How Do Secondary Science Teachers Understand and Implement Technological Design in Their Classrooms?

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LOYOLA UNIVERSITY CHICAGO

HOW DO SECONDARY SCIENCE TEACHERS
UNDERSTAND AND IMPLEMENT
TECHNOLOGICAL DESIGN IN THEIR CLASSROOMS?

A DISSERTATION SUBMITTED TO
THE FACULTY OF THE GRADUATE SCHOOL
IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

PROGRAM IN RESEARCH METHODOLOGY

BY
KATHRYN H. HEROUX

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ABSTRACT

This qualitative, phenomenological study examined how ten secondary science teachers from a variety of different schools around the country understand and implement technological design in their classrooms. The results of this study indicate that these teachers were drawn to the tenets of technological design because of its inherent challenge to their own pedagogical strategies, and its ability to stimulate and motivate their students. The future of science education with respect to technological design is examined, and compared with the standards that will emerge in the new science standards soon to be finalized and circulated.
CHAPTER ONE

BACKGROUND TO THE STUDY

Introduction

The objective of research into effective science education is to help those involved better meet the needs of students. All levels of involvement, including policymakers, professional development providers, school districts, science departments, and classroom teachers have a stake in increasing their understanding of what constitutes effective science education. This study provides a glimpse into effective science education at the interface of the secondary science classroom, from the perspective of teachers who are engaged in a teaching strategy known as technological design. This in-depth qualitative study focuses on a small sample of ten teachers from a variety of types of schools and school communities. These teachers constitute a knowledge community (Craig, 1995; Seaman, 2008) that has, each summer for at least three years, attended a professional development workshop to learn about and practice technological design teaching strategies. Each teacher has successfully incorporated technological design into his/her secondary science classroom, and found it to be a valuable strategy for increasing student motivation. Motivating students to want to learn science is a key objective of effective science education. Better understandings of how successful teachers understand and implement technological design can help all those involved provide more effective science education.
This research required a qualitative approach to ensure that the richly textured meaning of the lived experiences of the teachers who took part in the project could be gathered and analyzed. We felt that quantitative analysis could not capture the essence or make meaning of the complex relationships, interactions, and expectations that are the hallmark of teaching. Data based on teacher understanding and methods of implementation of technological design strategies used in the classroom were collected through semi-structured interviews and analyzed using phenomenological techniques. Ethnographic techniques were used to analyze classroom observations.

What constitutes effective science education has been a question that educators at all levels have discussed and made policy decisions about for over a century. The roles of scientific content and processes, and the evolution of technological design as an integrative link between them, have been at the center of debates over effective science education in American secondary schools. Chapter One will discuss the basis of those debates and then recount a brief history of how they played out from the Progressive period, through the aftermath of *A Nation at Risk* report, to the present. It will then examine the gap between the theory of technological design and its application in classroom practice.

**Debates over Science Education**

These debates have traditionally focused on a perceived dichotomy between content and process. On one hand, effective science education is understood as successful teacher transmission of knowledge products, that is, established scientific principles and theories, and the resulting absorption of that content by students. “Science is a collection of knowledge products (i.e., laws and theories), and a set of practices (i.e.,
observation, experimentation, argument)” (Abell & McDonald, 2004, p 249). This focus on the content of science has traditionally been advocated by professional and academic scientists (Bestor, 1953; Rickover, 1959; Physical Science Study Committee (PSSC), 1960).

On the other hand, effective science education is perceived as the successful construction of scientific principles and theories by students engaged in the process of solving problems facilitated by teachers. This focus on process has traditionally been advocated by pedagogical experts (Bruner, 1961, 1963; Rutherford, 1964; Schwab, 1962; Shulman, 1986).

At varying times in educational history each of these perspectives has dominated the public perception of effective science education. The following section discusses three pivot points where these perspectives shifted: 1) the introduction of progressive education, 2) the implementation of the National Defense Education Act (NDEA) (Public Law 85-864), and 3) the publication of the report, A Nation at Risk: The Imperative for Educational Reform (NCEE, 1983). It concludes with the publication of the National Science Education Standards (NSES) (NRC, 1996). This latter document attempts to integrate the dichotomy perceived to exist between content and process through the practical activity of technological design (AAAS 1990, 1993; NCEE, 1983; NRC, 1996; NSTA, 1982).

Science Education during the Progressive Period (1876 – 1957)

At the beginning of the twentieth century, science, as a specific and distinct discipline in secondary education, did not exist (Rudolph, 2005). Therefore, the first pivot point in this evolution was the creation of science as a subject with a distinct
Important scientific and technological developments at the turn of the twentieth century, coupled with political, economic, and social changes caused by immigration, industrialization, and urbanization elicited calls for the inclusion of science in the school curriculum (Kliebard, 2004). Leading scientists of the day argued for science curricula based heavily on content and inductive reasoning (DeBoer, 2000).

In *The Child and the Curriculum*, John Dewey (1902) recognized the conflicting elements of this debate over content versus process in regard to effective science education. He cautioned that to focus on “the realm of facts and laws” while ignoring the “world of persons and their personal interests” (p 9) is to establish a false dichotomy that leaves science teachers and the curriculum “forever oscillating between extremes” (Dewey, 1901, p 346). To counteract this possibility, Dewey advocates teaching the subject as “applied science” (Dewey, 1902, p 23). Applied science, for Dewey, is relevant and practical and an “indispensable instrument of free and active participation in modern social life” (p 23).

A contemporary of Dewey, William Heard Kilpatrick, translated Dewey’s integrative theory into instructional practice by re-dividing content and process. Kilpatrick proposed what came to be known as the "Project Method". This approach advocated a science education that provided students with "purposeful activity in a social environment" (Kilpatrick, 1918, p 320) and was widely accepted as the basis of a scientific curriculum (Kliebard, 2004). The project method was considered a logical and psychologically appropriate approach to stimulate the intellectual development of the child (Kilpatrick, 1918). Student-driven interest in natural phenomena and problem
solving, at the expense of content knowledge, lay at the heart of this curriculum which dominated the first half of the twentieth century (Atkin & Black, 2003; Kliebard, 2004).

Science Education in the Aftermath of Sputnik (1957 – 1983)

The second pivot point in the evolution of science education occurred in 1957 after the launch of the Soviet satellite Sputnik rocked the foundations of the American scientific community. This event shifted the ongoing debate over content and process strongly toward content. During the late Progressive period before Sputnik’s launch, science academics and professionals had agitated for the reform of American science education (Kliebard, 2004; Harris & Miller, 2005). They decried contemporary science education as "soft" and lacking intellectual rigor (DeBoer, 2000). Arthur Bestor (1953) in *Educational Wastelands: The Retreat from Learning in Our Public Schools* launched a bitter attack on American education, particularly the lack of scientific content knowledge among classroom teachers. The advent of Sputnik brought all of these earlier allegations into the public eye and triggered a flurry of political responses (Matthews, 1994), but the most representative of these responses was the passing of the *NDEA* by the 85th Congress in 1958 (Public Law 85-864).

The National Defense Education Act of 1957

*NDEA* was an “educational emergency bill” that shifted the focus of science education to acquisition of content knowledge in science and the related fields of mathematics, foreign language, and technology (Harris & Miller, 2005, p 158). It designated $700 million for the years 1958 to 1975 to secure “the fullest development of the mental resources and technical skills of [America’s] young men and women” (*NDEA*, 1958, ES-1).
NDEA signaled the end of the Progressive period’s emphasis on scientific process rather than content (DeBoer, 1991; Kliebard, 2004, p 227). Through NDEA funding the National Science Foundation (NSF) and its corps of academic and professional scientists took control of science curricula and instruction. They re-defined effective science education in terms of specialized and specific content, parsing science into discrete courses of study such as biology, chemistry, physics, and earth science (Matthews, 1994; Raizen, 1991). To support this emphasis on content, the NDEA funded the creation of written and well detailed laboratory procedures and processes for each branch of science. These supplemental curricular materials verified existing scientific content knowledge through step-by-step laboratory instructions, or what became known as “cookbook” labs (Charen, 1970).

While development of these laboratories seemed to address the dichotomy of content and process, in practice, these cookbook labs entrenched content as the focus of effective science education. Under the Progressives, science education had focused on student driven interest in natural phenomena and problem solving at the expense of content knowledge. Under NDEA, science education now focused on content knowledge to the exclusion of student interest and problem solving (Matthews, 1994; Kliebard, 2004).

Science Education in the Aftermath of A Nation at Risk (1983-1989)

The third pivot point in science education occurred in 1983 when the National Commission on Excellence in Education (NCEE) published A Nation at Risk: The Imperative for Educational Reform (NCEE, 1983). This report shifted the emphasis of the scientific education community from pure content toward an integration of content
within process. Examining statistics from the College Board’s Scholastic Aptitude Test (SAT), and other sources, from 1963 to 1980, it concluded that there had been a “virtually unbroken decline” in scientific and mathematical content knowledge of high school graduates (NCEE, 1983, p 11). The conclusion was that "a rising tide of mediocrity" threatened "our very future as a Nation and as a people"(NCEE, 1983, p 9).

While this seemed to signal increased emphasis on content, it introduced a new concept of scientific literacy which suggested a growing return to the integrative ideas of Dewey. The panel of authors, chaired by David Gardner, of A Nation at Risk, and of the twenty bills put before Congress in 1983 following its publication (Darling-Hammond, 1997; Matthews, 1994), recommended that curriculum development and science instruction should ensure "scientific and technology (sic) literacy for all" (Matthews, 1994, p 29). In the definition of scientific and technological literacy, these measures again attempted to dissolve the dichotomy between scientific content and process. To this end, they defined scientific literacy broadly as knowledge and skills regarding the concepts and processes of science, the methods of scientific inquiry, the applications of scientific knowledge to everyday life, and the social and environmental implications of scientific and technological development (NCEE, 1983, p 25).

From Scientific Literacy to the National Science Education Standards and Technological Design (1989 to present)

This re-definition of effective science education (in terms that re-integrated scientific content and process) gained momentum in this period. It was driven by the call for increasing clarification about the meaning of scientific literacy from professional, political, and educational groups. The American Association for the Advancement of
Science (AAAS), a group of professional and academic scientists, was the first to take up this issue through its major curriculum project known as Project 2061. In 1989 AAAS published *Project 2061: Science for all Americans*, which called for science content knowledge and practical skills to be integrated with personal, social, and technological perspectives previously relegated into separately taught content areas of science.

Subsequent AAAS publications sought to translate the abstractions of Project 2061 into practical indicators of student achievement; of particular relevance was the publication *Science for All Americans: Benchmarks for Scientific Literacy* (AAAS, 1993).

These *Benchmarks* were then picked up by the National Research Council (NRC) (Raizen, 1998) and published as the Content Standards for *NSES* in 1996. These standards have provided a "common vision" (Raizen, 1998, p 69) of science curricular innovation that continues to drive science education. The original AAAS *Benchmarks* had categorized two areas: that of science and that of technology and design as discrete foci. The *NSES* standards merged these two areas into one – Science and Technology. The pairing of science and technology in this standard elevated and integrated the role of technology and design within the realm of science and coined the phrase “technological design”. And, for the first time, at least in theory, the areas of scientific content and scientific process merged.

This study takes the view that technological design has value as a content standard, and, in fact, has untapped potential to engage and motivate students to want to study and learn science. This study reveals that technological design as a teaching strategy remains viable, and therefore valuable, in its potential to mesh together science content and process. For the purposes of this study, technological design is defined as a
practical activity, wherein students draw upon their own personal background knowledge, science content knowledge, and process skills to address a real world problem (Bybee, 1998; Roth, 1995; Rutherford & Ahlgren, 1990). Technological design requires that students work together in teams or groups to design and build an artifact or a process that could be used to solve a real world problem.

