to the DBS instruction and other factors such as gender, race and SES.

Data Analysis and Results

Effects of DBS on Problem Solving Competency across Gender, Race and SES

Research question one: Comparison of treatment and control groups.

The first research question is as follow: Does DBS have any effect on problem solving competencies of students in a high school traditional chemistry class? In order to answer the first part of this question, an ANCOVA was conducted to determine if there were significant differences between the means problem solving competency scores the treatment and control groups. The results show that there was a statistically significant difference between the treatment and control groups in their problem solving competency after the treatment (DBS instruction). This significant difference was observed across all three aspects of problem solving measured in the study.

The ANCOVA results comparing the mean total problem solving scores of the treatment and control groups are presented as follow. The following assumptions were tested, a) independence of observations, b) normal distribution of the dependent variable, c) homogeneity of variance, d) linear relationships between the covariate and dependent variable, and e) homogeneity of regression slopes. All assumptions were met. The results indicate that after controlling for the pretest scores on problem solving competency, there was a significant difference between the treatment and control groups in problem solving competency. Table II shows that the problem solving competency of the treatment and control groups were significantly different, F (1, 71) = 32.90, p < .001, eta² = .32. Thus
32 percent of the variance in problem solving scores is explained by the treatment. Table I presents the means and standard deviations for the two groups on problem solving competency, before and after controlling for problem solving pretest scores.

Table I

*Adjusted and Unadjusted Group Means and Variability for Problem Solving Competency Using Problem Solving Pretest Scores as Covariate*

<table>
<thead>
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<th>Adjusted</th>
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<td></td>
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<td>Control group</td>
<td>41</td>
</tr>
<tr>
<td>Treatment group</td>
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</tr>
</tbody>
</table>

Table II

*Analysis of Covariance for Problem Solving Competency as a Function of Group, Using Problem Solving Pretest Scores as Covariate*

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<tr>
<th>Source</th>
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<th>$MS$</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Problem solving pretest</td>
<td>1</td>
<td>47604131.04</td>
<td>21.90</td>
<td>&lt; .001</td>
<td>.30</td>
</tr>
<tr>
<td>Group</td>
<td>1</td>
<td>52939811.61</td>
<td>24.35</td>
<td>&lt; .001</td>
<td>.32</td>
</tr>
<tr>
<td>Error</td>
<td>71</td>
<td>2174182.62</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figures X and XI depict the effect of DBS in improving overall problem solving competency. Figure X compares the estimated mean problem solving competency of the Control group and the Treatment group.

Covariates appearing in the model are evaluated at the following values: Total Prob. Solving score (Pretest) = 2329.23

Figure X. Mean Problem Solving Scores for Treatment and Control Groups

Figure XI. Mean Problem Solving Scores (Pretest and Posttest) for Treatment and Control Groups

Figures X and XI depict the effect of DBS in improving overall problem solving competency. Figure X is compares the estimated mean problem solving competency.
scores of the control and treatment groups with pretest scores adjusted (controlled for). Figure XI on the other hand compares the pre/posttest mean problem solving competency scores of the control and treatment group. The latter graph shows that while the pretest scores were similar for the two groups, the posttest scores for the treatment group are much higher than those of the control group. Thus the DBS instruction appeared to have affected the problem solving competency of students. The problem solving items comprised of three types of problems, namely, decision-making (DM), system analysis and design (SAD), and troubleshooting (TS).

It may be necessary to dig deeper to determine whether the above effect of DBS on problem solving competency was evident in all three aspects of problem solving. The ANCOVA results for the subtotals for each of the three areas of problem solving competency measured, controlling for pretest scores for each aspect of problem solving, indicated statistically significant differences between the treatment and control groups. For decision making competency, $F (1, 71) = 18.47, p < .001, \eta^2 = .21$. Table III presents the mean and standard deviations for the control and treatment groups on decision making competency before and after controlling for decision making pretest scores.
Table III

*Adjusted and Unadjusted Group Means and Variability for Decision Making Competency Using Decision Making Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
<th></th>
<th></th>
<th>Adjusted</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SE</td>
</tr>
<tr>
<td>Control group</td>
<td>41</td>
<td>1426.37</td>
<td>988.90</td>
<td>1415.57</td>
<td>108.62</td>
</tr>
<tr>
<td>Treatment group</td>
<td>33</td>
<td>2101.36</td>
<td>766.98</td>
<td>2114.78</td>
<td>121.06</td>
</tr>
</tbody>
</table>

Table IV

*Analysis of Covariance for Problem Solving Competency as a Function of Group, Using Decision Making Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>eta²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision making pretest</td>
<td>1</td>
<td>23603294.30</td>
<td>48.81</td>
<td>&lt; .001</td>
<td>.41</td>
</tr>
<tr>
<td>Group</td>
<td>1</td>
<td>8934757.71</td>
<td>18.47</td>
<td>&lt; .001</td>
<td>.21</td>
</tr>
<tr>
<td>Error</td>
<td>71</td>
<td>483627.45</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The ANCOVA results for system analysis competency, show that F (1, 71) = 11.52, p < .05, eta² = .14. Table V presents the mean and standard deviations for the
control and treatment groups on system analysis and design competency before and after controlling for system analysis and design pretest scores.

Table V

*Adjusted and Unadjusted Group Means and Variability for System Analysis Competency Using System Analysis and Design Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
<th></th>
<th>Adjusted</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Control group</td>
<td>41</td>
<td>1326.68</td>
<td>1020.32</td>
<td>1310.07</td>
</tr>
<tr>
<td>Treatment group</td>
<td>33</td>
<td>1937.73</td>
<td>986.69</td>
<td>1953.37</td>
</tr>
</tbody>
</table>

Table VI

*Analysis of Covariance for System Analysis Competency as a Function of Group, Using System Analysis and Analysis Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>eta²</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Analysis pretest</td>
<td>1</td>
<td>25458677.26</td>
<td>38.19</td>
<td>&lt; .001</td>
<td>.35</td>
</tr>
<tr>
<td>Group</td>
<td>1</td>
<td>7677008.59</td>
<td>11.52</td>
<td>&lt; .05</td>
<td>.14</td>
</tr>
<tr>
<td>Error</td>
<td>71</td>
<td>666715.50</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The ANCOVA results for troubleshooting also show a significant difference between the treatment and control groups for troubleshooting competency, $F(1, 71) = 15.74$, $p < .001$, $\eta^2 = .18$. The assumption of homogeneity of variances was violated. However, because the cell sizes (41 and 33) were similar this violation did not present an issue (Leech, Barrett and Morgan, 2008). Table VII presents the mean and standard deviations for the control and treatment groups on troubleshooting competency before and after controlling for troubleshooting pretest scores.

---

**Table VII**

*Adjusted and Unadjusted Group Means and Variability for System Analysis Competency Using Troubleshooting Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
<th></th>
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<th>Adjusted</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$N$</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SE$</td>
</tr>
<tr>
<td>Control group</td>
<td>41</td>
<td>497.10</td>
<td>549.66</td>
<td>478.80</td>
<td>102.50</td>
</tr>
<tr>
<td>Treatment group</td>
<td>33</td>
<td>1076.42</td>
<td>749.82</td>
<td>1099.16</td>
<td>114.67</td>
</tr>
</tbody>
</table>
The above analysis suggests that DBS improves all three aspects of problem solving competency measured in the study. This, thus provides an answer to research question one, thereby disproving the null hypothesis that the DBS has no effect on problem solving competency.

**Research question two: problem solving competency across gender.**

The preceding section suggests that there is a significant effect of DBS on problem solving competency. This section is dedicated to analyzing the data for gender differences. To search for any significant gender differences an ANCOVA was conducted to determine whether there were differences between the average total problem solving scores of male and female students in the treatment and control groups, after controlling for problem solving pretest scores. Group and gender were used as fixed factors. The following assumptions were once again tested, a) independence of observations, b) normal distribution of the dependent variable, c) homogeneity of variance, d) linear
relationships between the covariate and dependent variable, and e) homogeneity of regression slopes. All the assumptions were met. The results indicate that the problem solving competencies of the male and female students in the treatment group on the one hand and the control group on the other were significantly different, $F(1, 51) = 5.58$, $p < .05$, $\eta^2 = .099$. The means and standard deviations for the two groups are presented in Table IX.

### Table IX

**Adjusted and Unadjusted Gender Means and Variability for Problem Solving**

**Competency Using Problem Solving Pretest Scores as Covariate**

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
<th>Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$N$</td>
<td>$M$</td>
</tr>
<tr>
<td>Control group</td>
<td>41</td>
<td>3214.07</td>
</tr>
<tr>
<td>Female</td>
<td>22</td>
<td>2882.09</td>
</tr>
<tr>
<td>Male</td>
<td>19</td>
<td>3598.47</td>
</tr>
<tr>
<td>Treatment group</td>
<td>33</td>
<td>5139.88</td>
</tr>
<tr>
<td>Female</td>
<td>15</td>
<td>5731.07</td>
</tr>
<tr>
<td>Male</td>
<td>18</td>
<td>4647.22</td>
</tr>
</tbody>
</table>
Table X

Analysis of Covariance for Problem Solving Competency as a Function of Gender, Using Problem Solving Pretest Scores as Covariate

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>eta^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving pretest</td>
<td>1</td>
<td>47604131.04</td>
<td>21.90</td>
<td>&lt; .001</td>
<td>.30</td>
</tr>
<tr>
<td>Gender</td>
<td>1</td>
<td>167923.86</td>
<td>.08</td>
<td>.782</td>
<td>.00</td>
</tr>
<tr>
<td>Group*Gender</td>
<td>1</td>
<td>12121040.13</td>
<td>5.58</td>
<td>&lt; .05</td>
<td>.10</td>
</tr>
<tr>
<td>Error</td>
<td>51</td>
<td>2174182.62</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The treatment (DBS) therefore explained about ten percent of the variance in female and male problem solving scores between the treatment and control groups. Figure XI shows that both males and females benefited from the treatment, with females in the treatment group a slight edge over males. Males in the control group performed better than females on the problem solving competency protocol. The interaction therefore indicates a small benefit of DBS for female students over male students on problem solving competency.
The ANCOVA results for the previous section indicate a significant difference between the treatment and control groups in problem solving competency. Thus, DBS appeared to have improved the problem solving competency of students. In an attempt to answer research question one, this section sought to investigate if this effect of DBS was significantly different when females and males were compared. The ANCOVA results suggest that there was a significant difference between males and females in the treatment group compared to those in the control group: although both males and females benefited from DBS, females (in the treatment group) appear to have benefited more from DBS instruction than males (in the treatment group). This
statistically significant, interaction rejects the second null hypothesis \((H_0 = \mu_{males} = \mu_{females})\).

**Research question three: problem solving competency across race.**

This section presents the results of analyses intended to answer research question three: Are the observed effects of DBS different for students of different races? An analysis of covariance was used to assess whether there were significant differences between the average total problem solving scores of Black and Hispanic students, after controlling for problem solving pretest scores. The small number of Asian students (one each in control and treatment groups), White students (all three in control group) and Native American students (one in control group, two in treatment group), warranted their exclusion from the analyses. The following assumptions were tested a) independence of observations, b) normal distribution of the dependent variable, c) homogeneity of variance, d) linear relationships between the covariate and dependent variable, and e) homogeneity of regression slopes. All assumptions were met. The results indicate that the problem solving competencies of Black and Hispanic students in the treatment and control groups were not significantly different, \(F (1, 51) = 1.07, p = .305, \eta^2 = .02\). The interaction of group, gender and race was however significant, \(F (1, 51) = 5.48, p < .05, \eta^2 = .097\). Thus the combination of group, gender and race explains about ten percent of the difference in variance of problem solving competency between the control and treatment group. These results, while accepting the third null hypothesis suggests significantly different effects of DBS on Hispanic males and Black males. The means and standard deviations for Black and Hispanic females and males in both treatment and control groups are presented in Table XI.
Table XI

*Adjusted and Unadjusted Group, Race and Gender Means and Variability for Problem Solving Competency Using Problem Solving Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
<th></th>
<th>Adjusted</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Control group</td>
<td>41</td>
<td>3214.07</td>
<td>2056.72</td>
<td>2831.31</td>
</tr>
<tr>
<td>Black</td>
<td>21</td>
<td>2288.86</td>
<td>1118.61</td>
<td>2545.29</td>
</tr>
<tr>
<td>Female</td>
<td>13</td>
<td>2264.31</td>
<td>1087.38</td>
<td>2441.11</td>
</tr>
<tr>
<td>Male</td>
<td>8</td>
<td>2328.75</td>
<td>1243.06</td>
<td>2649.47</td>
</tr>
<tr>
<td>Hispanic</td>
<td>20</td>
<td>4185.55</td>
<td>2376.71</td>
<td>3174.53</td>
</tr>
<tr>
<td>Female</td>
<td>9</td>
<td>3774.44</td>
<td>2813.74</td>
<td>2579.79</td>
</tr>
<tr>
<td>Male</td>
<td>11</td>
<td>4521.90</td>
<td>2030.37</td>
<td>4066.64</td>
</tr>
<tr>
<td>Treatment</td>
<td>33</td>
<td>5139.88</td>
<td>1934.76</td>
<td>5305.72</td>
</tr>
<tr>
<td>Black</td>
<td>19</td>
<td>5055.00</td>
<td>2019.20</td>
<td>5219.07</td>
</tr>
<tr>
<td>Female</td>
<td>7</td>
<td>4999.00</td>
<td>2655.63</td>
<td>5431.57</td>
</tr>
<tr>
<td>Male</td>
<td>12</td>
<td>5087.67</td>
<td>1679.83</td>
<td>5006.58</td>
</tr>
<tr>
<td>Hispanic</td>
<td>14</td>
<td>5255.07</td>
<td>1882.59</td>
<td>5409.69</td>
</tr>
<tr>
<td>Female</td>
<td>8</td>
<td>6371.63</td>
<td>1230.13</td>
<td>6174.24</td>
</tr>
</tbody>
</table>
Table XI continued