**Statement of the Problem**

While these professional organizations have laid out and defined technological design (AAAS 1990, 1993; NCEE, 1983; NRC, 1996; NSTA, 1982), and scholars have called for its implementation (Bybee, 1993; Haury, 2002; Lewis, 2006; Roth, 1995, 2001; Kohn, 2000; Atkin & Black, 2003), little research has been done on how this idea translates to classroom practice, or even on how teachers understand this newly minted concept. Additionally, there are few developed curricular resources to support this approach to effective science education. One notable exception is Northwestern University’s Materials World Modules (MWM), which has been available since 1993. MWM is a series of modules designed to integrate science content within the processes of scientific inquiry, history, and technological design. Researchers have looked comprehensively at the classroom implementation of MWM and its approach to scientific inquiry, but they have not focused specifically on how teachers understand and use the concept of technological design in their classroom practice. Baumgartner's (2000) ethnographic study of three high school teachers examined the use of MWM as a tool of inquiry, and Pellegrini's (2008) evaluation of MWM focused on student gains in learning. From earlier research we know that teachers’ understanding of important concepts
influences their work and their interactions with their students (Atkin & Black, 2003; Cohen, 1988; Cuban, 1993; NRC, 2001; Shulman, 1986; Tobin, 1990).

If the NSES objective of producing scientifically literate citizens is to be realized, it is imperative that research into teacher practice and pedagogy be conducted (Driver, 1986; Lemke et al, 1999; Lemke & Sabelli, 2008; Sunal & Wright, 2006). This study aims to provide empirical evidence of classroom interactions between teachers and their students as they experience technological design in their high school science classrooms. It is essential that representative examples of teaching practices and developments of new strategies and methods used to meet the requirements of NSES be examined and analyzed to ensure we move toward realizing a scientifically literate population (Bybee, 1995, 1998). Unfortunately, to date, science education continues to be characterized by an “emphasis on facts” with “science content devoid of context” rather than, as Bybee propounds, “content about scientific inquiry, technology as it relates to science, science as it connects to personal and social perspectives, and the history and nature of science" (Bybee, 2003, p 348). It is hoped that this research study will inform science teachers, curriculum designers, and professional development providers about a knowledge community of teacher practitioners who have successfully integrated technological design into their traditional science curricula.

This dissertation describes and analyzes the data from the teachers’ point of view, and reveals that a two-tiered complexity is inherent in each of the participating teachers’ perspectives. On the surface, the data reflects the teachers’ beliefs and behaviors in regard to their understandings and philosophies about teaching science, teaching technological design based strategies, and teaching students. Closer scrutiny of the
narratives, however, reveals the existence of a commonly held and deeply rooted commitment to motivating and engaging their students in a lifelong passion for science and science learning.

**Research Question**

To address this gap in the knowledge of the theory and practice of technological design, this dissertation will explore the following question: How do secondary science teachers understand and implement technological design in their classrooms?

**Disclaimer**

Given that this is a qualitative study based on data gathered and analyzed in the tradition of phenomenological research, the evidence presented in this dissertation provides examples of how ten teachers approached the task of teaching technological design. The lived experiences of these teachers may prove helpful to other teachers in the future. This study does not make an argument regarding the impact on students, as a result of integrating technological design into the classroom.
CHAPTER TWO

LITERATURE

Introduction

This study explores teachers’ understandings and use of technological design in secondary science classrooms. The following three concepts regarding science and its relationship to technological design and science education underpin this study: (1) science is a dynamic field of knowledge that integrates content into scientific process through observation and experimentation about how the physical world works; (2) effective science education builds on the dynamic, collaborative, interdisciplinary, and empirical nature of science, (integrating scientific content and process through active and authentic problem solving about how the physical world works), and; (3) science teachers’ beliefs about science and the nature of science, as well as their knowledge and understandings of scientific content and process, influence their classroom practice.

Science as a Field of Knowledge

The primary aspects of science are thus that it is dynamic, collaborative, interdisciplinary, and empirically based. Scientific content – accepted scientific principles – interacts with process, or ways of conducting research. This integration arises from a need to better understand how the physical world works and occurs naturally through technological design, defined as a practical activity, where students draw upon their own
personal background knowledge, science content knowledge, and process skills to address a real world problem. Technological design requires that students work together in teams or groups to design and build an artifact or a process that could be used to solve a real world problem (Bybee, 1998; Roth, 1995; Rutherford & Ahlgren, 1990). This integration is driven by human creativity and makes science a dynamic but tentative field of study (Bybee, 1998; Dewey, 1901, 1902, 1910a, 1910b, 1916; McComas, 1998).

The Dynamic Aspect of Science

Science modifies and changes ideas and principles over time as new evidence is gathered, tested, and eventually accepted by the scientific community (Chalmers, 1999; Kuhn, 1972). Ideally, scientists around the world accept common fundamental beliefs about the physical world that transcend cultural or physical differences. Scientific ideas are expected to change and be modified over time in response to problems as new evidence and new technologies are generated and eventually accepted by the scientific community (McComas, 1998; Lederman & Niess, 1997).

The Collaborative Aspect of Science

Science involves collaboration among individuals around a problem concerning how the physical world works (Galison, 1997, 2008; Kuhn, 1996). Each individual brings varying levels and areas of expertise to a problem in order to develop new knowledge about how the physical world works (Galison, 1997, 2008). While areas of expertise may vary, scientists collaborate within a discipline and use similar types of technologies, equipment, concepts, and theoretical models (Kuhn, 1996; Roth, 1992). Scientific enterprise is ideally unaffected by disciplinary and political boundaries in its
attempt to design technologies to solve regional and global problems faced by human society.

The Interdisciplinary Aspect of Science

Science involves integration of a “panoply of subcultures” (Galison, 1997, p 1150) that make up this field of knowledge. In this interdisciplinary aspect of science, physics, chemistry, biology, environmental, and earth sciences "evolve, overlap and intermingle" (AAAS, 2001, p 86). However, there is no hierarchy among these specializations (Galison, 1997). Instead, science represents a "consilience" of knowledge (Wilson, 1998, p 8) that links “facts and fact based theory across disciplines to create a common groundwork of explanation” (p 8). This groundwork includes the history, philosophy, and sociology of these specializations (Benenson, 2001; Bybee, 1998; Galison, 1997, 2008; Gardner, 1994; Lewis, 2006; McComas, 1998). These disciplinary areas intersect within technological design.

The Empirical Aspect of Science

Science depends on a process of collecting and analyzing empirical data through reproducible experiments that are based on established scientific paradigms within which the community works (Chalmers, 1999; Kuhn, 1996). Paradigms set the boundaries of the various fields within science. These boundaries shape the integration of content into process. They determine the types of questions that can be formulated, the avenues of inquiry that can be followed, and the methods that can be used to collect the empirical evidence (Kuhn, 1996).

Technological design merges content and process and human creativity within scientific paradigms in order to solve real world problems. The boundaries provided by
the paradigm are essential to scientific inquiry because "no natural history can be interpreted in the absence of at least some implicit body of intertwined theoretical and methodological belief that permits selection, evaluation, and criticism" (Kuhn, 1996, pp 16-17).

**Effective Science Education**

Effective science education aims to teach science, that is, the dynamic field of knowledge about how the physical world works. It thus reflects the dynamic, collaborative, interdisciplinary, and empirical aspects of science. As such, it teaches young people to (1) work like scientists; (2) know and understand scientific concepts and principles that comprise the subject specific paradigms, and; (3) integrate content into appropriate process around a real world problem through technological design.

**Working like Scientists**

Working like scientists means that students engage in a process of questioning how the physical world works. To address these questions, they apply their existing knowledge of scientific content and processes, inquiry and reasoning skills, and understanding of shared values from various disciplines (AAAS, 1990; Bybee, 2002). Working as part of a collaborative team, students, like scientists, solve problems by gathering and analyzing empirical evidence through processes practiced in laboratory, or hands-on work (DeBoer, 1991). This kind of work focuses on development and application of a solution to the recognized problem that will include technological design.

**Subject Specific Paradigms**

Scientific knowledge is interdisciplinary, yet organized and systematic (AAAS, 1990; Bybee, 2002; Bruner, 1963). Each specialized area of science investigates its own
major ideas comprising the content, the coherence, and the rigor of the discipline (AAAS, 1990). Science education reflects the real world of science through its subject specific curricular divisions. It has the potential to provide an increased understanding of the interdisciplinary nature of science and its scientific content and processes, inquiry and reasoning skills, and understanding of shared values from various disciplines by including technological design based problems (NRC, 1996).

Integrating Content into Appropriate Process

The empirical aspects of effective science education are represented by students' understandings of ways to investigate questions about how the physical world works in ways that are similar to the ways scientists gather accurate data (AAAS, 1990). Students, like scientists, find answers to their questions by designing experiments that allow them to gather empirical evidence. In designing and conducting experiments, students merge existing content knowledge with skills and knowledge of the processes of science to collect data, analyze results, and make suggestions for future work. The role of human creative thought (Karakas, 2009) and value judgments (AAAS, 1990) in the development of scientific explanations is expressed through technological design (NRC, 1996).

Technological Design in Science Education

Bybee (1998) identified science as "originating with questions about the natural world," whereas technological design "originates with problems of human adaptation to the environment" (p 40), and is "driven by the need to meet human needs and solve human problems" (NRC, 1996, p. 192). Technological design, as a learning strategy in classrooms, provides a naturalistic approach to learning (Roth, 2001) because it places students within the context of the problem, and requires that they draw upon interpersonal
skills and personal experiences, combined with knowledge of science content and processes (Roth, 1996b; Roth, 2001). This engenders inquiry and student-centered learning because new questions inevitably arise that teachers may not have previously encountered (Roth, 1996b). Design activities, by their nature, require students to think in the realm of concrete reality. Atkin (1996) notes that students can gain insight into their social responsibility because "schools tend to stress thinking directed toward scientific understanding rather than toward justifiable action" (p 5) because “technology, unlike science, is an enterprise directed almost exclusively toward altering the human condition, and it necessarily involves considerations of worth as well as the utilization of knowledge” (p 6). The student who engages in design must make considered decisions about the design he or she has created (Atkin, 1996). This form of active learning can not be taught as easily in any other way in the classroom, and is a direct reflection of how humans learn in real life (Bybee, 1998; Kolodner, 2003).

**Effective Science Teachers**

Science teachers' beliefs about their role in the classroom and about the nature of science can be distinguished from their subject specific knowledge and understanding of science (Pejares, 1992). Beliefs are drawn from experience or from one's culture, and affect the comprehension of subsequent events in one's life (Nespor, 1987). Beliefs affect perception, judgment, and behavior; they can be "deeply personal, rather than universal, and unaffected by persuasion" (Pejares, 1992, p 309). Teachers' knowledge can be different from their feelings and beliefs about a subject, a student, or about themselves.
Teachers' Beliefs

Understanding the belief structure of teachers is necessary to understand the effectiveness of their professional practice (Fenstermacher, 1979; Hodson, 1988; McComas, 1998; Pintrich, 1990). Beliefs can influence an individual's view of the world and can serve as the means by which they define tasks and choose the "cognitive tools with which to interpret, plan, and make decisions" (Pejares, 1992, p 325) regarding such tasks. One's self-efficacy beliefs or sense of competence are considered by Bandura (1986) to be the "strongest predictors of human motivation and behavior" (Pejares, 1992, p 329). Beliefs about teaching are established early, and underpin how a teacher decides on the most effective way to organize knowledge and information for students (Abelson, 1979; Bandura, 1986; Lewis, 1990; Nespor, 1987; Nisbett & Ross; 1980; Posner et al., 1982; Rokeach, 1968; Schommer, 1990).