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>6</td>
<td>3766.33 &amp; 1562.66 &amp; 4262.86 &amp; 643.11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table XII

*Analysis of Covariance for Problem Solving Competency as a Function of Group, Race and gender Using Problem Solving Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>eta²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving pretest</td>
<td>1</td>
<td>47604131.04</td>
<td>21.90</td>
<td>&lt; .001</td>
<td>.30</td>
</tr>
<tr>
<td>Race</td>
<td>1</td>
<td>1276836.92</td>
<td>.59</td>
<td>.447</td>
<td>.11</td>
</tr>
<tr>
<td>Group*Race</td>
<td>1</td>
<td>2335186.45</td>
<td>1.07</td>
<td>.305</td>
<td>.02</td>
</tr>
<tr>
<td>Group<em>Gender</em>Race</td>
<td>1</td>
<td>11919431.53</td>
<td>5.48</td>
<td>&lt; .001</td>
<td>.097</td>
</tr>
<tr>
<td>Error</td>
<td>51</td>
<td>2202501.27</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The significant effects and interactions between group, gender and race are depicted in Figure XIII - XVI below. Figure XIII shows that females benefited from DBS, as their mean problem solving scores improved, however female Hispanic students saw a greater improvement in their mean problem solving competency score.
Figure XI. Comparison of Female Students’ Problem Solving Scores in Treatment and Control Groups by Race

Figure XIV. Comparison of Male Students’ Problem Solving Scores in Treatment and Control Groups by Race
Figure XIV, on the other hand shows Black males benefiting more from DBS than their Hispanic counterparts in problem solving competency. Within each race, the effects of DBS on female and male students can also be compared. Figure XV shows that among the Black students females had a slight edge over males although the mean problem solving competency scores of both groups improved after the treatment. Also, among the Hispanic students, Figure XVI below shows that females appear to have benefited more from DBS instruction than their male counterparts, reversing the edge males had prior to the problem solving pretest. The mean problem solving competency scores for Hispanic males in the treatment and control group are similar, implying that in general Hispanic males appear not to have benefited from the DBS instruction.
Research question four: problem solving competency across SES.

This section presents results of the analysis intended to contribute to the resolution of research question four: are the problem solving competency differences (observed between treatment and control groups) consistent with SES? An analysis of covariance was conducted to ascertain whether there were differences in the effect of DBS on the problem solving competencies of students with different SES after controlling for problem solving pretest scores. The following assumptions were met: a) independence of observations, b) normal distribution of the dependent variable, c) homogeneity of variance, d) linear relationships between the covariate and dependent variable, and e) homogeneity of regression slopes. To enable easy comparison, SES values were grouped into three categories with equal widths: low (8 – 27.99), mid (28 – 47.99) and high (48 – 66). The results indicated that the observed differences in problem solving competencies between students with different SES in the treatment and control
group were not significantly, \( F(2, 51) = .86, p = .428, \eta^2 = .03 \). No interactions with SES (e.g. group and gender; group, gender and race) were statistically significant. The means and standard deviations for the treatment and control groups are presented in Table XIII for low, mid and high SES groups.

---

### Table XIII

*Adjusted and Unadjusted SES Group Means and Variability for Problem Solving Competency Using Problem Solving Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
<th></th>
<th>Adjusted</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( N )</td>
<td>( M )</td>
<td>( SD )</td>
<td>( M )</td>
</tr>
<tr>
<td>Control</td>
<td>Low SES</td>
<td>19</td>
<td>4133.11</td>
<td>2477.92</td>
</tr>
<tr>
<td></td>
<td>Mid SES</td>
<td>16</td>
<td>2392.63</td>
<td>1122.14</td>
</tr>
<tr>
<td></td>
<td>High SES</td>
<td>6</td>
<td>2494.33</td>
<td>1403.01</td>
</tr>
<tr>
<td>Treatment</td>
<td>Low SES</td>
<td>18</td>
<td>5204.11</td>
<td>1848.27</td>
</tr>
<tr>
<td></td>
<td>Mid SES</td>
<td>12</td>
<td>4723.92</td>
<td>2108.43</td>
</tr>
<tr>
<td></td>
<td>High SES</td>
<td>3</td>
<td>6418.33</td>
<td>1696.65</td>
</tr>
</tbody>
</table>
Table XIV

*Analysis of Covariance for Problem Solving Competency as a Function of SES Group, Using Problem Solving Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving pretest</td>
<td>1</td>
<td>47604131.04</td>
<td>21.90</td>
<td>&lt; .001</td>
<td>.35</td>
</tr>
<tr>
<td>SES</td>
<td>2</td>
<td>4326850.82</td>
<td>.08</td>
<td>.147</td>
<td>.07</td>
</tr>
<tr>
<td>Group*SES Group</td>
<td>2</td>
<td>1875317.77</td>
<td>.86</td>
<td>.428</td>
<td>.03</td>
</tr>
<tr>
<td>Error</td>
<td>51</td>
<td>2174182.62</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Differences in the problem solving competencies of the SES groups in the treatment and control groups were not significant. The slopes of graphs in Figure XVIII however show

![Figure XVII. Graph of Problem Solving Posttest Scores for Treatment and Control SES Groups](image)
that high and medium SES groups appear to have benefited more than low SES groups from DBS, with higher SES students scoring the highest on average.

**Summary**

In the above sections analyses of covariance were conducted to compare the mean problem solving competency scores of a) control and treatment groups, b) female and male students, c) Black and Hispanic students (within and between the two groups with aggregation across gender), and d) low-SES, mid-SES and high-SES students. These analyses were intended to answer research questions one to four respectively: 1) Does DBS have any effect on the problem solving competencies of students in a high school traditional chemistry class? 2) Does the effect of DBS on problem solving competency vary depending on gender? 3) Does the effect of DBS on problem solving competency vary depending on race? 4) Does the effect of DBS on problem solving competency vary depending on SES?

The above ANCOVA results suggest that a) DBS improves the problem solving competency of students in a high school traditional chemistry class, thereby disproving null hypothesis one, which states that there is no effect of DBS on problem solving competency \((H_0 = \mu_{\text{control}} = \mu_{\text{experimental}})\), b) the effects of DBS on problem solving competency significantly varies depending on gender, rejecting null hypothesis two, which states that there is no difference in the effect of DBS depending on gender \((H_0 = \mu_{\text{female}} = \mu_{\text{male}})\), c) the effects of DBS on problem solving competency does not significantly vary depending on race, accepting null hypothesis three, which states that there is no difference in the effect of DBS depending on race \((H_0 = \mu_{\text{Black}} = \mu_{\text{Hispanic}})\), d)
there is a statistically significant interaction between race and gender when the control and treatment groups were compared, suggesting that DBS instruction improves problem solving competency of Black females, Black males and Hispanic females but not Hispanic males, and e) the effects of DBS on problem solving competency does not significantly vary depending on SES, accepting null hypothesis four, which states that there is no difference in the effect of DBS depending on SES ($H_0 = \mu_{\text{LowSES}} = \mu_{\text{midSES}} = \mu_{\text{HighSES}}$).

**DBS and Chemistry Achievement**

This section presents analyses needed to answer research questions five to eight respectively: 5) Does DBS have any effect on chemistry achievement of students in a high school traditional chemistry class? 6) Does the effect of DBS on chemistry achievement vary depending on gender? 7) Does the effect of DBS on chemistry achievement vary depending on race? 8) Does the effect of DBS on chemistry achievement vary depending on SES?

**Research question five: DBS and chemistry achievement.**

The intent of research question five was to ascertain whether students who were given DBS instruction did better on a test of chemistry concepts than students in a control group. The results of the analysis are shared below. These results show that there was no significant difference in the chemistry achievement of students in the control and treatment groups.

An ANCOVA was performed, with CCI pretest as covariate to investigate if DBS instruction produced any significantly different CCI scores for the treatment group
compared with the control group. The following assumptions were met: a) independence of observations, b) normal distribution of the dependent variable, c) homogeneity of variance, d) linear relationships between the covariate and dependent variable, and e) homogeneity of regression slopes. All assumptions were met. The results indicate that there were no significant differences in knowledge gained in chemical change and chemical energy concepts between students in the treatment and control groups, $F(1, 51) = 0.45$, $p = .51$, $\eta^2 = .04$. The means and standard deviations for the two groups are presented in Table XV. Thus DBS instruction appears not to have any effect on the chemistry achievement of high school students in a traditional chemistry.

Table XV

*Adjusted and Unadjusted Group Means and Variability for Chemistry Concepts*

*Inventory (CCI) Using CCI Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
<th>Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$N$ $M$ $SD$</td>
<td>$M$ $SE$</td>
</tr>
<tr>
<td>Control group</td>
<td>41 13.27 2.40</td>
<td>13.00 0.35</td>
</tr>
<tr>
<td>Treatment group</td>
<td>33 13.67 1.63</td>
<td>13.58 0.39</td>
</tr>
</tbody>
</table>
Table XVI

*Analysis of Covariance for CCI as a Function of Group, Using CCI Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>eta²</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCI pretest</td>
<td>1</td>
<td>7.63</td>
<td>2.33</td>
<td>.133</td>
<td>.44</td>
</tr>
<tr>
<td>Group</td>
<td>1</td>
<td>1.47</td>
<td>.45</td>
<td>.506</td>
<td>.01</td>
</tr>
<tr>
<td>Error</td>
<td>51</td>
<td>4.71</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Research question six: DBS and chemistry achievement across gender.**

The goal of research question six was to investigate whether any effects of DBS depended on gender. The results of the analysis are shared below. These results show that there was no significant difference in the chemistry achievement between female and male students in the control and treatment groups.

An ANCOVA was then performed, with CCI pretest as covariate to investigate if DBS produced any significantly different CCI scores for female than male students. This analysis was intended to help resolve research question six. The following assumptions were tested and met: a) independence of observations, b) normal distribution of the dependent variable, c) homogeneity of variance, d) linear relationships between the covariate and dependent variable, and e) homogeneity of regression slopes. All assumptions were met. The results indicate that there were no significant differences in CCI scores when females and males from the treatment group were compared with those
in the control group, F (1, 51) = 0.91, p = .35, \eta^2 = .02. The means and standard deviations for the two groups are presented in Table XVII.

Table XVII

*Adjusted and Unadjusted Gender Means and Variability for Chemistry Concepts Inventory (CCI) Using CCI Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
<th></th>
<th>Adjusted</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Control group</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>22</td>
<td>12.73</td>
<td>2.64</td>
<td>12.78</td>
</tr>
<tr>
<td>Male</td>
<td>19</td>
<td>13.89</td>
<td>1.97</td>
<td>13.26</td>
</tr>
<tr>
<td>Treatment group</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>15</td>
<td>13.93</td>
<td>1.94</td>
<td>13.52</td>
</tr>
<tr>
<td>Male</td>
<td>18</td>
<td>13.44</td>
<td>1.34</td>
<td>13.65</td>
</tr>
</tbody>
</table>
Table XVIII

*Analysis of Covariance for CCI as a Function of Gender, Using CCI Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>eta²</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCI pretest</td>
<td>1</td>
<td>7.63</td>
<td>2.33</td>
<td>.133</td>
<td>.044</td>
</tr>
<tr>
<td>Group</td>
<td>1</td>
<td>1.47</td>
<td>.45</td>
<td>.506</td>
<td>.009</td>
</tr>
<tr>
<td>Group*Gender</td>
<td>1</td>
<td>2.98</td>
<td>.91</td>
<td>.345</td>
<td>.017</td>
</tr>
<tr>
<td>Error</td>
<td>51</td>
<td>3.28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The differences between the CCI scores for female and male students in the treatment and control groups were not statistically significant. Figure XVIII, however, shows that there was just a small gain in the CCI scores of both female and male students in the treatment group compared with those of the control group. However, females in the treatment group scored higher than their male counterparts.
Research question seven: DBS and chemistry achievement across race.

The intent of research question seven was to ascertain whether any effect of DBS instruction on chemistry achievement depended on race. The results of the analysis are shared below. These results show that there was no significant difference in the chemistry achievement of Black and Hispanic students in the treatment group when compared with those in the control group.