Teachers' Knowledge and Understandings

Effective teaching requires more than a teacher knowing the facts and specific content of a subject. A teacher must also understand how the subject is organized and structured, and what is legitimate to do and say in a field (Shulman, 1986). Teachers must know and understand the structure of the curriculum and what, how, and when to use the resources available to them (p 10). Teachers must also be familiar with curricular work in which students are engaged in other subjects, as well as the curriculum in their own subject area from the preceding years and continuing into the subsequent years (Ball et al., 2008). These Shulman (1986) termed the "lateral and vertical curriculum" (p 10).
Pedagogical Content Knowledge

Pedagogical content knowledge is a theoretical construct developed by Shulman (1986) and his colleagues who proposed that teachers possess a unique type of knowledge that "bridges content knowledge and the practice of teaching" (Ball et al., 2008). Shulman (1986) described the theoretical construct known as pedagogical content knowledge as the "most useful ways of representing and formulating the subject that make it comprehensible to others" (p 9).

Teacher as Facilitator

In technological design and problem solving lessons the teacher's role requires a different set of skills from those required by the traditional teacher, and is based on the teacher becoming a "facilitator" of dialogic interactions (Johnson & Johnson, 1994; Shor, 1989; Shor & Freier, 1987). A facilitator asks questions and engages in a dialogue with students. A facilitator uses initiative and skill to quickly adapt classroom situations that support divergent student thinking and reasoning, and to scaffold learning for individual students (Vygotsky, 1978). Teachers who adopt a facilitative role in the classroom engender a collaborative climate that can empower students through the verbal interactions between teacher and students (Cazden, 2001; Gillies & Boyle, 2008; vanZee & Minstrell, 1997, 1998).
CHAPTER THREE

METHODOLOGY

Statement of the Problem

The concept of technological design is defined as a practical activity wherein students draw upon their own personal background knowledge, science content knowledge, and process skills to address a real world problem (Bybee, 1998; Roth, 1995; Rutherford & Ahlgren, 1990). Technological design requires that students work together in teams or groups to design and build an artifact or a process that could be used to solve a real world problem, and it has been in evidence in various forms throughout the historical discussions of what constitutes effective science education (AAAS 1990, 1993; NCEE, 1983; NRC, 1996; NSTA, 1982). The NSES (NRC, 1996) created the term “technological design”, and professional organizations (NSTA, 1992, 1998) have called for its inclusion in science curricula as an equal partner to the six other content standards. Despite the presence of the concept of technological design in NSES, in educational publications, and in science curricula documents, it has remained little studied in terms of its actual implementation in science classrooms (Bybee, 1993; Haury, 2002; Lewis, 2006; Roth, 1995; Kohn, 2000; Atkin & Black, 2003). Classroom implementation strategies depend upon theoretical, methodological, and pedagogical beliefs held by the teacher. This study addresses the question of how teachers understand and subsequently implement technological design in their secondary science classrooms.
Overview of the Study Methodology

This dissertation addresses the research question through a phenomenological study based on teacher interviews. As a qualitative study, it uses the ethnographic technique of observation to provide data to support rich and textured understandings of teacher beliefs and practices (Geertz, 1973). This approach was selected because phenomenology enables researchers to get at the essence of meaning as experienced by the study participants (Creswell, 1998, 2003; Kvale & Brinkman, 2009; Merleau-Ponty, 1962; Merriam, 1998; Moustakas, 1994). Phenomenology focuses on careful descriptions and analyses of consciousness to understand lived experience of participants. Because this study is focused on how teachers understand and implement technological design in secondary science classrooms, the phenomenological approach allows the researcher to learn how the teacher participants understand and experience the phenomenon of technological design in their work.

Further, phenomenology provides a framework that allows the researcher to create a rich, textured picture of the phenomenon of technological design, by focusing on description of the phenomenon from the perspectives of those who are living the experience (Kvale & Brinkman, 2009; Geertz, 1973). A series of interviews generated qualitative data on teachers’ understandings and experience of technological design. Ethnographic observation of classroom practice generated complementary data that enabled “thick description” (Geertz, 1973, p 3) of those understandings and experiences.

The phenomenological approach was also appropriate because it built on the researcher’s first hand knowledge of the phenomenon being studied (Creswell, 1998, 2003; Merriam, 1998; Moustakas, 1994), that is, technological design and its use in
secondary science classrooms. The researcher has been involved with MWM since 1996 as a curriculum developer, field tester, workshop instructor, and user of the modules in her classroom practice. She has created a new course at her high school called Materials Science and Design. The course has evolved over the past eleven years from using only MWM modules and associated resources to using a broader interpretation of technological design based challenges. Her multifaceted experiences with teaching technological design and practical investigations into the MWM progressive approach to technological design have given her deep understandings of this phenomenon. The remainder of this chapter will detail sample selection, data collection, and data analysis.

Sample Selection

The sample for this study was drawn, through purposeful sampling, from a group of secondary science teachers who have participated in a series of professional learning programs that emphasize the MWM progressive approach to technological design, and seek to integrate science, technology, engineering, and mathematics (STEM). This program was created in 2006 by the Center for Advancement of STEM Education (CASE), based at Garrett College in McHenry, Maryland. In 2011 CASE became NCASE; the “N” stands for “national”. The CASE, now NCASE, workshops have been funded since 2006 through professional development grants awarded by the United States Department of Defense (DoD). The DoD grants support the NCASE workshops and guarantee the involvement of DoD scientists and engineers with the workshops and with teachers in their schools to help facilitate the integration of STEM initiatives. The grant requires the workshops to be based on the MWM modules and related STEM integration for middle and high school teachers from across the United States. NCASE collaborates
with the DoD, Building Engineering and Science Talent (BEST), National Institute of Aerospace (NIA), Northwestern University, and Tabula Digita. Among the instructional tools that NCASE uses are the MWM modules that were created at Northwestern University and other modules based on the MWM model.

The NCASE workshop that was run in the summer 2010, from which the research for this study was generated, consisted of four week-long modules, each with targeted groups of secondary teachers learning specific modules. These workshops were supported by ongoing professional learning throughout the school year. Participants in this program were drawn from urban, suburban, and rural schools, and ranged from veteran to novice in terms of their teaching experience. As always, professional development conducted during the 2010 program was based on the MWM model, and emphasized development and implementation of practical activities that address scientific content knowledge and scientific process skills in secondary science classrooms.

The sample for this study was drawn from the group of participating teachers who took part in the last or fourth week of the NCASE professional development workshop. This week was selected for data collection because the teachers attending had all attended NCASE workshops in previous years and had been introduced to technological design through the MWM modules. The teachers invited to this fourth week were required to have participated in prior workshops and implemented technological design in their classroom practice. A total of twenty four middle and high school teachers participated in the fourth week workshop and the study sample was drawn from this group. This selection took place in two phases.
Phase 1

In Phase 1 a purposeful sampling of ten teachers was selected to participate in a forty five minute to one hour interview. This interview focused on their understandings and experiences of the MWM progressive approach to technological design. Before the inception of the fourth week workshop NCASE sponsors wrote to the twenty four participating teachers who represented the potential group and notified them that the researcher would be contacting them via email to invite them to participate in the Phase 1 interview during the week long module. The researcher did this, and followed up with a consent form. At the bottom of the consent form, the researcher asked teachers if they would be willing to participate in further interviews and observation of their work with technological design. The researcher followed up these emails with a reminder within one week of the original contact. At the welcoming meeting on the first day of the NCASE workshop, the program sponsors invited those teachers who met the requirements of a minimum of five years teaching experience in secondary science to add their names to a contact list if they were interested in taking part in this research project. Ten teachers responded, and all ten were interviewed during the week the workshop was running at Garrett College.

Phase 2

Phase 2 consisted of a brief pre-observation interview, an observation of classroom practice, and a post-observation interview. Each of the interviews in Phase 2 lasted less than 30 minutes. The teachers were selected based on their consent to be observed, their intent to implement a taught lesson unit based on technological design during the first semester of the 2010-2011 academic year, and the geographic location of
their school. Consent was indicated in the forms obtained in Phase 1, as was information regarding implementation times and geographic location. It was important that the taught lesson unit was to be implemented during the first semester to enable the researcher to collect, transcribe, and analyze the data within the year. The proximity of the school to the researcher was a consideration of convenience sampling. The researcher tried to arrange to visit sites that minimized travel time, since collection of data had to be undertaken during her own school year.

Eight of the ten teachers interviewed in Phase 1 subsequently agreed to be considered for Phase 2 observations. Only four teachers were chosen based on three practical considerations: (1) the diversity of their school’s character and student population; (2) the teachers’ different subject disciplines, and; (3) their locations around the country. The four teachers who were chosen enabled the researcher to obtain ethnographic data from four schools in only three trips away from her own full-time teaching responsibilities. Each of the schools represented a specific population of students, from high achieving suburban to alternative urban to learners of English as a second language (ESL). The classes observed ranged from high school physics and chemistry to middle school environmental science lessons. The diversity of the participants’ teaching responsibilities was deemed to be an important characteristic for choice of whom to observe. Students of all types and levels of ability deserve to experience effective science education. By observing teachers working in such a variety of different contexts it became possible to draw broad based conclusions about how teachers understand and implement technological design.
Data Collection

Collection of data took place in two phases. Interview and observation protocols were semi-structured and provided a framework for ethnographic analysis of how teachers understand and implement technological design. These later proved to be too simplistic. The original interview and observation protocols incorporated the broad, general themes identified as being intrinsic to technological design; they were that the lessons should: (1) be a laboratory or practical activity; (2) be problem solving in nature; (3) involve knowledge of science content, and; (4) require practical skills associated with scientific process (AAAS, 1993; Bybee, 1998; Roth, 2001). Phase 1 data collection consisted of interviews with participants during the fourth week module. Phase 2 data collection consisted of pre-observation interviews, observations of classroom implementation of technological design, and post-observation interviews.

Phase 1 Interview

Phase 1 data collection involved ten teachers, and took place during the fourth week workshop at Garrett College, MD in July 2010. Interviews were digitally recorded and the researcher took hand notes to supplement the recording and capture non-verbal responses. Each interview lasted approximately one hour. The semi-structured protocol (Appendix A) used in each interview focused on teachers’ background, their understanding of the meaning of effective science education, and their recounting of how they had incorporated technological design in their classroom practices (Kvale & Brinkman, 2009; Seidman, 1998). The protocol provided for the inclusion of a narrative regarding the perception and description of an effective science lesson that used technological design. For the purposes of data analysis, it was this narrative that proved
the richest source of data. The interview protocol sought to get at teachers’ understanding and implementation of technological design as it occurred in their own classrooms. For that reason, the protocol questions did not specifically ask about the teachers’ professional development workshop experiences, or about their incorporation or interpretation of the MWM modules or philosophy.

**Phase 2 Interviews and Observations**

Phase 2 data collection involved four teachers, and took place in the first semester of the 2010-2011 academic year at each of the respective teacher’s schools. The pre-observation interview lasted less than 30 minutes in each case. The protocol focused on the details of the lesson that was about to be observed (Appendix B), including the four broad based themes of the practical activities, the nature of the real world problem, the targeted content knowledge, and the scientific process skills, as well as any identified student learning objectives (Seidman, 1998). This interview was digitally recorded and the researcher took hand notes to supplement the recording and capture non-verbal responses.

The observation shortly followed this interview. The observation protocols (Appendices C, D, & E) incorporated the general themes used in the interviews, but sought to capture additional evidence regarding the teacher’s role in the classroom. This evidence is important not only to help elucidate the research question of how teachers understand and implement technological design, but also because the use of technological design presumes a facilitative role for the teacher in lessons of a practical, problem solving nature (Johnson & Johnson, 1994; Shor, 1989; Shor & Freier, 1987).
The post-observation interview provided teacher participants the opportunity to reflect on the observed class (Appendix F). This third interview structured a space where the teacher could link intent, action, and outcome from the observed classroom experience through a metacognitive process of making meaning (Seidman, 1998).