An ANCOVA was then performed, with CCI pretest as covariate to investigate if DBS instruction produced any significantly different CCI scores for Black than Hispanic students. The following assumptions were met: a) independence of observations, b) normal distribution of the dependent variable, c) homogeneity of variance, d) linear relationships between the covariate and dependent variable, and e) homogeneity of regression slopes. All assumptions were met. The results indicate that there was no
significant differences in CCI scores when Black and Hispanic students from the
treatment group are compared with those in the control group, F (1, 51) = 3.09, p = .085,
$\eta^2 = .06$. The means and standard deviations for the two groups are presented in Table XIX.

Table XIX

*Adjusted and Unadjusted Race Means and Variability for Chemistry Concepts Inventory (CCI) Using CCI Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
<th></th>
<th>Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Control group</td>
<td>41</td>
<td>13.27</td>
<td>2.40</td>
</tr>
<tr>
<td>Black</td>
<td>21</td>
<td>12.05</td>
<td>1.99</td>
</tr>
<tr>
<td>Female</td>
<td>13</td>
<td>11.46</td>
<td>1.85</td>
</tr>
<tr>
<td>Male</td>
<td>8</td>
<td>13.00</td>
<td>1.93</td>
</tr>
<tr>
<td>Hispanic</td>
<td>20</td>
<td>14.55</td>
<td>2.14</td>
</tr>
<tr>
<td>Female</td>
<td>9</td>
<td>14.56</td>
<td>2.60</td>
</tr>
<tr>
<td>Male</td>
<td>11</td>
<td>14.55</td>
<td>1.81</td>
</tr>
<tr>
<td>Treatment</td>
<td>33</td>
<td>13.67</td>
<td>1.63</td>
</tr>
<tr>
<td>Black</td>
<td>19</td>
<td>13.42</td>
<td>1.47</td>
</tr>
</tbody>
</table>
Table XIX continued

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>13.86</th>
<th>1.35</th>
<th>13.83</th>
<th>.780</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>12</td>
<td>13.17</td>
<td>1.53</td>
<td>13.32</td>
<td>.740</td>
</tr>
<tr>
<td>Hispanic</td>
<td>14</td>
<td>14.00</td>
<td>1.84</td>
<td>13.59</td>
<td>.557</td>
</tr>
<tr>
<td>Female</td>
<td>8</td>
<td>14.00</td>
<td>2.45</td>
<td>13.22</td>
<td>.761</td>
</tr>
</tbody>
</table>

Table XX

*Analysis of Covariance for CCI as a Function of Race, Using CCI Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>eta²</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCI pretest</td>
<td>1</td>
<td>7.63</td>
<td>2.30</td>
<td>&lt; .001</td>
<td>.30</td>
</tr>
<tr>
<td>Race</td>
<td>1</td>
<td>5.22</td>
<td>1.59</td>
<td>.447</td>
<td>.11</td>
</tr>
<tr>
<td>Group*Race</td>
<td>1</td>
<td>10.14</td>
<td>3.09</td>
<td>.305</td>
<td>.02</td>
</tr>
<tr>
<td>Group<em>Gender</em>Race</td>
<td>1</td>
<td>.28</td>
<td>.09</td>
<td>.771</td>
<td>.002</td>
</tr>
<tr>
<td>Error</td>
<td>51</td>
<td>3.28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
When females and males in the two races in the treatment group were compared to those in the control group no significant differences are found (i.e. the interaction, group*gender*race was not significant), $F(1, 51) = .086, p = .771, \eta^2 = .002$.

**Research question eight: DBS and chemistry achievement across SES.**

The intent of research question eight was to ascertain whether any effect of DBS instruction on chemistry achievement depended on SES. The results of the analysis are shared below. These results show that there was no significant difference in the chemistry achievement of students from low, mid and high SES subgroups when the treatment group was compared with the control group.

An ANCOVA was performed, with CCI pretest as covariate to investigate if DBS produced any significantly different CCI scores for students in different SES groups. This was intended to assist in answering research question eight. The following assumptions were met: a) independence of observations, b) normal distribution of the dependent variable, c) homogeneity of variance, d) linear relationships between the covariate and dependent variable, and e) homogeneity of regression slopes. All assumptions were met. The results indicate that there are no significant differences in CCI scores when students from the treatment group are compared with those in the control group, by their SES groups $F(2, 51) = .67, p = .52, \eta^2 = .03$. The means and standard deviations for the two groups are presented in Table XXI.
Table XXI

*Adjusted and Unadjusted SES group Means and Variability for Chemistry Concepts Inventory (CCI) Using CCI Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
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</tr>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SE</td>
</tr>
<tr>
<td><strong>Control group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low SES</td>
<td>19</td>
<td>13.95</td>
<td>2.55</td>
<td>13.32</td>
<td>.470</td>
</tr>
<tr>
<td>Mid SES</td>
<td>16</td>
<td>12.69</td>
<td>2.21</td>
<td>12.78</td>
<td>.577</td>
</tr>
<tr>
<td>High SES</td>
<td>6</td>
<td>12.67</td>
<td>2.16</td>
<td>12.87</td>
<td>.819</td>
</tr>
<tr>
<td><strong>Treatment group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low SES</td>
<td>18</td>
<td>13.78</td>
<td>1.40</td>
<td>14.03</td>
<td>.467</td>
</tr>
<tr>
<td>Mid SES</td>
<td>12</td>
<td>13.75</td>
<td>1.87</td>
<td>13.89</td>
<td>.544</td>
</tr>
<tr>
<td>High SES</td>
<td>3</td>
<td>12.67</td>
<td>2.31</td>
<td>12.57</td>
<td>1.047</td>
</tr>
</tbody>
</table>
Table XXII

*Analysis of Covariance for CCI as a Function of SES Group, Using CCI Pretest Scores as Covariate*

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>eta^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCI pretest</td>
<td>1</td>
<td>7.63</td>
<td>2.33</td>
<td>.133</td>
<td>.04</td>
</tr>
<tr>
<td>SES</td>
<td>1</td>
<td>2.49</td>
<td>.76</td>
<td>.472</td>
<td>.03</td>
</tr>
<tr>
<td>Group*SES</td>
<td>2</td>
<td>2.19</td>
<td>.67</td>
<td>.518</td>
<td>.03</td>
</tr>
<tr>
<td>Error</td>
<td>51</td>
<td>3.28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Summary**

In the above sections analyses of covariance were conducted to compare the mean chemistry concepts inventory scores of a) control and treatment groups, b) female and male students, c) Black and Hispanic students, and d) low-SES, mid-SES and high-SES students. These analyses were intended to answer research questions five to eight respectively: 5) Does DBS have any effect on the chemistry achievement of students in a high school traditional chemistry class? 6) Does the effect of DBS on chemistry achievement vary depending on gender? 7) Does the effect of DBS on chemistry achievement vary depending on race? 8) Does the effect of DBS on chemistry achievement vary depending on SES?

The above ANCOVA results suggest that a) DBS does not improve the chemistry achievement of students in a high school traditional chemistry class, thereby accepting
null hypothesis five, which states that there is no effect of DBS on problem solving competency \((H_0 = \mu_{\text{control}} = \mu_{\text{experimental}})\), b) the effects of DBS on chemistry achievement does not vary depending on gender, accepting null hypothesis six, which states that there is no difference in the effect of DBS on chemistry achievement depending on gender \((H_0 = \mu_{\text{female}} = \mu_{\text{male}})\), c) the effects of DBS on chemistry achievement does not significantly vary depending on race, accepting null hypothesis seven, which states that there is no difference in the effect of DBS depending on race \((H_0 = \mu_{\text{Black}} = \mu_{\text{Hispanic}})\), d) the effects of DBS on chemistry achievement does not significantly vary depending on SES, accepting null hypothesis eight, which states that there is no difference in the effect of DBS depending on SES \((H_0 = \mu_{\text{LowSES}} = \mu_{\text{midSES}} = \mu_{\text{HighSES}})\).

Correlation between Problem Solving Competency and Chemistry Concepts Score

Research question nine: problem solving as predictor of chemistry scores.

To investigate whether the level of chemistry concepts acquired by a student may be predicted by his/her problem solving competency, a regression analysis was performed. This analysis involved all students, without a differentiation of control and treatment groups. The following assumptions were tested and met, a) independence of observations, b) linearity, and c) the dependent variable (chemistry concepts score) was approximately normally distributed. Problem solving competency \((M = 4320.13, SD = 2331.54)\), significantly predicted the chemistry concepts score \((M = 13.63, SD = 2.33)\), \(F(1, 80) = 31.03, p < .001\), adjusted \(R^2 = .27\). This implies that 27% of the variance in the chemistry concepts score is predicted by problem solving competency. Also an \(r\) value
\( (\sqrt{R^2}) \) of 0.53 indicates a high effect size. The beta weight, presented in Table XXIII, indicate that when the problem solving competency increases by one unit, chemistry concepts score increase by 0.001 units. The preceding analysis therefore disproves the null hypothesis, which states that problem solving competency is not predictive of chemistry concepts score \((H_0 = \mu_{CCI} = \mu_{\text{Problem solving}})\).

**Table XXIII**

*Simple Linear Regression Analysis for Problem Solving Competency Predicting Chemistry Concepts Score \((N = 82)\)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>( B )</th>
<th>( SEB )</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Solving Competency</td>
<td>0.001</td>
<td>0.00</td>
<td>.53***</td>
</tr>
<tr>
<td>Constant</td>
<td>11.35</td>
<td>.47</td>
<td></td>
</tr>
</tbody>
</table>

Note. \( R^2 = .27; F (1, 80) = 31.03, p < .001. \)
***\( p < .001. \)

**Summary**

This study investigated the effects of DBS on the problem solving competencies of high school students in a traditional chemistry class. It explored differences in the effects of DBS among groups by race, gender and SES. The study also ascertained if problem solving competency was predictive of chemistry achievement. ANCOVA was used to analyze the data. The findings are as follow: a) DBS significantly improved the problem solving competency of students in the study, b) DBS significantly improves the problem solving competency of both males and females, with a slight urge among females, c) the differences in the effects of DBS in improving problem solving competency among Black and Hispanic students in this study was not statistically
significant, however, Black students and Hispanic female students showed significant improvement in problem solving competency after the DBS instruction, d) DBS did not statistically significantly improve the problem solving competency of students of particularly SES group(s), and e) Problem solving competency is a strong predictor of higher chemistry concepts score among students in both treatment and control groups.
CHAPTER V
CONCLUSIONS

Introduction

Science (and math) achievement in the United States has been on the decline over the past couple of decades, both nationally and internationally (Ornstein, 2010; U. S. Department of Education 2004, 2006; NEAP, 2005). The following achievement gaps have been identified as contributing to the decline: a) achievement gaps between males and females (NSF, 2008; Ornstein, 2010) and b) achievement gaps between White and Asian students on the one hand and Black and Hispanic students on the other (Ornstein, 2010; Clewell & Ginorio, 1996; Creswell & Houston, 1980). Instructional methods such as DBS have the potential of improving students’ creativity/critical thinking, problem-solving ability, science-process skills and consequently science achievement (Mehalik, Doppelt and Schunn 2008; Fortus, Dershimer, Krajcik, Marx and Mamlok-Naaman, 2004, 2005; OECD, 2003; Chang, 2001a, 2001b). The purpose of this study was to investigate the effects of DBS on problem solving competency and science achievement, thereby contributing to the search for ways to close the achievement gap between males and females, students from different races and the rich and poor. Specifically, the questions addressed were:

1) Does DBS have any effect on the problem solving competencies of students in a high school traditional chemistry class?
2) Does the effect of DBS on problem solving competency depend on gender?
3) Does the effect of DBS on problem solving competency depend on race?
4) Does the effect of DBS on problem solving competency depend on SES?
5) Does DBS have any effect on the chemistry achievement of students in a high school traditional chemistry class?

6) Does the effect of DBS on chemistry achievement vary depending on gender?

7) Does the effect of DBS on chemistry achievement vary depending on race?

8) Does the effect of DBS on chemistry achievement vary depending on SES?

9) Is the problem solving competency of students in a traditional chemistry class predictive of their chemistry achievement?

The results of the study suggest that DBS contributes to the problem solving competency of students, when treatment and control groups were compared. The observed effects of DBS on problem solving competency were also significantly different for students of different gender: females benefiting significantly more than males. The effect of DBS on the problem solving competency of Black and Hispanic students was not significantly different. However, Hispanic males in the treatment group did not score significant higher than those in the control group, suggesting that DBS instruction may not be useful in improving problem solving skills of students in this group. One reason that may account for this similarity between Hispanic males in the control and treatment groups is the observation that during the design project a couple of groups that had more Hispanic males consistently sought to solve problems that were not only overly simplistic but also did not meet all the constraints laid out for the project. Most female students on the other hand were more focused and more resolved to meet the constraints of the project. Even though some did not produce a finished elaborate design, their determination was an indication of their acceptance of the challenge and consequently may have passed through the DBS instruction, acquiring intended skills.
The observed effects of DBS on problem solving competency scores were also found not to depend on SES. Also, DBS had no statistically significant effect on the chemistry achievement scores of students in the study. The results however suggest a strong correlation between problem solving competency and chemistry achievement. These findings will be discussed below followed by study limitations and implications for research and practice.