Data Analysis

It was originally anticipated that four overarching themes: (1) practical activity; (2) problem solving; (3) science content, and; (4) practical skills would be sufficient to code the data. However, once data collection began, it became obvious that these codes were not representative of the complexity of the data that was collected. A more intricate and descriptive coding system emerged, particularly because of the many examples and narratives each teacher had recounted. These narratives evidenced each teacher’s depth of knowledge, understanding, and integration of accepted and key theoretical, methodological, and pedagogic constructs learned and reinforced through their own research and practice, and through their professional development experiences. This was clear from the language and specialized terminology repeatedly used by all the teachers in their interviews, and practiced by the four teachers who were observed. The repetition of specific words and phrases and examples of methodologies for classroom implementation eventually led to the realization that data was associated either with how teachers understand technological design, or how they implement it in their classrooms, as reflected in the title and research question upon which this study is based.

As analysis of the data continued, it became clear that teacher understanding of technological design reflected the NSES (NRC, 1996) and MWM (www.www.materialsworldmodules.org) interpretations of science content knowledge.
and science process skills explored in the literature in Chapter Two. Although all the
teachers discussed incorporation of traditional conceptualizations of content, such as
vocabulary and mathematical formulas, and laboratory skills, such as hands on
manipulation of apparatus and following directions, they all expressed an understanding
of effective science education in terms that resonated with broader interpretations that
had a greater relevance to their students. These ideas first appeared in Science for All
Americans: Project 2061 (Rutherford & Ahlgren, 1990), and led to Science for All
Americans: Benchmarks for Science Literacy (AAAS, 1993), which in turn led to the
development of four content standards of NSES (NRC, 1996), that expanded upon
traditional science content and process. These four standards required that students
experience science lessons that include inquiry, the nature and history of science, science
and technology, and science in personal and social perspectives. MWM
(www.www.materialsworldmodules.org) clarified and simplified the NSES (NRC, 1996)
language into eight statements describing a broader understanding of what constitutes
science content and process. These published statements from MWM resonated clearly
with the language used by the participating teachers in this study, and provided a basis for
coding and data analysis to address the question of how teacher understand technological
design and its theoretical implications.

Analysis of the data also revealed that answering the question of how teachers
implement technological design diverged into two distinct categories; the methodological
and the pedagogical. The data associated with methodological concerns was most closely
associated with language the teachers used during their interviews or exhibited during
classroom observations. The teachers described how they conducted their lessons in
varieties of ways, but for each technological design topic they taught, there was clear
evidence that they incorporated lesson sequencing and objectives reminiscent of the
MWM six-step progression upon which all the modules are based.

The second category related to implementation emerged from the concerns each
teacher commonly discussed that related to their role in the classroom and the importance
they ascribed to meeting the needs of their students as individuals. These have been
consolidated as six pedagogical considerations.

The two parts of the research question, related to understanding and
implementation, therefore, emerged from the data as three categories, herein described as
theoretical, methodological, and pedagogical. Each of these categories was subsequently
more discreetly coded into themes that captured the more specific commonalities in
language and terminology used by the teachers (Bernard & Ryan, 2010; Strauss & Quinn,
1997). Thick description (Geertz, 1973, p 3) was used to illustrate teacher understanding
and implementation strategies. After the pre- and post-observation interviews had been
coded, the researcher used the same codes to analyze the narrative that she created from
her observation notes. She also analyzed the narrative in terms of what was said in the
initial and pre-observation interview, looking especially for points of comparison,
contrast, and alignment (Varenne & McDermott, 1998).

Teacher Understanding

The data revealed that the teachers did not provide a direct answer to how they
understand technological design. The Phase 1 Interview Protocol and its use of semi-
structured interview questions was useful in that these questions initiated a dialogue
about effective science education. However it was apparent that the teachers were best
able to explain how they understood technological design by recounting descriptions of lessons that they believed represented their understandings. From these narratives the data began to fall into descriptive statements that could be aligned with each of the science content and science process statements published by MWM (www.www.materialsworldmodules.org). As discussed earlier, these statements represent a broader interpretation of science content and process skills than those traditionally associated with science education (Rutherford & Ahlgren, 1990; AAAS, 1993; NSES, 1996). The MWM (www.www.materialsworldmodules.org) statements were then used as codes, and the data was matched to these codes. The codes related to evidence of science content were to: (1) relate to real world problems; (2) integrate scientific, technological, and engineering background knowledge; (3) examine human interaction with the environment, and; (4) examine the history and nature of science and technology. The codes related to evidence of science process skills that engage students are: (1) asking researchable questions; (2) planning and conducting investigations; (3) working collaboratively, and; (4) reflecting and redesigning.

Teacher Implementation

With respect to how the teachers implemented technological design, the data was quite clear. During both the interviews and observations, the teachers all used narratives and examples of lessons to describe their strategies for implementation. Their language and terminology with respect to methodology was consistent with the MWM six-step lesson progression sequence and was coded as: (1) the hook; (2) the hunt; (3) research; (4) quantitative investigation; (5) teacher-initiated design challenge, and; (6) student-initiated design challenge. Analysis of Phase 1 and Phase 2 data revealed that the
teachers all referred to their work in these terms. They either cited their inclusion of specific steps, or described how they integrated two steps together as they progressed through a topic. This progression was established as the MWM methodology of lesson structure and sequence (Northwestern University, 1993) and is central to the NCASE professional development experience of all the participant teachers.

The teachers’ narratives reflected their beliefs that technological design based lessons allow them the opportunity to be more effective teachers, but that this type of lesson can be more demanding than traditional science lessons. Therefore, a third category emerged from the data that included the pedagogical implications of implementing technological design lessons. As a function of implementation, technological design affords certain benefits and costs, noted by all or most of the teachers that coalesced into six pragmatic considerations of implementing technological design in secondary science classrooms.

Additional Pragmatic Considerations

This third category relates to considerations that teachers of any secondary science lesson might reasonably be expected to experience. However, because of the specific type of science content knowledge and process skills, and the methodology of instruction that it entails, the teachers expressed a heightened awareness of certain pragmatic considerations. The data that emerged associated with these considerations all relate to pedagogical content knowledge and behaviors that the teachers specifically discussed during the interviews or exhibited during the observations.

All the teachers believed that technological design based lessons were more interesting and therefore motivational for their students. All the teachers discussed the
additional responsibilities that they associated with this type of lesson. Analysis revealed six clearly defined pedagogical considerations that were coded as: (1) instruction; (2) facilitative role in the classroom; (3) classroom discourse; (4) resource allocation and limitations; (5) curricular considerations, and; (6) assessments. All the participating teachers discussed some or all of these additional considerations. Therefore, they comprise a third category worthy of consideration and analysis for a clearer overall picture of how teachers implement technological design in their secondary science classrooms.

**Ethical Considerations**

The researcher has the responsibility to ensure integrity, reliability, and honest interpretation in reporting data drawn from participant responses to interview questions, and in describing events during classroom observations. These ethical considerations reflect "on the possible consequences for the persons taking part in the study …and for …the larger groups the participants represent" (Kvale & Brinkman, 2009, p 73). To protect the identities of teachers and schools, pseudonyms have been assigned to the participating teachers. Generalized locations have been assigned to their schools, such as urban, suburban, rural and southwestern or southeastern United States. Descriptions of school populations have been generalized.

To support the integrity of the study and protect the identity of participants, field notes were handwritten and remained confidential until they were transcribed and contextualized to the interview notes. Audio recordings of all interviews were listened to and transcribed by the researcher. These recordings were saved under a pseudonym on a
computer that requires a password for access. Hand-written field notes of classroom observations were transcribed by the researcher, and then shredded.

**Limitations of the Study**

This study is limited due to its focus on secondary school science teachers and their beliefs and practices regarding the six-step MWM lesson sequence and approach to technological design. Because of this, the research conducted for this study can not be generalized to other studies regarding high school science and science education. This study will not examine students or student outcomes, and therefore, it can not begin to analyze or even consider the effectiveness of technological design in terms of student learning. Data gathered from this study can not be generalized to other approaches to technological design that may exist. Nonetheless, it can provide questions that may be considered.
CHAPTER FOUR

RESEARCH PARTICIPANTS

Introduction

This chapter will describe the background of this research project with respect to the participating teachers as a knowledge community. Ten teachers were interviewed in Phase 1, and four teachers were interviewed and observed in Phase 2. This chapter will provide background for this research project. First, it will provide a description of the professional development program, NCASE, from which the participants were drawn. Second, it will outline a brief biography of each of the ten teachers who volunteered to take part in this research. Third, it will provide a short biography about the researcher and her experience with NCASE, MWM, and technological design.

The NCASE Workshop

Each summer for the past 5 years the National Center for the Advancement of STEM Education (NCASE) has provided professional development for teachers who are interested in learning more about how to include technological design, engineering design, and STEM teaching strategies in their classroom practice. The week-long workshops have been held at Garrett College in McHenry, Maryland for the past five years, run by Drs. Stephen and Nancy Priselac. NCASE is supported directly by a Department of Defense (DoD) grant for the professional development of teachers, and
indirectly through a unique partnership agreement linking public schools local to their Army, Navy, and Air Force bases around the country. Figure 1 shows how the NCASE professional development initiatives are supported by the DoD.

Figure 1. NCASE Links DoD Support with Science Classrooms

DoD funding enables NCASE to employ lead instructors, provide stipends and pay travel expenses for participating teachers, pay for venues, and purchase necessary teaching materials. DoD funding also provides for technical support in the form of DoD scientists and engineers (S&E’s). Liaison between the teachers and the S&E’s is facilitated by the Point of Contact (PoC) who works from a military base nearest the school. The PoC matches an S&E with a teacher or teachers taking part in the NCASE workshop. The teachers and their S&E’s develop a rapport, plan how they will
implement their technological design, engineering design, or STEM-based module once they get back to their home state, and then carry out those plans throughout the school year. The teachers are encouraged to contact the PoC’s with any requests or problems they encounter once they return to their schools. The S&E’s report directly to their PoC’s and work in the classroom with students, supporting and promoting NCASE.

The NCASE workshops base their professional development training on the Materials World Modules (MWM) developed at Northwestern University, together with similar modules developed in house by the NCASE team. Additional workshops that incorporate mathematics and robotics run concurrently with the science based modules. The workshops are highly interactive, and are designed to put the teachers into the role of students experiencing the pedagogical constructs relevant to technological design. Each of the NCASE instructors is an expert in the module he or she presents. Teachers become familiar with two different MWM modules during the week long workshop. All the MWM modules are based on materials science subjects. Although materials science is not a traditional secondary school science subject, it provides common ground for the integration of MWM philosophy and teaching methodology that teachers can easily transpose to the traditional subjects of physics, chemistry, biology, and environmental science that they teach. The materials science content is understood to be relevant, in these cases, only for professional development purposes, and is not necessarily expected to transfer into classrooms.

The week-long workshop that was held during the fourth week in July, 2010 was set aside specifically for teachers who had attended the NCASE workshops in previous years. Most of the returning teachers had attended two or three previous years. From the
group of twenty-four returning teachers, ten voluntarily agreed to take part in Phase 1 of this research project. Phase 1 entailed an hour-long personal interview with each individual teacher undertaken on site at the NCASE workshop. From the original group of ten, eight teachers offered to take part in the Phase 2 observations and interviews. Four teachers were selected based on the topics they would be covering, their availability, and the locations of their schools. Phase 2 involved classroom observations as the teachers demonstrated how they implemented technological design based teaching strategies in their own classrooms during the first semester of the 2010 academic year. Data from the four classroom observations were supplemented by a pre-observation interview and a post-observation interview.

**Phase 1 Participating Teachers**

Each of the ten teachers who took part in the initial interviews had attended the NCASE workshops at least twice prior to the July 2010 workshop, and have maintained a close working relationship with the PoC’s and S & E’s from their local DoD base. Seven of the ten teachers began their working life in careers other than teaching. All have taught different ability levels of students within the physical sciences in high school and middle school. The longest service of the five male and five female teachers was more than thirty years and the shortest service was eight years. Their schools are located in rural (4 teachers), suburban (3 teachers), and urban areas (3 teachers) across the country, and their students range from higher to lower socioeconomic status. The names of the participating teachers have been changed to protect their identity.
Jack W.

Jack is the longest serving teacher of all the participants. He began his high school teaching career over thirty years ago. He teaches basic chemistry and three levels of physics, including advanced placement (AP) physics at his large suburban high school. Jack also teaches high school students who attend a summer course at a local university in the Engineering Innovation Program, and a non-credit summer school course at a local community college for advanced 8th through 12th graders. Jack explained that for him, the primary objective of his teaching is to “stimulate thought and interest” in his students. He believes that his students will be motivated to learn if the science, technology, and engineering presented to them in the classroom relates to their own real world experiences.

Cassandra A.

Cassandra has taught in five different school districts over a 23 year period. She began by teaching chemistry and added physics fifteen years ago. She now works in a small rural high school in the southeastern United States. She has attended two NCASE workshops. To Cassandra, physics allows her to help her students make sense of math. She says “physics means applied math” and she sees herself “painting pictures with the math” as an effective science teacher. She expects to change students’ view of the world, to give them the tools they can use to analyze their surroundings, and experience it by applying what they have learned in physics. Cassandra was the only teacher who discussed the curricular pressures of standardized testing, and she was the only teacher who described her students designing products and considering their marketing potential.
Karl P.

Karl initially studied agricultural sciences when he was working towards his Bachelor of Science degree, and later switched to the general science education degree program. He also holds a master’s degree in curriculum development. He has worked at two suburban high schools over the past seven years. Karl’s career in teaching began eleven years before that, however, when he joined the Peace Corps and taught agricultural science on a small South Pacific island. Karl presently teaches at a small rural high school that graduates seventy students each year. He teaches second year physics students. His school does not offer AP physics but does offer a course in engineering, and each year three or four of the graduates go on to study engineering in higher education. Karl has been involved with MWM and NCASE for five years, the longest of any of the participants. His approach to teaching science is to first develop a good rapport between himself and his class, and then foster a classroom environment where: “Students get turned on to science, make a connection to the subject, and become life long learners in science.” Karl’s approach to achieving this goal is by making science “fun and exciting” where students will feel comfortable enough to test their own ideas and take intellectual risks. He describes his classroom as a safe place where students can share ideas without judgment.

Colin D.

Colin began his professional career in the private sector as a marketing and advertising event manager after receiving his Bachelor of Arts degree in speech communications. He eventually became disenchanted with this career choice, and decided to follow his love of science. He returned to higher education to work towards
certification in science education. Once he had passed the praxis exam for earth sciences he began teaching in a long-term substitute teacher position without the benefit of student teaching experience. He taught pre-algebra and physical science at the 8th grade level. Six years later he is still at the same suburban middle school near Washington, D.C. teaching physical science. Colin’s objective is to get his students to love science. He says, “The rest is just details.” Colin’s enthusiasm transfers to his students.

Colin is one of the two middle school teachers who participated in this study. Colin described his school neighborhood as a mix of working class and professionals. His school has been awarded “blue ribbon status” at the state and national levels. Colin has attended three NCASE workshops. Colin explained that his school’s curriculum follows state guidelines for eighth grade science, that is: “One quarter devoted to Newtonian gravity and the Laws of Motion, one quarter devoted to electromagnetism, electricity and magnetism, wave theory, a third quarter devoted to beginning chemistry starting with the periodic table and properties of matter and then, finally, a fourth quarter in advanced chemistry.” Colin was the only participating teacher who came into science education from a profession outside the field of science. He brings a unique perspective to his role as a science teacher. His understanding of technological design includes discussions about both science content and science process skills.

Steve M.

After completing a Bachelor of Science degree in chemistry, Steve worked in the manufacturing industry doing quality control research and development (R & D) work. Eventually, Steve found this work monotonous and lacking in social interaction. Inspired
by his two sisters, both teachers, Steve decided to make a career change to education.  
For the past 10 years he has taught general and honors chemistry at the same large urban high school in the mid-Atlantic region of the United States. He also worked on a team to write the chemistry curriculum for his district. Steve sees his role in the classroom as a mentor. Steve says, “It’s the thought process you want to get across versus the actual chemistry itself.” He believes that helping his students understand and practice logical thinking as they grow into adults is the underlying reason why chemistry is an important subject for them to study.

Bethany H.

Bethany holds a Bachelor of Civil Engineering and a Bachelor of Arts and Sciences in chemistry. She is also a licensed professional environmental engineer and had been working in this capacity for many years before she decided to take time off to have children. After ten years at home she attempted to get back into the field on a part-time basis, but there were no jobs at that time, so she turned to teaching instead. She was encouraged to take the National Praxis Test for Physical Science and apply as a substitute. When she applied for a substitute teaching position she was instead offered the job of a full time teacher. She took the position with trepidation because she had had no classroom teaching experience, and had qualified through “an alternative route.” This happened fifteen years ago, and she has been teaching physics and chemistry at the same large suburban high school since then. Bethany’s initial approach at the start of each academic year is to impress upon her students the link between science and the world of work. Bethany sees evidence of the effectiveness of science education in its application to a job or career. As she gets to know each student better over the course of the year she
tries to “individualize” her instruction for each student to meet their emotional as well as intellectual needs

**Phase 1 and Phase 2 Participating Teachers**

Karen J.

Karen began her working life as a nurse, after achieving an associate’s degree in nursing. She decided to move into the realm of education and achieved a master’s degree in science teaching. She worked in three different states before arriving at her present location in the southwestern United States. Karen works at an alternative high school that takes only those students who have no other option for achieving a high school diploma. The students at her small urban institution are there because of a variety of personal problems ranging from being on probation for crimes to recovering from drug addiction. The school is a Title 1 charter school with 165 students. Karen did not set out to work in an alternative high school, but when she saw the job advertised, she decided to go in for an interview. She was offered the job on the spot, and after some deliberations, she decided to accept. Karen considers science education as being effective if her students “demonstrate their critical thinking skills and apply what they’ve learned in class.” For the past five years she has revolutionized and adapted the science curriculum at her school. By entering her students in a variety of local and national competitions, Karen has managed to improve her students’ sense of self worth, confidence, ability, and interest in science as a challenging subject that has real world applications and benefits.

Rodrigo R.

Rodrigo is a bilingual science teacher at a large urban high school where most of his students are English as Second Language (ESL) students. The school is a Title 1
school with approximately two thousand, primarily Hispanic, students. He holds a Bachelor of Science degree in Range and Animal Sciences from a Chihuahua university, Mexico, and worked in research there before coming to the United States. He holds several bilingual teaching certificates, and has been teaching in the U.S. for over ten years. Rodrigo teaches bilingual physics, chemistry, geology, and astronomy. For him, effective science education means that students can not only articulate their understanding of concepts, but also understand how to use these concepts, and why they are important.

Angela R.

Angela’s original working life began as a chemical engineer after completing a Bachelor of Science degree in physics and a Master of Science degree in geophysics and geology. She worked as an R & D principal researcher, primarily concerned with environmental protection, for several years. She became disillusioned with this work as the level of contaminants she had to work with continued to escalate. The part of her job that she enjoyed most was training new employees, and working with people. She decided to go back to complete requirements for working in the field of education. Angela has worked in two suburban high schools for the past 12 years teaching chemistry and physics. Her present high school is not a Title 1 school, but all the contributing middle and junior high schools are classified as Title 1 schools. Angela believes she has been an effective science educator when she sees evidence that her students are combining everything that they have learned and “can figure out what to take out of their tool bag and apply [it].” She wants her students to understand the background and apply their science knowledge to solve problems.
Lydia Y.

Lydia earned a Bachelor of Science degree in elementary education and secondary earth and space science, but due to having to move a number of times in her early married life, she did not start her teaching career right away. Instead, she stayed at home raising her six children through high school before she returned to begin her teaching career. That was eight years ago, and now Lydia is the science department chair at a middle school in a small Gulf Coast town. She teaches environmental science.

Lydia’s approach to being an effective science teacher is to help students think. She encourages them to “think the way scientists think in real life.” She explains that to her this means her students can “use scientific thought to solve problems and use logical thinking regardless of the professions they go into.” Even more important to Lydia is that students can “take care of things that might happen in the future before they become a problem” and be on the “offensive rather than always on the defensive.” Considering the location of her school in the Gulf of Mexico, and her subject of environmental science, this is an obvious match of objectives to the real world and to the scientific world.

Researcher Biography

My own biographical sketch begins with having grown up in the United States, but having completed university in the United Kingdom. I graduated with a Bachelor of Science degree in chemistry with a second qualification in Science, Technology, and Society (STS). I qualified as a science teacher with a Post Graduate Certificate of Education (PGCE) one year later, and taught at an inner city school near Manchester, England for seven years. During that time I completed a Master of Arts in Science Education from Manchester University. I returned to the United States and began
teaching high school chemistry at Lake Forest High School (LFHS), in Illinois, in 1996. I became involved with Northwestern University’s MWM program shortly thereafter. This led to my development of the Materials Science and Design (MS&D) course at LFHS over ten years ago. Although I began to be interested in technological design as an integral part of effective science education during my time in the UK, the MS&D course at LFHS has given me the opportunity to delve deeply into its potential for science teaching and learning. Through my involvement with MWM I have presented at conferences and provided training at workshops to various groups of professionals in the field of science education. It is my hope that this research will help to improve the professional development experiences for teachers interested in science education and technological design.

Conclusions

Most of the teachers mentioned their interest in technological design in relation to their desire to find ways to motivate their students to “love” science and want to learn the subject of science. For three teachers, this was translated into “helping students develop the knowledge and skill base” or the “tools” necessary to solve real world problems. The teachers used “relevant and stimulating” activities to motivate their students. Two predominant categories emerged in terms of approach. In one, the teacher creates a visually and physically engaging classroom culture, where science can be experienced first-hand, and students are encouraged to think of science as being “esoteric” and “fun and exciting.” In the other approach, the teachers create a visually and physically engaging classroom culture that is more “realistic” or pragmatic. Here science is seen as a way to solve problems, or is recognized as being a good preparation for handling the
responsibilities that come with adulthood, including possibilities for future employment. Perhaps it is not surprising to note that the teachers who came from a science career outside of teaching had mostly worked in the chemical industry; theirs were the pragmatic classrooms. And, in two examples of large urban high schools, the pragmatic classroom was set up in response to the perceived needs of the student population.

Although the teachers’ experiences and backgrounds are varied, they have one obvious thing in common. They adhere to the notion that in order to provide effective science education they must find ways to engage their students’ interest, thereby enticing them to commit to learning the sometimes difficult content. Getting students to buy into science by individualizing the subject material and making it relevant to each individual student was another motivating factor, and a common objective discussed by most, if not all, of the participating teachers.

Two curricular areas emerged as natural conduits for technological design. They were physics and environmental science. Even though seven of the ten teachers teach high school chemistry courses and three have BS degrees in chemistry, few contributed an example of a technological design lesson for chemistry. Some of the chemistry teachers cited the “highly structured” nature of chemistry, or various safety concerns as reasons why a technological design approach would not work in a chemistry class.

During the interviews each of these teachers expressed their own “love of science.” This emotional connection to the subject is a motivating factor in their desire to teach; it drives them to continue to go through professional development sessions each year, and helps them remain vital, innovative, and inspirational for their students. All the
teachers expressed the notion, in one way or another, that they themselves are life-long
learners, and they expect their students to recognize that there is always more to learn. It
is perhaps this quest for understanding that is at the heart of their pedagogical approach to
technological design.