**Findings and Interpretation of Results**

**Effects of DBS on Problem Solving Competency**

Research questions one to four were intended on assessing whether DBS had any effects on problem solving competency and if there was, how the effect differed depending on gender, race and SES. The results suggest a significant difference in problem solving competency between the treatment group and the control group. Due to the difficulty in measuring problem solving as a whole, the PISA problem solving protocol focuses on three areas of problem solving, namely, decision making, system analysis and design, and troubleshooting. These three components were also present in the DBS instruction particularly during the design project.

First students needed to decide on exactly what problem they wanted to solve. This stage was not that challenging since the decision was driven primarily by interest. Decision making was however present in the other stages as well. The next stage of system design involved identifying the various components of the system. Students, in applying the design process were required to produce drawings showing different angles of their system, including a plan (top view) and an elevation (side view). During this stage they had to decide on the types of materials to use to produce the best desired
results. Students also had to determine the arrangement of system components that would produce the best results. Students had to make all these decisions cognizant of the chemistry concepts or reaction(s), which form the fundamental aspect of the system. This stage was quite challenging for the students, as they were clearly not used to this level of critical thinking. Students needed a lot of guidance and direction or else they were inclined to give up. In fact they preferred being told what to do at this stage. During the third stage when they had completed their design and the system was either not working at all or not working as anticipated, students had to troubleshoot by investigating possible causes. Even if the system initially worked students had to determine conditions for optimum results. During this and the previous stages students had to think critically in order to move on with their projects. The level of difficulty of each of these stages may have produced different learning environments for the students that may reflect in their performance on the problem solving assessment.

The results of the problem solving competency pretest put the treatment and control groups at practically the same level in all three measured categories of problem solving. The use of ANCOVA as analysis further leveled the playing field by way of controlling for these pretest scores. The results showed that the treatment group performed better on the posttest than the control group on all three problem solving categories (Tables IV, VI and VIII).

The above results support findings by Kolodner, Camp, Crismond, Fasse, Gray, Holbrool, Puntambekar, and Ryan, (2003) and Silk, Schunn and Strand, (2007). Their findings suggest that engaging students in design-based learning or problem-based learning within a science classroom has the potential of helping students develop problem
solving skills and scientific inquiry skills. The difference between the above referenced statements and the findings of the current study is that whereas the current study provides empirical evidence relating to a chemistry classroom the other is not based on any evidence.

**Effects of DBS on Problem Solving Competency across Gender**

Differences in science achievement between males and females have been adequately researched and established. Males appear to perform better than females in science particularly at the high school level (Ingels & Dalton, 2008; Bacharach, Baumeister & Furr, 2003; Jones, Mullis, Raizen, Weiss, &Weston, 1992). The search for ways to close this achievement gap is ongoing. In this regard the results of this study may contribute an understanding of instructional methods that support female excellence in science.

The data from the current study suggests that there is no statistically significant difference the problem solving scores when males and females in the treatment are compared with those in the control groups (Table X). However, using the adjusted means of problem solving score in Table X for treatment and control groups, females (mean gain = 2564.19) appear to have benefited more from DBS instruction than males (mean gain = 1314.26). This relationship is displayed in Figure XI. Although this interaction between group and gender is not statistically significant, it is worth replicating this study with a larger group, since a larger sample size may improve the reliability and power of analysis. Thus when females in the treatment group are compared with those in the control group, it becomes evident that females may stand to benefit more than males.
The items on the problem solving protocol were generally not gender biased and as a result they add to the credibility of any conclusions drawn from the above results. It is however, worth noting that if females would break through the glass ceiling in STEM related careers they must be continually supported in working past societal stereotypes about female and male roles: that males build while females nurture.

Effects of DBS on Problem Solving Competency across Race

Conversations involving achievement gaps cannot be complete without the inclusion of Native American, Black and Hispanic students’ performance – trailing White and Asian Students. This study thus also sought to investigate the effects DBS may have on problem solving competency depending on race. Research question three sought to ascertain the effects of DBS instruction on the problem solving competency of different races so as to determine if DBS has a potential to help close the achievement gap associated with race. Due to circumstances beyond researcher control, the number of Black and Hispanic students in the study sample was larger than other races. Also, the numbers of Asian, Native American and White students in the study sample were too small to be included in the analysis. If they had been included deductions on the effects of DBS on problem solving competency for these groups would not be meaningful.

The results (Table XII) show that there is no significant difference in the problem solving scores of Black and Hispanic students. Due to the fact that these results are close to being significant, the interactions are worth discussing to bring to the fore the potential differences between subgroups in terms of benefits of DBS. Figure XII depicts the similarity in the gains in problem solving score for Black and Hispanic females. Figure XIII shows the problem solving competency scores of Black males in the treatment group.
increasing while those of their Hispanic counterparts remaining almost unchanged. The Hispanic males therefore appeared to have benefited from DBS: whereas the gains in problem solving scores for Black females and males were close (Figure XII), those of Hispanic females and males showed that the females scored higher (Figure XV).

Historically, in the school where the study was conducted there has been a disproportionately high number of Black and Hispanic students in traditional science courses. The racial composition of the study sample vis-à-vis that is the school as a whole attests to this observation: 2.4% Asian, 48.8% Black, 41.5% Hispanic, 3.6% Native American and 3.6% White. The current distribution of students of different races in this school includes: 4.3% Asian, 41.7% Black, 23.3% Hispanic, 0.9% Native American and 29.3% White. Most of the Black and Hispanic students in the classes studied give a couple of reasons for avoiding higher level courses. These include their a) lack of motivation and b) perception that science is difficult. Such students hitherto wish to get by with a grade of D, even in traditional courses. If DBS can improve the problem solving competency of these students it can go a long way in improving their self-confidence. Expanding this study to improve the power and reliability of the analysis is therefore important. Expansion may include involving students from more school sites.

Effects of DBS on Problem Solving Competency across SES

The results of the PISA 2003 problem solving competency assessment suggest a strong correlation between problem solving competency and SES (OECD, 2003). It is common knowledge that a high proportion of Black, Hispanic and Native American students fall within low SES in the United States. The implication of the PISA 2003 problem solving assessment results is that students from these races are more likely to
have low problem solving competencies. The goal of research question four was thus to establish the correlation between SES and problem solving and to ascertain if DBS has a potential of improving the problem solving competency of low SES students. In their study of the effects of DBS on science achievement among middle school students by gender, socioeconomic status (SES) and race-ethnicity, Mehalik, Doppelt and Schuun (2008) reported that low-achieving African American students benefited the most from DBS.

The results of the current study show that there is no significant difference between the problem solving skills of low SES, mid SES and high SES when students in the control and treatment groups are compared. It may however be noted that while the interaction between group and SES group was not significant (Table XIV), all three SES groups in the treatment groups had higher problem solving scores than their peers in the control group (Figure XVI). This suggests that all SES groups appear to have benefited from DBS in their problem solving competency. The insignificant effect of DBS on problem solving skills across SES group remained so even after reducing the SES groups to two (lowSES and midSES), negating any fear that that SES groupings earlier used may be unrepresentative of the larger population..

**Effect of DBS on Chemistry Achievement across Gender, Race and SES**

The results of preliminary studies by Fortus, Dershimer, Krajcik, Marx and Mamlok-Naaman, (2005) and Puntambekar & Kolodner, 2005 imply that DBS and other inquiry-based pedagogies have the potential of helping students develop science knowledge. The results of the current study, however suggest that DBS does not have a statistically significant effect of chemistry achievement of the students in this study.
neither across gender, race nor SES. This implies that teachers and administrators are likely not to shun DBS or they may have a neutral attitude to using it in their classrooms/schools. However, if DBS improves problem solving competency, as suggested from the answer to research question one and problem solving competency correlated to chemistry achievement, then there will be a long-term benefit of DBS not only in improving problem solving competency but also indirectly improving chemistry achievement.

**Problem Solving Competency as Predictor of Chemistry Achievement**

Data from the PISA 2003 revealed a high correlation of 0.8, between problem solving competency and science achievement. The current study suggests that DBS has a significant effect on problem solving competency. If problem solving is a predictor of chemistry achievement then most of the students whose problem solving competency scores improved or students who scored high on the problem solving protocol would do well on the CCI. However, the results of the current study indicated no difference in the chemistry achievement between the treatment and control group, although there was a significant difference in problem solving score between the two groups.

When all students in the study (treatment and control groups together) were pooled for the analysis there was a strong correlation between problem solving scores and CCI scores. In other words problem solving scores appeared to be a predictor of chemistry achievement. Hence the observation that even though problem solving competency on the treatment group improved but their chemistry achievement was not different from students in control group implies that the benefits of DBS towards chemistry achievement were not immediate.
During the design challenge tasks students were expected to use some of the concepts and knowledge tested by the Chemistry Concepts Inventory (CCI). Thus the design challenge tasks had direct bearing (knowledge-wise and concepts-wise) with what was assessed by the CCI. The PISA problem solving items however had no direct bearing on the design challenge. Despite these facts students in treatment group improved on problem solving items over the control group. This was not the case for Chemistry Concepts Inventory (CCI). A number of reasons could be advanced to account for the similar CCI scores for the treatment and control groups: a) Students in the treatment group may have been so focused on solving their specific problem that they lost attention of chemistry concepts that were tested, b) students in control group are more academically motivated and performed better, c) the DBS instruction did not foster the acquisition of broad-base chemistry knowledge: perhaps problem solving competency alone is not sufficient to enable students to score higher on the CCI.

Problem-Solving Theories and Current Study

Three problem-solving theories were used as lenses to understand the results of the current study, namely, constructivist, expert-novice and cognitive theories. Through the identification of need-based problems by students for resolution, to the construction of prototypes, various student actions may be interpreted by these theories. This section discusses if and how these theories were at play during the design challenge projects as students attempted solving specific problems.

In attempting to solve their chosen problem, students tapped into their prior knowledge (misconceptions or otherwise). For instance students who were enrolled in the school’s JROTC (Junior Reserve Officer Training Corps) program were more inclined to
identify MRE (meals ready to eat) as a source of chemical energy. MREs are food packages provided to military personnel. The package comes with a sachet of powdered magnesium, which upon mixing with water generated enough heat to warm up food. However, these students had no understanding of the chemical reaction responsible for the heat generated. Thus by the end of their projects such students exhibited better conceptual understanding of their domain. Also, at the beginning of the project students demonstrated little to no declarative conceptual understanding but by the end of the project could explain the origins of energy change. Throughout the project however, students had a hard time with deciding the procedure they needed to apply in solving the problem. More opportunities for students to attempt similar challenges may provide more insight to students thereby showing their growth in expert problem solving procedural skills.

The five components of the DBS framework were intended to assist in the development of students’ conceptual understanding of the problem they intended to solve. The framework also challenged students to elicit both declarative and automated skills in order to resolve problems. In other words beyond the problem being resolved in the current study, students would recognize the need to look inward to elicit knowledge and skills required to solve any problem on hand. Students in the current study were successfully guided to this realization since the teacher/researcher refrained from giving direct answers to student questions. At times some students were frustrated that they did not get direct answers. In the end however, they appreciated that they had the answer to most of their questions and needed to process deeper for themselves.
Constructivist, novice-expert and cognitive theories, as reviewed above explain the observed significant effect of DBS instruction in improving the problem solving competencies of students, when the control and treatment groups were compared. This relationship may be due to the fact the DBS framework and the five-step DBS learning cycle are consistent with these theories. By tapping into their prior knowledge students constructed new knowledge for themselves. Also, as they were challenged by the design problem they developed the declarative conceptual understanding and procedural knowledge needed for problem resolution. Finally, the desire by students to eliminate their cognitive dissonance was enhanced by their inspiration to resolve a problem in order to meet their own need(s).

**Summary**

The findings of the study may apply to high school students in a traditional chemistry course, in an urban district similar to that in this study. The findings are as follow: a) DBS significantly affects the problem solving competency of students, b) DBS improves the problem competency of both males and females, with a statistically insignificant urge among females, c) DBS does not produce a statistically significant difference in problem solving competency between Black and Hispanic students both whom appear to benefit from DBS except Hispanic males, d) DBS had no significant effect on problem solving competency depending on socioeconomic status, and e) Problem solving competency is a strong predictor of higher chemistry concepts score among both treatment and control groups.
Generalizations

Due to the limitations of sampling and various defining sample characteristics, the generalizability of the findings of this study is restricted to: a) students of traditional chemistry who are taking chemistry for the first time, b) students who are generally not highly motivated to study chemistry, and c) schools in an urban school district with similar student characteristics as the one used in this study. This is because testing one school makes generalization difficult since the individual school tested may generate better or worse results for students using that particular educational instruction. The students in one school may be from a completely different socioeconomic background or culture and therefore cannot be a representative sample of the population.

Delimitations of the Study

This study limited itself to high school students in a traditional chemistry class. These students were sophomores who were taking chemistry for the first time and participated in the school district’s pre-course assessment. The pre-course assessment results and CCI pretest scores were used to determine the treatment and control groups. For purposes of homogeneity of student chemistry learning experiences, students who had taken a semester one class in chemistry but who could not complete semester two during the year preceding this study were not included.