The data collected through the ten Phase 1 interviews and the four Phase 2
interviews and observations was so rich with description provided by each of the teachers
that it was difficult not to include all their stories and examples in the data analysis. Each
teacher has an area of emphasis that differs from the others. The interests and strengths
of knowledge develop over years of teaching practice. These ten teachers are drawn to
technological design because it exemplifies what they believe education should be. In the
next chapter more detail is presented in an effort to get at the commonalities of purpose
for the type of teacher who will make the effort and take the time to become a
technological design teacher.
CHAPTER FIVE

ANALYSIS OF THE DATA IN THREE PARTS

Introduction

Data taken from the Phase 1 and Phase 2 personal interviews and classroom observations were analyzed using a phenomenological approach to examine the research question. Semi-structured interview protocols and ethnographic observation techniques were used to generate data. Most often, the teacher participants responded to the interview questions with narratives drawn from their classroom experiences. The data gathered from classroom observations of technological design based lessons reinforced the interview data and helped get at the essence of meaning as experienced by the teachers (Creswell, 1998, 2003; Kvale & Brinkman, 2009; Merleau-Ponty, 1962; Merriam, 1998; Moustakas, 1994).

Initial analysis revealed three broad categories which were later separated into discrete themes to more clearly address the research question: “How do teachers understand and implement technological design in their secondary science classrooms?” The categories and their associated themes are: (1) theoretical, related to how teachers understand technological design with respect to science content knowledge and science process skills; (2) methodological, related to how technological design based lessons are implemented in the classroom with respect to lesson structure and sequence, and; (3) pedagogical, also related to how teachers implemented technological design, but more
specific to how these types of lessons affected their roles and responsibilities within
the context of the classroom and with their students as individuals. Figure 2 below is a
flow chart that outlines how the data analysis is organized in this chapter.

Figure 2. Technological Design Flow Chart of the Organization of Data Analysis in this
Study

The Categories of Technological Design:

Theoretical, Methodological, and Pedagogical

The first category derived from the data, and addressed in this chapter, describes
how the teachers who participated in this study understand technological design from a
theoretical standpoint. The narrative descriptions they provided during data collection, of
their beliefs and practices, resonated with how technological design has been defined by
professional organizations (AAAS 1993; NCEE, 1983; NRC, 1996; NSTA, 1982) and
researchers, (Bybee, 1993; Haury, 2002; Lewis, 2006; Roth, 1995, 2001; Kohn, 2000;
Atkin & Black, 2003), and published as part of the science and technology standard in NSES (NRC, 1996). However, the common themes that emerged from the teachers’ descriptions most closely matched with the characterization of technological design that was clarified and published as Materials World Module (MWM) learning objectives (www.www.materialsworldmodules.org). The MWM learning objectives delineate eight distinct themes. Four themes address science content knowledge and four address science process skills. These themes appear in Table 1 on page 54 in a slightly modified form that better fits the data collected. Each has been individually analyzed in this chapter.

The second category derived from the data, and addressed in this chapter, relates to how the teachers implement technological design in their secondary science classrooms. The data revealed the widespread use of the lesson structure and sequence published as MWM methodology (www.www.materialsworldmodules.org). The examples of lessons that were described in all the teachers’ narratives reflect a consensus of belief in the efficacy of the six-step MWM methodological approach to technological design (Baumgartner, 2000; Pellegrini, 2008). Descriptions of each of the steps appear in Table 2 on page 67.

The third category derived from the data, and addressed in this chapter, focuses on the pedagogical connotations specific to technological design based lessons. Analysis of the data revealed six common themes that describe how the teachers’ beliefs about technological design affect their practice and pedagogical role and responsibilities in the classroom (Atkin & Black, 2003; Cohen, 1988; Cuban, 1993; NRC, 2001; Shulman, 1986; Tobin, 1990). Descriptions of each theme appear in Table 3 on page 76.
Theoretical:

Teacher Understanding of Technological Design and the Learning Objectives of Science Content Knowledge and Science Process Skills

The theory underpinning lessons that follow a technological design based approach can be seen to achieve effective science education as it is presently described in NSES (NRC, 1996). Analysis of the data revealed that the participating teachers value technological design lessons because they believe that this type of lesson reflects a natural balance between science content and process. Technological design lessons, therefore, transcend the century-old tensions described in Chapter One of this dissertation between academic scientists, advocating the importance of content knowledge (Abell & McDonald, 2004; Bestor, 1953; Rickover, 1959; Physical Science Study Committee (PSSC), 1960), against pedagogical experts, advocating the importance of problem solving process skills (Bruner, 1961, 1963; Rutherford, 1964; Schwab, 1962; Shulman, 1986). Furthermore, technological design lessons provide teachers with the opportunity to integrate these traditional conceptualizations of appropriate science content and process with the broader based interpretations of science content and process advocated in the literature that emerged from Science for All Americans: Project 2061 (Rutherford & Ahlgren, 1990; AAAS, 1993), NSES (NRC, 1996), and MWM (www.www.materialsworldmodules.org).

Traditional content such as scientific vocabulary, mathematical equations, and measurements specific to each of the science disciplines of physics, chemistry, biology, environmental science, and earth science (AAAS, 1993; Bybee, 2003; Galison, 1997); and traditional process skills associated with laboratory work, such as following
laboratory instructions, conducting experiments, and manipulating scientific apparatus specific to each of the science disciplines (Kuhn, 1996; Millar & Driver, 1987; Roth, 1992) were discussed by the teachers in their interviews and incorporated into observed lessons. Traditional content and process was seen by the teachers as being integral to the topics that were taught as technological design lessons. However, all the teachers recognized that although traditional content and process is important for students to know and understand, the value of technological design lessons is in the inherent nature of its broader interpretation and wider application. The teachers all described their dedication to these types of science lessons in terms of the potential for technological design lessons to provide a richer, more relevant, and more interesting experience for their students (Bennet, Lubben, & Hogarth, 2007; Pickens & Eick, 2009; Theobold, 2006).

Viewed from this perspective, the teachers who participated in this study can be seen to understand technological design as an effective approach to science education. They recognize the value of the technological design approach because of its potential to integrate science content knowledge and science process skills in a way that is balanced (AAAS 1990, 1993; NCEE, 1983; NRC, 1996; NSTA, 1982) and makes sense to their students (Bennet, Lubben, & Hogarth, 2007; Pickens & Eick, 2009; Theobold, 2006).

Analysis of the data revealed that the terminology and examples provided by the teachers closely match the learning objectives published by MWM (www.materialsworldmodules.org). They appear below with slight modifications from the MWM published lists based on the teachers’ descriptions that emerged from the data.
Table 1. Theoretical Category: Science Content Knowledge and Science Process Skills Learning Objectives Developed from the Original found in NSES and MWM

<table>
<thead>
<tr>
<th>Science Content Knowledge</th>
<th>Science Process Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science content should:</td>
<td>Science process skills should engage students in the ability to:</td>
</tr>
<tr>
<td>be related to real world problems</td>
<td>develop and ask researchable questions</td>
</tr>
<tr>
<td>integrate scientific, technological, and engineering background knowledge</td>
<td>plan and conduct investigations based on real world problems</td>
</tr>
<tr>
<td>examine human interaction with the environment</td>
<td>work collaboratively with other students and the teacher</td>
</tr>
<tr>
<td>examine the history and nature of science and technology</td>
<td>design, test, reflect, re-design, and re-test artifacts or processes created</td>
</tr>
</tbody>
</table>

Analysis of the teachers’ narratives revealed their common understanding and appreciation for the balanced approach to both content and process that is afforded by technological design. This balance is necessary for students to be able to understand science in relation to the real world (Fenstermacher, 1979; Hodson, 1988; McComas, 1998; Pintrich, 1990). When students relate science to their own and to real world problems, to society, and to technology they become more engaged in learning (AAAS, 1993; Bennet, Lubben, & Hogarth, 2007; Roth, 1990).

The Phase 1 and Phase 2 interviews provided data most often in the form of narratives describing actual examples of lessons, experiences, or of objectives the teachers had had for their lessons (Geertz, 1973). As such, the narratives reflected the complexity and integrative nature of how teachers understand technological design. Analysis of the data, therefore, meant it was impossible to completely separate the themes without losing meaning. The most illustrative examples representing the
individual themes of science content and science process are presented here. Within some of those examples may be evidence of a second or third intertwined theme. This aspect of phenomenological data analysis reflects the complexity of attempting to categorize for understanding the lived experience of the teachers participating in this study (Creswell, 1998, 2003; Geertz, 1973; Kvale & Brinkman, 2009; Merleau-Ponty, 1962; Merriam, 1998; Moustakas, 1994).

Content Related to Real World Problems

All the teachers discussed how, early in the academic year, they quickly size up their classes, and begin to get to know their students as soon as possible. As science teachers, this task involves making a connection for each student with the subject. When students relate science to their own and to real world problems, to society, and to technology they become more engaged in learning (AAAS, 1993; Bennet, Lubben, & Hogarth, 2007; Roth, 1990). Even reluctant learners will engage if they see how it will benefit themselves (Bennet, Lubben, & Hogarth, 2007; Pickens & Eick, 2009, Theobold, 2006).

In Jack’s experience, getting to know about his students is necessary for creating a positive classroom culture that endures throughout the year. Jack explained his approach,

One of the first things I do when the kids come into my class is I have them fill out a form that tells me as much about them, their hobbies, and their interests, their likes and dislikes as I can. Then I make myself a compilation of these lists so when I’m working up a lesson plan, I can try to pick at it. I can go ahead and try to bring in some application to as many different areas as I possibly can, so the kids can relate to it. And it’s not some abstract thing that they’ll think “Well why should I learn this? I’ll never need this. I don’t see any need for this. I’m never going to …” I mean, you try to relate it to things, and even things that they may not specifically realize apply to them as far as they’re aware; but things that apply to them because
of engineers or people who’ve designed them for their safety, for example, such as how the crumple zones are put together on an automobile, and how it has been designed for safety for them.

Then I try to relate it to the coursework throughout the year, and stimulate their interest. Can I stimulate their thought by asking them, “What would you do to make this product or that invention better?” I try to get them into their groups and have them brainstorm and then present to the class what they would do to make it better. (Jack Phase 1 interview)

Jack also discussed an assignment he uses each year for which his students are required to conduct research into a product they use in their own lives. They work on their own, outside of class, on this project. Jack requires them to integrate aspects of the scientific, engineering, technological, social, environmental, and/or historical importance of their product, and then present it to the class in some form. One of the examples Jack offered during his interview was that of a student who was a competitive horse back rider. She chose to report on the technological and historical evolution of products associated with horse back riding, such as halters, bridles, and saddles. When this student presented her report to the class her mother drove to the school with her horse in a horse trailer. The class went outside as she demonstrated her collection, using her horse as a model. Most memorable for Jack was her collection of saddles. The different vintages were differently constructed and made from different materials. The oldest example was a Spanish saddle from the 1700’s.

This technique requires class time for the presentations, but all the research is conducted outside of class. Jack, however, follows up on this theme at the end of the school year. He has his students re-present the same topic, with the expectation that the second presentation must include the relevant content they have gained during the
academic year. Jack considers this to be an informal assessment. He explained that it “gives me a good idea of how much they have learned that year.” This second presentation, he says, is “a motivating factor. I live in hope that they will want to continue with science in college because they want to know more about how it relates to their own lives.” Jack has found that this technique has many positive outcomes. It quickly creates a collaborative environment in his classes, it allows him to conduct informal assessments of his students’ learning and his own effectiveness, and he learns a lot from his students in the process.