Limitations of the Study

There are five limitations to the study. First, the present study is not framed in a true experimental research design with random assignment of subjects to treatment and control groups. Therefore, the generalizability of the results to the total high school student population of the nation is limited. Like any other age group, high school students
are a very heterogeneous population. The fact remains that certain segments of the high
school population, by virtue of their micro-culture, abilities, etc., may not be included.
However, since the research design utilizes student-level data, the results can provide
valuable preliminary information about the effects of DBS on student problem solving
competency among different student groups.

Secondly, the study does not necessarily establish cause-and-effect study
relationships. This is because in such social science research there are a number of other
variables that are either not present in the study context or are not apparent in the study.

Third, anytime an instrument is used the results are subject to the known
reliability and validity of that instrument. Although some information about the
instrument in regard to reliability and validity is known, the instrument may have
limitations in measuring what they purport to measure. Only subsequent research with
other audiences and with other instruments will help further our understanding of the
concepts being measured in the study.

The fourth limitation of this study is the teacher as researcher. Due to teacher’s
familiarity with students, the teacher’s observations may be biased or influenced. To
minimize this peer observers were requested and visited two class periods as well as
reviewed student work graded by teacher/researcher.

Finally, the proportion of Asian and White students in the study sample was much
lower than what pertains in the school as these students tend to participate in higher level
chemistry classes. Hence, the few Asian and White students in the study were not
included in the analyses that involved race.
Implications for Research

Due to the exploratory nature of this study, the primary suggestion for future research is to build on the present study by replicating it in the future, with some modifications. These modifications include: a) the use of random sampling techniques that select a number of schools within one or more cities to increase the generalizability, b) to include various academic levels such Advance Placement and International Baccalaureate, c) include sufficient students from all races, d) include other science subjects such as physics and biology, and e) use DBS curriculum that involve more than one unit over a longer period than used in this study.

Secondly, studies are clearly needed to develop a more broad-spectrum problem solving competency protocol. The PISA 2003 problem solving protocol measures only three aspects of problem solving: decision making, system analysis and design, and Trouble shooting. A more comprehensive protocol must perceive problem solving primarily as an internal and sequential process that includes cognitive, affective, and psychomotor behaviors. It must be stated that problem solving is a complex concept for measurement and includes ill-defined and well-defined problems. The later appear to be easier to measure than the former.

Finally, if the strong correlation between problem solving and chemistry achievement is further established, research is needed to identify effective school-wide best practices and culture around the use of real-world problem solving to spur science achievement. After all, problem solving does not involve a set of skill limited to successful academic life but rather the very existence of the human race.
Implications for Practice

The “Next Generation Science Standards” ([http://www.nextgenscience.org/next-generation-science-standards](http://www.nextgenscience.org/next-generation-science-standards)) is about to be released, after going through the final phase of public review. One of the cornerstones of the new standards is the integration of science with engineering design. In retrospect, a large scale empirical investigation of the kind in this study is long overdue to identify mainstream trends as well as the deviations from the norm: how do different high school student groups respond to engineering design (or design based science)? The current study thus provides some insights as to how teachers should view the influences of DBS on their students.

The strong correlation between problem solving and chemistry (and hopefully science) achievement suggests that a greater emphasis needs to be placed on problem solving earlier in the child’s education. DBS can be viewed as one of the ways to incorporate problem solving instruction into science classrooms since for the study subjects and conditions, it has been shown to have a significant effect on problem solving competency. The challenge is the lack of a comprehensive design based science curriculum. Also, science teachers will need intensive training in DBS to make them effective in integrating science with design.

The implications of the continuously widening achievement gaps between different student groups make the findings of this study compelling. According to the McKinsey consulting firm (2009), the gap in science and math achievement between 1983 and 1998, cost the U.S. a Gross Domestic Product (GDP) of approximately $2 trillion higher. The achievement gap between Black and Hispanic students on the one hand and white and Asian students by 1998 cost the U.S. about $400 to $500 billion. The
results of this study suggest that the use of DBS instruction could improve the problem solving competencies of Black students (in particular) as well as Hispanic students. DBS instruction could also improve female achievement since females respond well to it.

Collaboration is one of the twenty first century skills that will enable students to be successful at the workplace. DBS instruction also serves to improve collaboration among students as it involves students in group projects. Collaboration provides students the opportunity to learn from each other and develop communication skills.

Finally, staying current and well informed about research exploring the effects of design based science instruction on problem solving competency and academic achievement is an important exercise in science teacher professional development. Furthermore, science teachers should seek opportunities to share the implications of such research with school administrators, faculty members, and parents of children enrolled in their schools.

**Summary**

This study investigated the effects of DBS on the problem solving competencies of high school students in a traditional chemistry class. It explored differences in the effects of DBS among groups by race, gender and SES. The study also ascertained if problem solving competency was predictive of chemistry achievement. The findings are as follow: a) DBS significantly affects the problem solving competency of students, b) DBS improves the problem competency of both males and females, with a statistically insignificant urge among females, c) DBS does not produce a statistically significant difference in problem solving competency between Black and Hispanic students both whom appear to benefit from DBS except Hispanic males, d) DBS had no significant
effect on problem solving competency depending on socioeconomic status, and e) Problem solving competency is a strong predictor of higher chemistry concepts score among both treatment and control groups.

Due the limitations of the study the following are recommendations for future research: a) the use of random sampling techniques that select a number of schools within one or more cities to increase the generalizability, b) to include various academic levels such Advance Placement and International Baccalaureate, c) include sufficient students from all races, d) include other science subjects such as physics and biology, and e) use DBS curriculum that involve more than one unit over a longer period than used in this study.
References


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Eubanks, I. D. & Eubanks, L. P. (1993). ACS test-item bank for high school chemistry. American Chemical Society Division of Chemical Education Examinations Institute, Milwaukee.


Wavering, J. J. (1980). What are the basics of science education? What is important to know, how to use knowledge or how to obtain answers? Science and Mathematics, 80, 633-637.


APPENDIX A

The Barratt Simplified Measure of Social Status (BSMSS)
Measuring SES
Will Barratt, Ph.D.

Circle the appropriate number for your Mother’s, your Father’s, your Spouse / Partner’s, and your level of school completed and occupation. If you grew up in a single parent home, circle only the score from your one parent. If you are neither married nor partnered circle only your score. If you are a full time student circle only the scores for your parents.

<table>
<thead>
<tr>
<th>Level of School Completed</th>
<th>Mother</th>
<th>Father</th>
<th>Spouse</th>
<th>You</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 7th grade</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Junior high / Middle school (9th grade)</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Partial high school (10th or 11th grade)</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>High school graduate</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Partial college (at least one year)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>College education</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Graduate degree</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
</tbody>
</table>

Circle the appropriate number for your Mother’s, your Father’s, your Spouse / Partner’s, and your occupation. If you grew up in a single parent home, use only the score from your parent. If you are not married or partnered circle only your score. If you are still a full-time student circle the scores for your parents. If you are retired use your most recent occupation.

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Mother</th>
<th>Father</th>
<th>Spouse</th>
<th>You</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day laborer, janitor, house cleaner, farm worker, food counter sales, food</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>preparation worker, busboy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garbage collector, short-order cook, cab driver, shoe sales, assembly</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>line workers, mausos, baggage porter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Painter, skilled construction trade, sales clerk, truck driver, cook,</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>sales counter or general office clerk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automobile mechanic, typist, locksmith, farmer, carpenter, receptionist,</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>construction laborer, hairdresser</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machinist, musician, bookkeeper, secretary, insurance sales, cabinet</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>maker, personnel specialist, welder</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supervisor, librarian, aircraft mechanic, artist and artisan, electrician,</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>administrator, military enlisted personnel, buyer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nurse, skilled technician, medical technician, counselor, manager, police</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>and fire personnel, financial manager, physical, occupational, speech</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>therapist</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical, nuclear, and electrical engineer, educational administrator,</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>veterinarian, military officer, elementary, high school and special</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>education teacher</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physician, attorney, professor, chemical and aerospace engineer, judge,</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>CEO, senior manager, public official, psychologist, pharmacist, accountant</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Level of School Completed Scoring

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>If you grew up with both parents add <strong>Mother</strong> + <strong>Father</strong> and divide by 2. If you grew up with one parent enter that score to the right.</td>
</tr>
<tr>
<td>2</td>
<td>If you are married or partnered add <strong>Spouse</strong> + <strong>You</strong> and divide by 2. If you live alone enter <strong>Your</strong> score to the right. If you are a full-time student leave this blank.</td>
</tr>
<tr>
<td>3</td>
<td>Double your score from line 2. If you are a full-time student leave this blank.</td>
</tr>
<tr>
<td>4</td>
<td>If you are a full-time student enter only your parents’ score. Add line 1 and line 3 then divide by 3 (three) for a TOTAL EDUCATION Score should be between 3 and 21</td>
</tr>
</tbody>
</table>

### Occupation Scoring

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>If you grew up with both parents add <strong>Mother</strong> + <strong>Father</strong> and divide by 2. If you grew up with one parent enter that score to the right.</td>
</tr>
<tr>
<td>2</td>
<td>If you are married or partnered add <strong>Spouse</strong> + <strong>You</strong> and divide by 2. If you live alone enter <strong>Your</strong> score to the right. If you are a full-time student leave this blank.</td>
</tr>
<tr>
<td>3</td>
<td>Double your score from line 2. If you are a full-time student leave this blank.</td>
</tr>
<tr>
<td>4</td>
<td>If you are a full-time student enter only your parents’ score. Add line 1 and line 3 then divide by 3 (three) for TOTAL OCCUPATION Score should be between 5 and 45</td>
</tr>
</tbody>
</table>

**TOTAL Score:**

Add **TOTAL EDUCATION** + **TOTAL OCCUPATION**: Score should be between 8 and 66
Energy Needs

**Daily energy needs recommended for adults**

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Activity level</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 18 to 29</td>
<td>Light</td>
<td>10660</td>
<td>8360</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>11080</td>
<td>8780</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>14420</td>
<td>9820</td>
</tr>
<tr>
<td>From 30 to 59</td>
<td>Light</td>
<td>10450</td>
<td>8570</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>12120</td>
<td>8990</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>14210</td>
<td>9790</td>
</tr>
<tr>
<td>60 and above</td>
<td>Light</td>
<td>8780</td>
<td>7500</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>10240</td>
<td>7940</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>11910</td>
<td>8780</td>
</tr>
</tbody>
</table>

**Activity level according to occupation**

- **Light:** Indoor sales person, Office worker, Housewife
- **Moderate:** Teacher, Outdoor salesperson, Nurse
- **Heavy:** Construction worker, Labourer, Sportsperson

**ENERGY NEEDS – Question 1**

Mr David Edison is a 45-year-old teacher. What is his recommended daily energy need in kJ?

Answer: ........................................... kJ.

Jane Gibbs is a 19-year-old high jumper. One evening, some of Jane’s friends invite her out for dinner at a restaurant. Here is the menu:

<table>
<thead>
<tr>
<th>MENU</th>
<th>Jane’s estimate of energy per serving (kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soups:</strong></td>
<td></td>
</tr>
<tr>
<td>Tomato Soup</td>
<td>355</td>
</tr>
<tr>
<td>Cream of Mushroom Soup</td>
<td>585</td>
</tr>
<tr>
<td><strong>Main courses:</strong></td>
<td></td>
</tr>
<tr>
<td>Mexican Chicken</td>
<td>960</td>
</tr>
<tr>
<td>Caribbean Ginger Chicken</td>
<td>795</td>
</tr>
<tr>
<td>Pork and Sage Kebabs</td>
<td>920</td>
</tr>
<tr>
<td><strong>Salads:</strong></td>
<td></td>
</tr>
<tr>
<td>Potato salad</td>
<td>750</td>
</tr>
<tr>
<td>Spinach, Apricot and Hazelnut Salad</td>
<td>335</td>
</tr>
<tr>
<td>Couscous Salad</td>
<td>480</td>
</tr>
<tr>
<td><strong>Desserts:</strong></td>
<td></td>
</tr>
<tr>
<td>Apple and Raspberry Crumble</td>
<td>1380</td>
</tr>
<tr>
<td>Ginger Cheesecake</td>
<td>1005</td>
</tr>
<tr>
<td>Carrot Cake</td>
<td>565</td>
</tr>
<tr>
<td><strong>Milkshakes:</strong></td>
<td></td>
</tr>
<tr>
<td>Chocolate</td>
<td>1590</td>
</tr>
<tr>
<td>Vanilla</td>
<td>1470</td>
</tr>
</tbody>
</table>

The restaurant also has a special fixed price menu.

**Fixed Price Menu**

- **50 zeds**
- Tomato Soup
- Caribbean Ginger Chicken
- Carrot Cake
ENERGY NEEDS – Question 2

Jane keeps a record of what she eats each day. Before dinner on that day her total intake of energy had been 7520 kJ.

Jane does not want her total energy intake to go below or above her recommended daily amount by more than 500 kJ.

Decide whether the special “Fixed Price Menu” will allow Jane to stay within ±500 kJ of her recommended energy needs. Show your work.

This problem is about finding a suitable time and date to go to the cinema.

Isaac, a 15-year-old, wants to organise a cinema outing with two of his friends, who are of the same age, during the one-week school vacation. The vacation begins on Saturday, 24th March and ends on Sunday, 1st April.