Rodrigo structures his physics lessons to be as relevant to his students’ real world problems as possible within the constraints of few resources. They live in a hot, dry climate, where water reclamation and energy conservation are particularly important. Rodrigo described two examples of real world problems his students work on in addition to their normal curriculum. He plans to continue to develop these projects year after year. Rodrigo gave the background on these two projects; he explained,

Most of my labs are made with household items or something that they don’t need to spend money on. I am hoping my students are able to develop a way to collect, clean, and recycle the water from the dishwasher and washing machine to reuse over and over. These are energy conserving technologies that would help my students’ lives.

and

Another idea that students have worked on is a film, a protective film that also can capture the solar energy and transform it. I want my students to develop a film to be placed on the window. It will be a different kind of film that maybe uses gelatin or whatever they find out in their minds but they have to be testing it constantly during classes. For example, so far this year they have used a bubble wrap added to the windows. With it we got very good insulation on the interior. The amount of natural light is reduced but the air conditioner time is lasting
less. And of course the money that is paid on the electric bill is reduced. So let’s see during winter what is going to happen. (Rodrigo, *Phase 1 interview*)

Rodrigo is setting the bar high with respect to the science, technology, and engineering that is needed to solve these problems, but they are real problems to which his students can relate, and he encourages them to think about these problems so they realize science and technological design has the potential to improve their lives.

**Integrating Scientific, Technological, and Engineering Background Knowledge**

Bethany’s background in civil engineering was evident in her answers to the interview questions. She described her understanding of technological design as an interaction amongst science, technology, and engineering. Bethany summed up her understanding in this way,

> I want my students to understand that the job of science is to describe what’s around us. The scientists are true to the essence of whatever discipline they choose to study and then the engineers apply that information and then try to see what productivity or improvement in our society we can derive from it. When you become an engineer, you take the tools of the scientists and see how you can apply them for the greater good of your society or for the improvement of your society; understanding that there are some applications that are not appropriate. And most importantly, if it doesn’t work the first time, figure out why it’s not working and then make it work. Students have to understand why their solutions might fail, or are not perfect, or not adequate. This is when real learning takes place, when you have to go back to the drawing board. (Bethany, *Phase 1 interview*)

As Bethany said, “the real world application [of technological design] includes the understanding that failure is a learning experience.” Iterative design work, where there is the opportunity to design, test, redesign, and retest is part of the process of learning science. It is one of the important aspects that technological design brings into the classroom that is often lost in traditional lessons.
Examining Human Interaction with the Environment

Lydia’s location on the Gulf Coast enables her to create a learning environment that is as close to being the real life experience of her students as possible. Her classroom is less than a block from the ocean and her students spend a great deal of time exploring the natural environment of the beach, the shoreline, and tidal pools in the area. The countertops around Lydia’s classroom are covered by aquariums full of plants and animals that the students have brought back to class, including one full of jellyfish. Lydia teaches middle school environmental science, and her lessons include understanding how human interaction affects the environment. The visit to Lydia’s classroom took place just months after the tragic oil spill in the Gulf of Mexico. Lydia believes this event affected both her own and her students’ attitude and approach to the curriculum. She explained, “There is a need for us to be on the offensive and try to take care of things that might happen in the future, that haven’t become a problem yet, instead of always having to fix the mistakes we have already made.” She believes that her students have become sensitized to their local environment, and more engaged in trying to understand how the social and environmental responsibilities of science, technology, and engineering can be understood and controlled.

Examining the History and Nature of Science and Technology

Cassandra purposefully integrates social studies with the organic chemistry topic of food science as a way to motivate and engage her students. Cassandra has her students work together in groups to investigate how armies throughout history have managed to feed their soldiers. Students choose a time period and a war, such as the Revolutionary War, World War I, World War II, etc. They develop their own questions to examine the
various environmental factors affecting the production, nutritional value, preservation, and distribution of food. Cassandra explained that her students gain a real world understanding by developing their own questions and conducting their own research. She explained that, “technological design can be related to chemistry in this way, as well as to biology and physics because they have to answer questions about how soldiers were fed during WWI, how was it packaged then, before we had plastic containers, [and] how was it distributed to them in the field.” Cassandra also gave several examples of how she uses questioning to initiate student thinking about the history and nature of science. She explained that she might ask a question such as, “Why did the Industrial Revolution take place?” and expects the answer to be: “Well, it is based on the Renaissance Age and the Golden Age of Science, when the lights were turned on and when we made all these inventions based on all these simpler machines.” She says, “Students appreciate the importance of the past.” And by placing their thinking within the relevant context of history and society, students can appreciate the science; it provides them with a way to understand how a real world problem was solved (Bybee, 1998; Kolodner, 2003; Roth, 2001).

Colin, on the other hand, believes it is the inherent physicality of doing science that in turn contributes to his students’ intellectual development. In his interview, Colin said,

Hands-on is the physical manifestation of brainstorming. Instead of simply coming up with ideas and writing them on the board, the kids, working together, are literally saying, “Hey let’s try this!” and immediately new ideas emerge. We forget that so much of the brain is also devoted to the body itself, and the more we can get the body involved with doing anything, it is beneficial. I have my students practice mind-body interactions for homework. I tell them, “Go home,
get a piece of sidewalk chalk and write the vocabulary words in big giant letters on your driveway because that will get your large motor skills involved and that will access a different part of your brain.” (Colin, Phase 1 interview)

Colin considers the nature of science to be an interaction between the physical and the intellectual. Improving his middle school students’ physical coordination and intellectual stimulation, he believes, will ultimately motivate them to want to continue with science studies as they go into high school and beyond. He explained, “If they don’t love it, really in 8th grade, this is the last chance that you have to really change the direction of the ship, then the odds of them becoming a scientist or an engineer are very low.” During the Phase 1 interview with Colin, he twice referred to a report published by the American College Testing (ACT), called the Forgotten Middle: Ensuring that All Students Are on Target for College and Career Readiness before High School (ACT, 2008) as having had a major impact on how he understands and approaches his teaching practice.

Developing and Asking Researchable Questions

Questioning skills and techniques were commonly discussed by all the teachers. Cassandra’s interview provided a succinct example that reflects how important all the teachers believed this skill to be for their students. Technological design based lessons were seen to support student development of these skills because they approach science from a practical standpoint, and create an environment of open communication amongst students and between students and teachers (Roth, 1996b; Roth, 2001). Cassandra explained that she tries to “invigorate their thinking and questioning of the natural world around them.” She explained,

It’s the questioning: The not-just-accepting-what’s-given-to-you approach; and a greater appreciation for things that come along. I
mean, you take for granted so many things in your life, but did you ever, EVER take half a second and ask: “I wonder how they made that?” That’s the part that makes it science. It’s the questioning. And it’s really no different than the musician or the artist who wants to apply what they see or are experiencing inside. Mathematicians do the same thing. I really can’t see any part of life that doesn’t incorporate this. (Cassandra, Phase 1 interview)

Cassandra explained that her primary teaching goal is to: “Ignite that spark that the kids have forgotten they have. Or that they have never been given enough space to explore. And then it becomes an inside out experience; from inside the technology to outside the science.” Cassandra considered questioning to be “a tool” that they will carry with them throughout their lives and use as necessary.

Karen uses a lot of questions during her lessons, as was evident during the classroom observation. Her students are not typical high school students, but have found their way into her school as a last resort. They are reticent at first, but quickly find that Karen’s classroom is a non-threatening environment. Karen’s insight into questioning is apparent in this quote,

> I think one of the problems is that by the time the kids get to high school any curiosity or enjoyment has been stamped out of them, so when I can get that started back in the class, then I find I can take them a little further, and I can take them deeper too, because they start asking the right questions. When they start asking the questions, it means they want to know the answer. But if I am asking the questions, they want to know what I want to hear. So that’s a big difference. (Karen, Phase 2 post observation interview)

Karen’s strategy is simply to get them to start talking, and from this opening, she uses her own questioning techniques to get them to realize she does not know all the answers, and will rely on their ability to reason and brainstorm. This is an empowering experience for her students.
Planning and Conducting Investigations

At the end of the year, Jack requires his Advanced Placement physics students to take part in a group based design challenge, to build a 26-step Rube Goldberg device, where each step represents the action of a simple machine. This culminating project requires collaboration and continual reflection and redesigning before the final testing phase (Roth, 1995, 2001). Jack organizes his students into large groups of between eight and ten students, who must then divide themselves into three or four subgroups. The individuals in these subgroups collaborate closely with each other, but work outside of class over a two month period until the last week of the school year, when they bring their parts of the whole machine back to class for final testing and re-design. Jack said, “Those subgroups have to realize it’s just like the real world. Even without face to face contact, people must find ways to relate to certain parameters, and relate to somebody who’s working in another office in another state somewhere.” Students have to make predictions, use abstract reasoning, accurate measurements, and there must be: “A lot of give and take within their groups to ensure successful assembly during the final week when the machine is tested.” Jack believes this final project provides his students with a unique experience. He described it as being a “summative learning experience” where his students have to incorporate the content and processes they learned throughout the year and the final design must actually achieve the goal set by Jack. This project is assessed based on one parameter: how well the machine worked.
Karen discussed the importance of having her students collaborate, and included herself as a component of that collaboration. She explained the collaborative climate she seeks to engender in her classroom,

I think you can role model everything. For example, with brainstorming activities, as you move through the year, you see the kids starting to do their own brainstorming, and they say to themselves, “Ok, well this is what we all wanted, this is what we want to know, and this is why, and this is how it answers the question.” (Karen, Phase 2 post observation interview)

She described her role,

It goes back to the relationship that you have with your students. I find that one of the things that’s really big is letting them know that we’re going to learn together. They know that I don’t know all the answers and it’s really funny to me when you’re talking to the kids, they’ll go, “I’ve never heard a teacher say they didn’t know before.” I think they get really fired up when I say, “Well, we’ll learn together.” And they get really excited about showing you what they found because they’re not sure if you know or not. When they know you’re going to share that with them, it just makes a whole different classroom. (Karen, Phase 2 post observation interview)

Karen continued,

I find that one of the ways to get the kids interested, or willing to work, is if you’re doing cooperative learning with them, it’s not so scary to them if someone doesn’t know an answer, because maybe somebody else in their group knows an answer. This reduces anxiety and encourages the kids to do more.”

She went on to explain,

The kids think, “Even if there really wasn’t too much for me to do, I found there was something I could do, there was something I could contribute.” And I think that we’re such social creatures that if you find that you’ve got a way to contribute to your small group, then the buy-in just really picks up and you see people getting more and more active. And that’s when I feel like I’ve really got a successful group,
is when that buy-in is there. (*Karen, Phase 2 post observation interview*)

As mentioned earlier, Karen works with a unique student population. Her students have had little success in school before coming to Karen’s classroom, and they need a great deal of encouragement and reassurance. Karen’s approach creates a non-threatening, collaborative working environment for her small classes.

**Designing, Testing, Reflecting, Re-designing, and Re-testing**

This example is taken from the pre-observation interview conducted with Angela, and relates to an honors physics class that had been working in small groups to build and program a Lego robot. The students originally planned to have their robots take part in a tug-of-war, but after the S&E from the local Army base visited their classroom, the class decided to change the final design. This left them with a more complex set of problems to solve.

Angela explained how she handled this re-design problem the day before the observation, and how it was going to impact the lesson being observed. She said,

Most of the groups finished physical construction of their tug-of-war robot, but because Mike, the S&E, talked about uses of robots in the Army, and they liked his idea of a bomb-finding robot, they all wanted to make a bomb-sniffing robot. But, instead of having a bomb-sniffer - because we don’t have that sensor and we don’t have bombs - they did red balls and light sensors. So, the red balls are now representing bombs, and then they had their robots navigating through the mine field. And they’re thinking of programming by timing. They are thinking, “We know where the field is, so if we go two seconds here and then stop, and turn right…” Well, I know that never works. So, I want them to use the sensors to figure it out instead. So, now they’re further behind because they decided to try a more complex logic problem. (*Angela, Phase 2 pre-observation interview*)

Angela was aware of the problems the students would encounter, but she allowed them to discover these difficulties themselves. She was able to assess
the levels of involvement of her students by observing them, and by assessing the
time of the questions they were asking each other. Some teachers routinely
used questioning to assess learning levels in their class. This can be quickly
and easily accomplished if students are working collaboratively in groups
(Beghetto, 2004; Pickens & Eick, 2009).