Isaac asks his friends for suitable dates and times for the outing. The following information is what he received.

Fred: “I have to stay home on Monday and Wednesday afternoons for music practice between 2:30 and 3:30.”

Stanley: “I have to visit my grandmother on Sundays, so it can’t be Sundays. I have seen Pokamin and don’t want to see it again.”

Isaac’s parents insist that he only goes to movies suitable for his age and does not walk home. They will fetch the boys home at any time up to 10 p.m.

Isaac checks the movie times for the vacation week. This is the information that he finds.

<table>
<thead>
<tr>
<th>TIVOLI CINEMA</th>
<th>Advance Booking Number: 01924 4230000</th>
</tr>
</thead>
<tbody>
<tr>
<td>24-hour phone number: 01924 420071</td>
<td></td>
</tr>
<tr>
<td>Bargain Day Tuesdays: All films £3</td>
<td></td>
</tr>
<tr>
<td>Films showing from Fri 23rd March for two weeks:</td>
<td></td>
</tr>
<tr>
<td><strong>Children in the Net</strong></td>
<td><strong>Pokamin</strong></td>
</tr>
<tr>
<td>113 mins</td>
<td>Suitable only for persons of 12 years and over</td>
</tr>
<tr>
<td>14:00 (Mon-Fri only)</td>
<td>13:40 (Daily)</td>
</tr>
<tr>
<td>21:35 (Sat/Sun only)</td>
<td>16:35 (Daily)</td>
</tr>
<tr>
<td><strong>Monsters from the Deep</strong></td>
<td><strong>Enigma</strong></td>
</tr>
<tr>
<td>164 mins</td>
<td>Suitable only for persons of 18 years and over</td>
</tr>
<tr>
<td>19:55 (Fri/Sat only)</td>
<td>15:00 (Mon-Fri only)</td>
</tr>
<tr>
<td><strong>Carnivore</strong></td>
<td><strong>King of the Wild</strong></td>
</tr>
<tr>
<td>148 mins</td>
<td>Suitable only for persons of 18 years and over</td>
</tr>
<tr>
<td>18:30 (Daily)</td>
<td>14:35 (Mon-Fri only)</td>
</tr>
<tr>
<td></td>
<td>18:50 (Sat/Sun only)</td>
</tr>
</tbody>
</table>
Cinema Outing

**CINEMA OUTING – Question 1**

Taking into account the information Isaac found on the movies, and the information he got from his friends, which of the six movies should Isaac and the boys consider watching?

Circle “Yes” or “No” for each movie.

<table>
<thead>
<tr>
<th>Movie</th>
<th>Should the three boys consider watching the movie?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children in the Net</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Monsters from the Deep</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Carnivore</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Pokamin</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Enigma</td>
<td>Yes / No</td>
</tr>
<tr>
<td>King of the Wild</td>
<td>Yes / No</td>
</tr>
</tbody>
</table>

**CINEMA OUTING – Question 2**

If the three boys decided on going to “Children in the Net”, which of the following dates is suitable for them?

A. Monday, 26th March  
B. Wednesday, 28th March  
C. Friday, 30th March  
D. Saturday, 31st March  
E. Sunday, 1st April
Holiday

This problem is about planning the best route for a holiday. Figures 1 and 2 show a map of the area and the distances between towns.

**Figure 1. Map of roads between towns**

**Figure 2. Shortest road distance of towns from each other in kilometres.**

<table>
<thead>
<tr>
<th></th>
<th>Angaz</th>
<th>Kado</th>
<th>Lapat</th>
<th>Megal</th>
<th>Nubon</th>
<th>Piras</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angaz</td>
<td>550</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kado</td>
<td>350</td>
<td>500</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lapat</td>
<td>300</td>
<td>850</td>
<td>550</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Megal</td>
<td>500</td>
<td>1000</td>
<td>450</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nubon</td>
<td>300</td>
<td>850</td>
<td>800</td>
<td>600</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Piras</td>
<td>500</td>
<td>1000</td>
<td>450</td>
<td>600</td>
<td>250</td>
<td></td>
</tr>
</tbody>
</table>

**HOLIDAY – Question 1**

Calculate the shortest distance by road between Nubon and Kado.

Distance: ...................................... kilometres.

**HOLIDAY – Question 2**

Zoe lives in Angaz. She wants to visit Kado and Lapat. She can only travel **up to 300 kilometres** in any one day, but can break her journey by camping overnight anywhere between towns.
Zoe will stay for two nights in each town, so that she can spend one whole day sightseeing in each town.

Show Zoe's itinerary by completing the following table to indicate where she stays each night.

<table>
<thead>
<tr>
<th>Day</th>
<th>Overnight Stay</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Camp-site between Angaz and Kado.</td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Angaz</td>
</tr>
</tbody>
</table>
Transit System

The following diagram shows part of the transport system of a city in Zedland, with three railway lines. It shows where you are at present, and where you have to go.

- **Means a station on a railway line**
- **Means a station that is a junction where you can change from one railway line to another (Lines A, B or C).**

The fare is based on the number of stations travelled (not counting the station where you start your journey). Each station travelled costs 1 zed.

The time taken to travel between two adjacent stations is about 2 minutes.

The time taken to change from one railway line to another at a junction is about 5 minutes.
TRANSIT SYSTEM – Question 1

The diagram indicates a station where you are currently at (“From here”), and the station where you want to go (“To here”). **Mark on the diagram** the best route in terms of cost and time, and indicate below the fare you have to pay, and the approximate time for the journey.

Fare: ........................................... zeds.

Approximate time for journey: ........................................... minutes.
The John Hobson High School library has a simple system for lending books: for staff members the loan period is 28 days and for students the loan period is 7 days. The following is a decision tree diagram showing this simple system:

![Decision Tree Diagram]

The Greenwood High School library has a similar, but more complicated, lending system:

- All publications classified as “Reserved” have a loan period of 2 days.
- For books (not including magazines) that are not on the reserved list, the loan period is 28 days for staff, and 14 days for students.
- For magazines that are not on the reserved list, the loan period is 7 days for everyone.
- Persons with any overdue items are not allowed to borrow anything.
LIBRARY SYSTEM – Question 1

You are a student at Greenwood High School, and you do not have any overdue items from the library. You want to borrow a book that is not on the reserved list. How long can you borrow the book for?

Answer: ........................................ days.

LIBRARY SYSTEM – Question 2

Develop a decision tree diagram for the Greenwood High School Library system so that an automated checking system can be designed to deal with book and magazine loans at the library. Your checking system should be as efficient as possible (i.e. it should have the least number of checking steps). Note that each checking step should have only two outcomes and the outcomes should be labelled appropriately (e.g. “Yes” and “No”).
Design by Numbers

Design by Numbers is a design tool for generating graphics on computers. Pictures can be generated by giving a set of commands to the program.

Study carefully the following example commands and pictures before answering the questions.

Paper 0

Paper 50

Paper 100

Paper 0
Pen 100
Line 20 0 80 60

Paper 100
Pen 0
Line 20 20 80 20
Line 80 20 50 80
Line 50 80 20 20
**DESIGN BY NUMBERS© – Question 1**

Which of the following commands generated the graphic shown below?

A. Paper 0  
B. Paper 20  
C. Paper 50  
D. Paper 75

![Graph 1](image)

**DESIGN BY NUMBERS© – Question 2**

Which of the following set of commands generated the graphic shown below?

A. Paper 100  Pen 0  Line 80 20 80 60  
B. Paper 0  Pen 100  Line 80 20 60 80  
C. Paper 100  Pen 0  Line 20 80 80 60  
D. Paper 0  Pen 100  Line 20 80 80 60

![Graph 2](image)

**DESIGN BY NUMBERS© – Question 3**

The following shows an example of the “Repeat” command.

```
Paper 0  
Pen 100  
Repeat A 50 80  
{  
  Line 20 A 40 A  
}
```

The command “Repeat A 50 80” tells the program to repeat the actions in brackets { }, for successive values of A from A=50 to A=80.

Write commands to generate the following graphic:

![Graph 3](image)
Course Design

**COURSE DESIGN – Question 1**

Each student will take four subjects per year, thus completing 12 subjects in three years.

A student can only take a subject at a higher level if the student has completed the lower level(s) of the same subject in a previous year. For example, you can only take Business Studies Level 3 after completing Business Studies Levels 1 and 2.

In addition, Electronics Level 1 can only be taken after completing Mechanics Level 1, and Electronics Level 2 can only be taken after completing Mechanics Level 2.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>E1</td>
<td>Electronics Level 1</td>
</tr>
<tr>
<td>4</td>
<td>E2</td>
<td>Electronics Level 2</td>
</tr>
<tr>
<td>5</td>
<td>B1</td>
<td>Business Studies Level 1</td>
</tr>
<tr>
<td>6</td>
<td>B2</td>
<td>Business Studies Level 2</td>
</tr>
<tr>
<td>7</td>
<td>B3</td>
<td>Business Studies Level 3</td>
</tr>
<tr>
<td>8</td>
<td>C1</td>
<td>Computer Systems Level 1</td>
</tr>
<tr>
<td>9</td>
<td>C2</td>
<td>Computer Systems Level 2</td>
</tr>
<tr>
<td>10</td>
<td>C3</td>
<td>Computer Systems Level 3</td>
</tr>
<tr>
<td>11</td>
<td>T1</td>
<td>Technology and Information Management Level 1</td>
</tr>
<tr>
<td>12</td>
<td>T2</td>
<td>Technology and Information Management Level 2</td>
</tr>
</tbody>
</table>
Decide which subjects should be offered for which year, by completing the following table. Write the subject codes in the table.

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Children’s Camp

The Zedish Community Service is organising a five-day Children’s Camp. 46 children (26 girls and 20 boys) have signed up for the camp, and 8 adults (4 men and 4 women) have volunteered to attend and organise the camp.

**Table 1. Adults**

<table>
<thead>
<tr>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mrs Madison</td>
</tr>
<tr>
<td>Mrs Carroll</td>
</tr>
<tr>
<td>Ms Grace</td>
</tr>
<tr>
<td>Ms Kelly</td>
</tr>
<tr>
<td>Mr Stevens</td>
</tr>
<tr>
<td>Mr Neill</td>
</tr>
<tr>
<td>Mr Williams</td>
</tr>
<tr>
<td>Mr Peters</td>
</tr>
</tbody>
</table>

**Table 2. Dormitories**

<table>
<thead>
<tr>
<th>Name</th>
<th>Number of beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>12</td>
</tr>
<tr>
<td>Blue</td>
<td>8</td>
</tr>
<tr>
<td>Green</td>
<td>8</td>
</tr>
<tr>
<td>Purple</td>
<td>8</td>
</tr>
<tr>
<td>Orange</td>
<td>8</td>
</tr>
<tr>
<td>Yellow</td>
<td>6</td>
</tr>
<tr>
<td>White</td>
<td>6</td>
</tr>
</tbody>
</table>

**Dormitory rules:**

1. Boys and girls must sleep in separate dormitories.
2. At least one adult must sleep in each dormitory.
3. The adult(s) in a dormitory must be of the same gender as the children.
**CHILDREN’S CAMP – Question 1**

**Dormitory Allocation**
Fill the table to allocate the 46 children and 8 adults to dormitories, keeping to all the rules.

<table>
<thead>
<tr>
<th>Name</th>
<th>Number of boys</th>
<th>Number of girls</th>
<th>Name(s) of adult(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purple</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Irrigation

Below is a diagram of a system of irrigation channels for watering sections of crops. The gates A to H can be opened and closed to let the water go where it is needed. When a gate is closed no water can pass through it.

This is a problem about finding a gate which is stuck closed, preventing water from flowing through the system of channels.

Michael notices that the water is not always going where it is supposed to.

He thinks that one of the gates is stuck closed, so that when it is switched to open, it does not open.

IRRIGATION – Question 1

Michael uses the settings given in Table 1 to test the gates.

Table 1. Gate Settings

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open</td>
<td>Closed</td>
<td>Open</td>
<td>Open</td>
<td>Closed</td>
<td>Open</td>
<td>Closed</td>
<td>Open</td>
</tr>
</tbody>
</table>

With the gate settings as given in Table 1, on the diagram below draw all the possible paths for the flow of water. Assume that all gates are working according to the settings.
IRRIGATION – Question 2

Michael finds that, when the gates have the Table 1 settings, no water flows through, indicating that at least one of the gates set to open is stuck closed.

Decide for each problem case below whether the water will flow through all the way. Circle “Yes” or “No” in each case.

<table>
<thead>
<tr>
<th>Problem Case</th>
<th>Will water flow through all the way?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate A is stuck closed. All other gates are working properly as set in Table 1.</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Gate D is stuck closed. All other gates are working properly as set in Table 1.</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Gate F is stuck closed. All other gates are working properly as set in Table 1.</td>
<td>Yes / No</td>
</tr>
</tbody>
</table>

IRRIGATION – Question 3

Michael wants to be able to test whether gate D is stuck closed.

In the following table, show settings for the gates to test whether gate D is stuck closed when it is set to open.

Settings for gates (each one open or closed)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
</table>
Freezer

Jane bought a new cabinet-type freezer. The manual gave the following instructions:

- Connect the appliance to the power and switch the appliance on.
- You will hear the motor running now.
- A red warning light (LED) on the display will light up.
- Turn the temperature control to the desired position. Position 2 is normal.

<table>
<thead>
<tr>
<th>Position</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-15°C</td>
</tr>
<tr>
<td>2</td>
<td>-18°C</td>
</tr>
<tr>
<td>3</td>
<td>-21°C</td>
</tr>
<tr>
<td>4</td>
<td>-25°C</td>
</tr>
<tr>
<td>5</td>
<td>-32°C</td>
</tr>
</tbody>
</table>

- The red warning light will stay on until the freezer temperature is low enough. This will take 1 - 3 hours, depending on the temperature you set.
- Load the freezer with food after four hours.

Jane followed these instructions, but she set the temperature control to position 4. After four hours, she loaded the freezer with food.

After eight hours, the red warning light was still on, although the motor was running and it felt cold in the freezer.
**FREEZER – Question 1**

Jane read the manual again to see if she had done something wrong. She found the following six warnings:

1. Do not connect the appliance to an unearthed power point.
2. Do not set the freezer temperatures lower than necessary (−18 °C is normal).
3. The ventilation grills should not be obstructed. This could decrease the freezing capability of the appliance.
4. Do not freeze lettuce, radishes, grapes, whole apples and pears, or fatty meat.
5. Do not salt or season fresh food before freezing.
6. Do not open the freezer door too often.

Ignoring which of these six warnings could have caused the delay in the warning light going out?

Circle “Yes” or “No” for each of the six warnings.

<table>
<thead>
<tr>
<th>Warning</th>
<th>Could ignoring the warning have caused a delay in the warning light going out?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning 1</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Warning 2</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Warning 3</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Warning 4</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Warning 5</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Warning 6</td>
<td>Yes / No</td>
</tr>
</tbody>
</table>
FREEZER – QUESTION 2

Jane wondered whether the warning light was functioning properly. Which of the following actions and observations would suggest that the light was working properly?

Circle “Yes” or “No” for each of the three cases.

<table>
<thead>
<tr>
<th>Action and Observation</th>
<th>Does the observation suggest that the warning light was working properly?</th>
</tr>
</thead>
<tbody>
<tr>
<td>She put the control to position 5 and the red light went off.</td>
<td>Yes / No</td>
</tr>
<tr>
<td>She put the control to position 1 and the red light went off.</td>
<td>Yes / No</td>
</tr>
<tr>
<td>She put the control to position 1 and the red light stayed on.</td>
<td>Yes / No</td>
</tr>
</tbody>
</table>
## Appendix C

### Features of the Three Types of Problem Solving skills

<table>
<thead>
<tr>
<th>Decision making</th>
<th>System analysis and design</th>
<th>Trouble shooting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Choosing among alternatives under constraints</td>
<td>Identifying the relationships between parts of a system and/or designing a system to express the relationships between parts</td>
<td>Diagnosing and correcting a faulty or under-performing system or mechanism</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Processes involved</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding a situation where there exist several alternatives and constraints and a specified task</td>
<td>Understanding the information that characterises a given system and requirements associated with a specified task</td>
<td>Understanding the main features of a system or mechanism and its malfunctioning, and the demands of a specific task</td>
</tr>
<tr>
<td>Identifying relevant constraints</td>
<td>Identifying relevant parts of the system</td>
<td>Identifying causally related variables</td>
</tr>
<tr>
<td>Representing the possible alternatives</td>
<td>Representing the relationships among parts of the system</td>
<td>Representing the functioning of the system</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Possible sources of complexity</th>
<th>Number of constraints</th>
<th>Number of inter-related variables and nature of relationships</th>
<th>Number of inter-related parts to the system or mechanism and the ways in which these parts interact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number and type of representations used (verbal, pictorial, numerical)</td>
<td>Number and type of representations used (verbal, pictorial, numerical)</td>
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<td></td>
</tr>
</tbody>
</table>
Appendix D

PISA 2003 Problem Solving Scale

Level

3
700
- Transit System Q1
- Library System Q2
- Children’s Camp Q1
- Course Design Q1
- Design by Numbers Q3

2
600
- Energy Needs Q2
- Holiday Q2
- Design by Numbers Q2
- Design by Numbers Q1
- Freezer Q2
- Irrigation Q2
- Irrigation Q3

1
500
- Holiday Q1
- Cinema Outing Q1
- Freezer Q1
- Irrigation Q1

Below Level 1
400
- Energy Needs Q1
- Cinema Outing Q2
- Library System Q1

Decision making
System analysis and design
Trouble shooting
APPENDIX E

ASSESSING ACADEMIC GAINS FROM THE HEATING/COOLING UNIT

Chemical Concepts Inventory Sample Items:
This inventory consists of 22 multiple choice questions. Carefully consider each question and indicate the one best answer for each. Several of the questions are paired. In these cases, the first question asks about a chemical or physical effect. The second question then asks for the reason for the observed effect.

1. Which of the following must be the same before and after a chemical reaction?

   a. The sum of the masses of all substances involved.
   b. The number of molecules of all substances involved.
   c. The number of atoms of each type involved.
   d. Both (a) and (c) must be the same.
   e. (e) Each of the answers (a), (b), and (c) must be the same.

2. Assume a beaker of pure water has been boiling for 30 minutes. What is in the bubbles in the boiling water?

   a. Air.
   b. Oxygen gas and hydrogen gas.
   c. Oxygen.
   d. Water vapor.
   e. Heat.

3. A glass of cold milk sometimes forms a coat of water on the outside of the glass (Often referred to as 'sweat'). How does most of the water get there?

   a. Water evaporates from the milk and condenses on the outside of the glass.
   b. The glass acts like a semi-permeable membrane and allows the water to pass, but not the milk.
   c. Water vapor condenses from the air.
   d. The coldness causes oxygen and hydrogen from the air combine on the glass forming water.

4. What is the mass of the solution when 1 pound of salt is dissolved in 20 pounds of water?

   a. 19 Pounds.
   b. 20 Pounds.
   c. Between 20 and 21 pounds.
   d. 21 pounds.
   e. More than 21 pounds.
5. The diagram represents a mixture of S atoms and O$_2$ molecules in a closed container. Which diagram shows the results after the mixture reacts as completely as possible according to the equation:

\[ 2S + 3O_2 \rightarrow 2SO_3 \]

![Diagram showing the reaction of S atoms and O$_2$ molecules leading to SO$_3$ formation.]

6. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container. What would the magnified view show after the water evaporates?

![Diagram showing liquid water and evaporated water.]

What would the magnified view show after the water evaporates?

![Possible magnified views of evaporated water.]

7. True or False? When a match burns, some matter is destroyed.
8. What is the reason for your answer to question 7?
   a. This chemical reaction destroys matter.
   b. Matter is consumed by the flame.
   c. The mass of ash is less than the match it came from.
   d. The atoms are not destroyed, they are only rearranged.
   e. The match weighs less after burning.

9. Heat is given off when hydrogen burns in air according to the equation
   \[ 2H_2 + O_2 \rightarrow 2H_2O \]

Which of the following is responsible for the heat?
   a. Breaking hydrogen bonds gives off energy.
   b. Breaking oxygen bonds gives off energy.
   c. Forming hydrogen-oxygen bonds gives off energy.
   d. Both (a) and (b) are responsible.
   e. (a), (b), and (c) are responsible.

10. Two ice cubes are floating in water:

After the ice melts, will the water level be:
   a. higher?
   b. lower?
   c. the same?

11. What is the reason for your answer to question 10?
   a. The weight of water displaced is equal to the weight of the ice.
   b. Water is more dense in its solid form (ice).
   c. Water molecules displace more volume than ice molecules.
   d. The water from the ice melting changes the water level.
12. A 1.0-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27.0 grams.

![Iodine solid](image)

The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be:

a. less than 26.0 grams.
b. 26.0 grams.
c. 27.0 grams.
d. 28.0 grams.
e. more than 28.0 grams.

13. What is the reason for your answer to question 12?

a. A gas weighs less than a solid.
b. Mass is conserved.
c. Iodine gas is less dense than solid iodine.
d. Gasses rise.
e. Iodine gas is lighter than air.

14. What is the approximate number of carbon atoms it would take placed next to each other to make a line that would cross this dot: •

a. 4
b. 200
c. 30,000,000
d. $6.02 \times 10^{23}$

15. Figure 1 represents a 1.0 L solution of sugar dissolved in water. The dots in the magnification circle represent the sugar molecules. In order to simplify the diagram, the water molecules have not been shown.
16. 100 mL of water at 25°C and 100 mL of alcohol at 25°C are both heated at the same rate under identical conditions. After 3 minutes the temperature of the alcohol is 50°C. Two minutes later the temperature of the water is 50°C. Which liquid received more heat as it warmed to 50°C?
   
   a. The water.
   b. The alcohol.
   c. Both received the same amount of heat.
   d. It is impossible to tell from the information given.

17. What is the reason for your answer to question 16?
   
   a. Water has a higher boiling point than the alcohol.
   b. Water takes longer to change its temperature than the alcohol.
   c. Both increased their temperatures 25°C.
   d. Alcohol has a lower density and vapor pressure.
   e. Alcohol has a higher specific heat so it heats faster.

18. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:

   a. less than the nail it came from.
   b. the same as the nail it came from.
   c. more than the nail it came from.
   d. It is impossible to predict.
19. What is the reason for your answer to question 18?

a. Rusting makes the nail lighter.
b. Rust contains iron and oxygen.
c. The nail flakes away.
d. The iron from the nail is destroyed.
e. The flaky rust weighs less than iron.

20. Salt is added to water and the mixture is stirred until no more salt dissolves. The salt that does not dissolve is allowed to settle out. What happens to the concentration of salt in solution if water evaporates until the volume of the solution is half the original volume? (Assume temperature remains constant.)

The concentration

a. increases.
b. decreases.
c. stays the same.

21. What is the reason for your answer to question 20?

a. There is the same amount of salt in less water.
b. More solid salt forms.
c. Salt does not evaporate and is left in solution.
d. There is less water.

22. Following is a list of properties of a sample of solid sulfur:

i. Brittle, crystalline solid.
ii. Melting point of 113°C.
iii. Density of 2.1 g/cm³.
iv. Combines with oxygen to form sulfur dioxide

Which, if any, of these properties would be the same for one single atom of sulfur obtained from the sample?

a. i and ii only.
b. iii and iv only.
c. iv only.
d. All of these properties would be the same.
e. None of these properties would be the same.
## APPENDIX F

### CHEMISTRY CONCEPTS AND BIG IDEAS IN HEATING AND COOLING UNIT

<table>
<thead>
<tr>
<th>Subsystem &amp; Big Idea</th>
<th>Key concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reaction I</strong></td>
<td>• Matter is made up of particles that have mass and occupy space.</td>
</tr>
<tr>
<td>Energy released or absorbed during chemical transformations is dependent on the shape and structure of the particles involved in the transformation.</td>
<td>• Particles have a unique composition. The composition of particles determines their physical and chemical properties.</td>
</tr>
<tr>
<td></td>
<td>• Particles interact with each other; this interaction may result in an increase or decrease in temperature.</td>
</tr>
<tr>
<td></td>
<td>• Exothermic reactions are measured by an increase in the temperature of the system. Endothermic reactions are measured by a decrease in the temperature of the system.</td>
</tr>
<tr>
<td></td>
<td>• The composition of particles determines how they interact with each other.</td>
</tr>
<tr>
<td></td>
<td>• Interactions are the attraction between particles. Interactions between particles may result in transformations.</td>
</tr>
<tr>
<td></td>
<td>• Transformations involve changes in attractions between particles.</td>
</tr>
<tr>
<td></td>
<td>• Generally, as the size of the cation/anion increases the final temperature of the reaction involving the rearrangement of these ions will be lower.</td>
</tr>
<tr>
<td></td>
<td>• Higher energy levels are related to the size of the cation/anion.</td>
</tr>
<tr>
<td></td>
<td>• The size of the cation/anion is directly related to the distance to the nucleus and the attraction of the valence electrons of one nucleus to another nucleus.</td>
</tr>
</tbody>
</table>

| **Reaction II**      | • Mass affects the amount of energy in the system.  |
| Energy released or absorbed during chemical transformations is dependent on the mass and temperature change in the system. | • An increase in mass results in more particle interactions, and consequently increases the energy of the system.  |
|                      | • The mass of a reactant affects the change of temperature of the system.  |
|                      | • All reactions have a specific maximum amount of energy.  |
|                      | • Increases/decreases in mass are not directly proportional to increases/decreases in temperature.  |
|                      | • Changes in temperature are directly proportional to changes in energy.  |

| **Container**        | • The container is made up of particles that have unique composition that determines how they interact with the environment.  |
| Energy transfers from particles with high kinetic energy to particles with lower kinetic energy through collisions. | • Conduction is the mechanism by which energy is transferred when two objects are in contact.  |
|                      | • Thermal conductivity is the transfer of kinetic energy through conduction.  |
|                      | • Thermal conductivity is a unique property of matter.  |
|                      | • The atomic mass and structure of a substance affect its ability to transfer energy between adjoining atoms.  |
|                      | • Substances that transfer heat energy quickly are called conductors.  |
|                      | • Substances that transfer heat energy slowly are called insulators.  |
### APPENDIX G

**STUDENT ACTIVITY FOR CONTROL AND TREATMENT GROUPS**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Experimental Group Activity</th>
<th>Control Group Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretests</td>
<td>• Students provide biographical data (race gender, SES)</td>
<td>• Students provide biographical data (race gender, SES)</td>
</tr>
<tr>
<td></td>
<td>• Students take pretests (CCI) and PISA Problem Solving</td>
<td>• Students take pretests (CCI) and PISA Problem Solving</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Design</td>
<td>• Students assigned to watch videos: “Engineering Design Process” and “Bombing Hitler’s Dams”.</td>
<td>• Students watched the “Bombing Hitler’s Dams” video and had to write an essay about the role of science in ending WWII.</td>
</tr>
<tr>
<td></td>
<td>• Class discussion to relate the two videos in terms of the design process.</td>
<td>• No viewing of “Engineering design process” video</td>
</tr>
<tr>
<td></td>
<td>• Students completed worksheet enabling them to think about how the engineering design process was applied by investigators in “Bombing Hitler’s Dam” video.</td>
<td>• No end-of-unit design challenge project</td>
</tr>
<tr>
<td></td>
<td>• End-of-unit design challenge project presented, with options clearly stated on handout</td>
<td></td>
</tr>
<tr>
<td>Conservation of Mass</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Unit Activities</em></td>
<td>Students were provided with materials and required to design an experiment to determine if mass is conserved at the end of a chemical reaction.</td>
<td>Conservation of Mass Students were presented with directions as to how to carry out the same experiment.</td>
</tr>
<tr>
<td>Types of Chemical Reactions</td>
<td>• Students learned about seven types of chemical reactions: Combustion, Synthesis, Single displacement, Double displacement, Decomposition, Neutralization and Redox. (Lecture, worksheets, homework, experiments test)</td>
<td>Types of Chemical Reactions • Students learned about seven types of chemical reactions: Combustion, Synthesis, Single displacement, Double displacement, Decomposition, Neutralization and Redox. (Lecture, worksheets, homework, experiments, test)</td>
</tr>
<tr>
<td></td>
<td>• Students performed experiments involving endothermic and exothermic reactions.</td>
<td>• Students performed experiments involving endothermic and exothermic reactions.</td>
</tr>
<tr>
<td></td>
<td>• Students designed a prototype gas-powered rocket propelled by igniting a mixture of hydrogen and oxygen gases in a plastic tube (rocket).</td>
<td>• No gas-powered experiments</td>
</tr>
<tr>
<td></td>
<td>• Students required to design an experiment to determine the best solvent for paints (from double displacement reactions).</td>
<td>• Students provided instructions on how to determine the best of three solvents for paint.</td>
</tr>
<tr>
<td></td>
<td>• Students practiced how to write different types of chemical equations.</td>
<td>• Students practiced how to write different types of chemical equations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Students prepare wet cells and investigate factors that determine optimum voltage</td>
</tr>
<tr>
<td><strong>Stoichiometry</strong></td>
<td>Students practice balancing of chemical equations</td>
<td>No mini project</td>
</tr>
<tr>
<td>---</td>
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</tr>
<tr>
<td></td>
<td>Students practice solving stoichiometric problems.</td>
<td>Students perform electroplating experiment (No applications research).</td>
</tr>
<tr>
<td></td>
<td><strong>Unit Design Challenge Project</strong></td>
<td><strong>Posttests</strong></td>
</tr>
<tr>
<td>Students design solutions to problems: options include a) using heat energy change from chemical reactions to solve problems at a winter camp, summer camp, dating, sports, etc. b) design an age-appropriate toy that uses chemistry concepts learned in this unit.</td>
<td>CCI</td>
<td>CCI</td>
</tr>
<tr>
<td>“Connecting with an idea” and Design Cycle activity</td>
<td>PISA Problem Solving Competency test</td>
<td>PISA Problem Solving Competency test</td>
</tr>
<tr>
<td>Designs to be presented to classmates as a board of a company looking for ideas to invest in.</td>
<td>Design challenge open-ended survey (Appendix H)</td>
<td></td>
</tr>
</tbody>
</table>

*Unit on atomic structure and chemical bonding was completed before above unit.*
APPENDIX H

SITE PRINCIPAL APPROVAL

Principal Consent Form

I. Research Background (to be completed by researcher)

Title of the Study: Effects of Design-Based Chemistry Instruction on the Science Problem-solving Skills and Science Achievement among Different Groups of High-School Students

Name of Researcher: Cohina Anu Larson
Phone: (720) 690-3271

Street address: 3812 S. Ceylon Way, City: Aurora, State: CO, Zip: 80013
E-mail: cлярсон@yahło.co.uk

II. Description of Research Proposal

A group of students will be exposed to design-based Chemistry instruction (units culminate in a 2D or 3D artifact). Pretests and posttests will be administered to measure problem solving competency and science achievement. The purpose of the research is to investigate the effects of design-based Chemistry instruction on problem solving competency and science achievement across gender, race/ethnicity and socio-economic status. A control group will be used. However, if the treatment is found to produce significantly higher student achievement and better problem solving competency, the control group will also be given the treatment. The research questions of the study are: a) Is Design Based Instruction in high school chemistry associated with higher performance on measures of problem solving and chemistry concepts? b) Are the effects of design based instruction, if they exist, consistent for students of different gender, ethnicity, and SES? Chemistry content to be taught is the DPS approved curriculum for Active Chemistry.

(Researcher is to provide the principal with a copy of the executive summary and the time requirement form)

III. Agreement (to be completed by principal)

I, , principal of George Washington high school, understand

- the study and what it requires of the staff, students, and/or parents in my school,
- that the privacy and confidentiality of any staff or student will be protected,
- that I have the right to allow or reject this research study to take place at my school,
- that I have the right to terminate the research study at any time,
- that I have the right to review all consent forms and research documents at any time during the study and up to three years after the completion of the study.

☐ I grant permission to the researcher to conduct the above named research in my school as described in the proposal.
☐ I DO NOT grant permission to the researcher to conduct the above named research in my school as described in the proposal.
☐ I understand that data should be released only by the departments that own them. My staff and I shall not release data to the researcher without approval from the district’s Research Review Board.

Signature of Principal
APPENDIX I

DISTRICT APPROVAL LETTER

DENVER PUBLIC SCHOOLS
900 Grant Street, Rm 610, Denver, CO  80203

September 13, 2012

Your research project, Effects of design-based chemistry instruction on the science problem-solving skills and science achievement among different groups of high school students, has been reviewed and approved by the Denver Public Schools IRB for implementation based upon the following conditions:

1. The voluntary nature of the study is made clear to all potential participants including pupils, teachers, and administrators. Final approval for the study is contingent on the principals, students, and parents’ agreement to participate.

2. The researchers agree to maintain the anonymity of the research participants as outlined in your proposal.

3. All rules in the district's research procedures are followed including maintaining the anonymity of the district, the schools, and the study participants.

4. If your request involves the release of data you agree to limit the use of said data to the terms specified in your application. The data will not be released to any third party and you agree not to copy, reproduce, disseminate transmit, license, sublicense, assign, lease, or release the data to any other party. All data should be maintained in a secure fashion with access being restricted to the persons identified in the research application to prevent unauthorized use of the data. Following the use of the data for the prescribed reasons the data should be destroyed.

5. This letter does not reflect a commitment on behalf of Denver Public Schools towards the requestor. At any point, the approval status involving the release of data or access to students/staff for research may be withdrawn. A violation of any of the conditions within this letter and/or deceptive practices by the researcher will lead to immediate termination of all research privileges. Furthermore, the release of future data and/or research privileges may be indefinitely terminated.

6. A report of the findings is made available to the Department of Accountability, Research & Evaluation at the conclusion of the study.

7. This letter is returned by mail or via FAX (720-423-3646) prior to initiating your study with the requestor acknowledging agreement with the terms described above by signature.

Please contact Accountability, Research & Evaluation at 720-423-3736 if you have any questions.
Please return this letter with the following statement verified by signature:

I, __ Cobina Adu Lartson __, agree to abide by the conditions described in this document and will carry out my research practices in accordance with those conditions. I assume complete responsibility for the described study and will work according to best-practices when working with Denver Public Schools data and/or conducting scientific inquiry within the Denver Public Schools district.

__________________________
Signature of Requestor
APPENDIX J

PARENT CONSENT LETTER


Parent Consent

Dissertation Research Title: Effects of Design-Based Chemistry Instruction on the Science Problem-solving Skills and Science Achievement among Different Groups of High-School Students

Principal Investigator: Cobina Adu Larson, Sch. of Ed. & Human Development. Univ. of Colorado Denver.

You are being asked to participate in a program where data will be collected for the purposes of research investigating the effect of a classroom instruction on student achievement and problem-solving competency.

Benefits/Why is this study being done?

This program is being done to help the researchers learn how to increase the number of African Americans and Latinos in science, technology, engineering and mathematics careers. Results from the program may improve how teachers enable African American and Latino children to take harder courses in science and mathematics in high school. You may benefit from this research because of the positive effect it may have on your future. If the treatment is found to significantly improve problem solving skills, the researcher will ensure that students in control group obtain the benefits of the treatment in the same or subsequent units.

The learning objectives of the research are as follow: To

• Increase students’ Chemistry content knowledge.
• Improve student problem-solving skills; decision-making, critical thinking and troubleshooting skills.
• Increase participant interest in taking science courses and having a STEM career.
• Encourage students to use science to meet needs in their communities.

What happens if you join this study? In order to achieve the above goals, we will hold a ten-week energy change unit for high school students (ages 12-18) during which students design a product intended to solve a specific problem. Another group of students will study the same content without a design component. Before and after taking the unit, we will measure student achievement and problem solving competency by using pre and posttests. The hours you put in towards the study is the same as regular class hours. You will be eligible for a credit towards paying for your tie-dye classroom project. You will respond to socioeconomic status, and demographical surveys.

Is participation voluntary? At any time you may decide not to stay in the study. Your decision will not affect your relationship with the researcher. You will not be punished in any way if you decide to leave the study, however you must compete the science content for the study since it is the district approved curriculum that is being used.

What are the possible discomforts or risks? There is minimal risk and very slight discomfort to children who join in this study. Discomforts you may experience while in this study include being asked to complete a test and survey and perform a class presentation.

Will your personal information be released to anyone by the researcher? □ Yes □ No

Regulatory organizations that ensure researcher compliance with laws that protect human subjects may see all information related to this research. All the information about you, including pre and posttests will be kept in a safe place: infinite campus/password-protected classroom computer. In this way, the risk of others finding out about your test scores and survey results is reduced to the barest minimum. All data and information collected will be destroyed within two years of completing the study.

Who is paying for this study? This research is being conducted as a requirement for a Ph.D. through the University of Colorado Denver as an extremely low-budget student research study and at no cost to you.

Who do I call if I have questions? Parents, please be aware that under the Protection of Paper Rights Act, you have the right to review a copy of the questions asked of or materials that will be used with your students. If you would like to do so, please call the Principal Investigator, Mr. Cobina A. Larson (720.690.3271 or clarton@yahoo.co.uk) or study supervisor, Dr. Geeta Verma at Geeta Verma@ucdenver.edu. You may also call the Human Subject Research Committee (HSRC) at 303.724.1055.

Agreement to participate in this study

□ I agree to my child’s participate in this research. □ I do not agree to my child’s participate in this research.

Student name: ____________________________________________ Date: ____________________

Parent Signature: ____________________________________________ Date: ______________
APPENDIX K

STUDENT CONSENT LETTER

Effects of Design-Based Chemistry Instruction on the Science Problem-solving Skills and Science Achievement among Different Groups of High-School Students  
COMIRB protocol number: 12-1150  
PI: Cobina Larson  09/28/2012

Student Consent

Dissertation Research Title: Effects of Design-Based Chemistry Instruction on the Science Problem-solving Skills and Science Achievement among Different Groups of High-School Students

Principal Investigator: Cobina A. Larson, Sch. of Ed. & Human Development, Univ. of Colorado Denver

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Is participation voluntary? At any time you may decide not to stay in the study. Your decision will not affect your relationship with the researcher. You will not be punished in any way if you decide to leave the study, however you must complete the science content for the study since it is the district approved curriculum that is being used.

What are the possible discomforts or risks? There is minimal risk and very slight discomfort to children who join in this study. Discomforts you may experience while in this study include being asked to complete a test and survey and perform a class presentation.

Will your personal information be released to anyone by the researcher?  
☐ Yes  ☑ No

Regulatory organizations that ensure researcher compliance with laws that protect human subjects may see all information related to this research. All the information about you, including pre and posttests will be kept in a safe place: infinite campus/password-protected classroom computer. In this way, the risk of others finding out about your test scores and survey results is reduced to the barest minimum. All data and information collected will be destroyed within two years of completing the study.

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Agreement to participate in this study

☐ I agree to participate in this research.  ☐ I do not agree to participate in this research.

Student name: __________________________  Date: __________________________

Signature: __________________________