The findings reported here are just a few of the examples of how the
teachers understand and appreciate how well technological design based
lessons can integrate and balance science content and process skills. These
eight theme headings represent the intellectual and social level of achievement
that is possible within a technological design based lesson.

**Methodological:**

**Classroom Implementation of Technological Design and**

**The Six-Step Lesson Structure and Sequence Derived from MWM**

The data that addressed how the teachers implement technological design was
clear-cut. Each of the ten teachers used the exact same terminology and lesson objectives
in their narratives, distinctly reflecting the MWM methodology of the six-step structure
and sequence of activities. Depending upon the ability level of a particular group of
students, or the resources available, teachers remained flexible and adaptive of their
teaching methods, but all were clearly aligned with the MWM model that is outlined
below.
Table 2. Methodological Category: The Six-Step Lesson Structure and Sequence
The MWM Model

<table>
<thead>
<tr>
<th>Step</th>
<th>Name</th>
<th>Objective</th>
</tr>
</thead>
</table>
| 1    | Hook | To introduce a relevant connection to the material being studied  
      |      | To engage students’ wonder and curiosity  
      |      | To generate questions from observations of seeming anomalies  
      |      | Example: The Composites module has students compare samples of ice that appear to be identical, but one sample has shredded paper frozen inside and one does not. Students try to break each sample. The non-reinforced ice breaks easily but the reinforced, or composite sample is very difficult to break. |
| 2    | Hunt | To have students find samples of a material in the environment  
      |      | To heighten awareness of the pervasiveness of the material  
      |      | To generate thinking about uses of the material in the real world  
      |      | Example: The Polymers module has students collect as many examples of polymers, or “plastics” as they can find. Eventually the recycle codes impressed on each sample will be identified and named. |
| 3    | Research | To engage students in thinking and learning more about a material  
      |      | To engage students in using relevant technologies  
      |      | To engage students in writing for science  
      |      | Example: The Food Packaging module asks students to find out which type of bag to ask for at the grocery store, paper or plastic. Students’ develop their own research question and make the case for one or the other packaging material. |
| 4    | Quantitative Lab | To increase students’ content knowledge of science and mathematics in traditional lab setting  
      |      | To improve laboratory skills including measurement, observation, recording, drawing conclusions, etc.  
      |      | To work in groups to complete a prescribed laboratory  
      |      | Example: In the Concrete as Infrastructure module students conduct a series of experiments that relate to the properties of concrete. This background content knowledge will assist them when they design a concrete sample and test it for strength. The labs begin with an investigation into densities of aggregates, the exothermic nature of hydration of concrete, the effect of additives to the curing of concrete and how to test for the property of strength in concrete.  
      |      | To provide a design challenge with known outcomes  
      |      | To enable the teacher to control whatever aspects or variable |
| 5 | Teacher-initiated Design Challenge | necessary due to limitations of time or resources  
To engage students in collaborative design and redesign work with peers  
Example: In the Sports Materials module students must adapt the structure of a small wiffle golf ball by adding mass to the center, or materials to the outside so that it will perform in a series of different ways when dropped from a certain height, a certain distance from a target, and angle. |
| 6 | Student-initiated Design Challenge | The ultimate objective of the technological design based steps in MWM.  
To provide experience of student-centered learning  
To change the dynamics of the interactive learning experience for the student and the teacher  
To engage the teacher as a facilitator  
Not all the module topics have the capacity for getting to this point. |

It is important to note that the subject specific content of materials science that is provided for clarity in the above table was rarely mentioned in any teacher interview. There were a few exceptions. Karl discussed his past use of concrete as a test material when his students investigate forces in his physics class, and Bethany discussed a project based on recycling polymers which is further detailed in the next section. Both of these examples involve materials science content that had been adapted from MWM. Karen, because she has a group of students who are not in the mainstream educational system, uses the materials science content most often.

Although the MWM modules are based on materials science content, and the NCASE workshops faithfully present the modules as they are written, the teachers spoke almost exclusively in terms of their physics or physical science lessons although most of the participating teachers hold degrees in chemistry, and teach the subject along with physics. It was clear from the data that although the teachers take away both the
It is a testament to the value of this methodology, that regardless of student age or ability, and regardless of the subject or topic being studied, all the teachers repeatedly and exclusively talked in these exact same methodological terms. There were some slight variations; some teachers combined certain steps, and most skipped at least one or two of the steps. And most surprisingly, only one of the ten teachers shared an example of experiencing the sixth step student-initiated design challenge, which is the highest level activity present in most of the MWM modules. All the teachers, however, described at least one example of engaging students at the level of step five, the teacher led design challenge, as their best example of how they had implemented technological design in their secondary classrooms. The following is an overview that illustrates the most interesting or innovative approaches taken by the individual teachers as they implemented technological design based lessons.

The Hook

The first step in the MWM lesson structure and sequence is designed to “hook” students’ interest by initiating a topic with a seeming anomaly, a surprising demonstration, or a short hands-on activity. The hook is designed to generate a sense of wonder and curiosity, thereby motivating students to think about the topic in a different way, ask good questions, and want to learn more (DeBoer, 1991; Roth, 1996b; Roth, 2001). Six of the ten teachers discussed how they had invested time and resources in
making sure they included this step. Karen talked about her understanding of the importance of this step in the post-observation interview. She explained,

Today was the ‘get them engaged and get them playing’ day - the ‘hook’ day. Tomorrow I hope they start refining and tuning it down. It was fun to watch them play. I think we don’t give them enough time to play. I like to get the hook going, let them find something to explore, then come back to it later. I like to ask the kids the day after a hook day, “What did you find particularly interesting yesterday? Then we can move on. (Karen, Phase 2 post observation interview)

Karen’s use of the hook activity is more extensive than the other teachers, as she revisits the activity for the purposes of reviewing and re-engaging with her students.

The teachers all described various techniques they use to engage their students in thinking and to motivate them to want to learn more; although most approaches did not exactly mirror the MWM concept of the ‘hook’ activity, the intent and outcome is the same, to stimulate interest and wonder, and motivate students to want to learn more of the science behind the hook. For example, Cassandra, Karl, and Jack use questioning techniques to pique interest and extend thinking skills (Cazden, 2001; van Zee & Minstrell, 1997). Cassandra has her students move directly from this type of hook introduction to researching their own ideas on the internet. She presents many examples of machines or materials that represent the topic about to be studied, engaging students in asking questions and wondering about the things she is presenting to them. Colin and Lydia, both middle school teachers, gave examples of unique projects that were designed to engage students immediately in doing research and then design. Lydia’s hook with her fish project was first a field trip to the ocean and then researching, and then launching into a design project. Bethany described several examples of quick design challenges that she uses in her physics class. She has her students make the tallest structure possible
from one sheet of paper. This is one of the several traditional physics challenges discussed by several teachers that they incorporate as hook activities.

The Hunt

The second step is called the “hunt” activity. In the MWM modules students seek and collect examples of the material, or products that represent the material being studied. There were many variations on this theme. For example, Jack, Bethany, Karl, and Cassandra described bringing in unusual or unfamiliar objects, such as antiquated or bizarre tools, to try to engage students in thinking about how it worked, what its function could be, and how was it designed.

Bethany provided an example of using the hunt activity as the introduction to a project on the environment in her chemistry class. She has her students conduct a hunt in the school building and at home for polymers and classify them as having either been put into the recycling bin or into the regular trash bin. Her students then identify the types of polymers they have found, either from the recycle codes impressed into the bottles, plates, etc., or through experiment. The students collaborate and analyze the data they have collected to determine which department, or area the building has been the most efficient at recycling, which of the seven types of polymers is most often recycled, and what form it is in. They investigate the process of collection, sorting, and recycling that is established for their community. Bethany explained that “The objective is for students to understand how people are treating the recycled things, and how the industry works.” After gaining some insight into their community’s treatment of recyclable polymers, students do research on various aspects associated with their community’s recycling program, adopt a position, and then conduct a debate that Bethany called, “Encouraging
the community to be more green.” Through this activity Bethany expects her students
to have gained an appreciation for limited resources in our environment, and develop a
heightened awareness of their own social responsibility (Atkin, 1996; Bybee, 1999).

Karen explained that she always introduces new topics by providing multiple
samples of items that relate to the topic being studied. However, rather than expecting
her students to bring in items, she does the hunt and then encourages her students to add
to her examples. Karen uses these items to engage her students’ interest in the new topic,
as the ‘hook’. Cassandra’s approach to a hunt activity is to “Have students do a virtual
treasure hunt for information using the internet or other media outlets.” This approach
overlaps with the next step, the research activity, as do many of the examples discussed
by the teachers.

Research

The research activity, MWM step three, has three purposes; they are: (1) to
increase student background knowledge of a material in terms of its history or
development; (2) to engage students in using information technologies resources
available to them, and; (3) to have students practice skills associated with scientific
writing. Cassandra and Karen discussed their use of this step in most detail. Cassandra
often begins a new topic with a research component. Students spend their first lesson
researching the topic, collecting information, then create posters of their findings, which
they hang on the wall. After class, Cassandra conducts what she called a “wall tour” of
the posters. She condenses their ideas into several good questions that the students then
follow up on the next day. Karen’s approach is to respond to student questions and
conjectures that arise during class. As her students’ questions become more and more
refined, Karen suggests they find out for themselves by looking it up on one of the computers she has in her classroom. From the classroom observation is was obvious that Karen’s students were motivated and excited to find answers to their own questions in this way and then share those answers with her and with the rest of the class.

Quantitative Experiment

The quantitative lab activity, MWM step four, is usually set up as a science experiment that requires students to follow step-by-step directions written out by the teacher, sometimes called “cookbook” labs (Charen, 1970). These labs were repeatedly discussed by all the teachers, and were considered a valuable and necessary part of their methodological approach. Traditional science laboratories exclusively engage in this type of work, and the teachers recognize them as efficient methods of transmitting certain content knowledge to students, especially as part of the progression to a design project.

Teacher-initiated Technological Design

All the teachers discussed examples that represent step five in the MWM sequence. Six teachers gave examples that extended traditional physics investigations and used them with their physics classes. In each of these cases, student designed, built, tested, redesigned, and retested a product, but it was not a product that would, in and of itself, solve a real world problem. A few of the examples include: (1) Jack’s egg drop contest where students measure acceleration and force of impact; (2) Jack and Cassandra’s Rube Goldberg machines where students use their knowledge of mechanics to make energy transfers; and, (3) Karl’s toothpick bridge where students measure loads and calculate forces.
Several teachers discussed unique and creative examples. Karl described how he had his students design ways to organize and interpret data they had collected online from the SOHO satellite as it monitored the sun’s activities. Colin described having his students design superheroes based on their research into the elements on the Periodic Table. Lydia had her environmental science class design fish with adaptations that would allow them to survive in different habitats. This example will be more fully described later in this paper as a pedagogical strategy because of its cross-curricular implications.

Student-initiated Technological Design

Step six in the MWM progression toward technological design is supposedly the ultimate goal of the MWM pedagogical approach. At this level, teachers become true facilitators. They should guide students in various ways, provide resources, monitor safety issues, and support students in their creativity. Working at this level requires the students to bring all previous steps, or other background content and process knowledge and skills to bear in solving a real world problem. The students, working together in collaborative groups, create an artifact, or product to solve the problem they have decided upon. The process of refining the product will take students through stages of designing, building, testing, redesigning. Rodrigo gave the two examples of a water recycling system and a window covering that could conserve energy. These two projects, at the time of the interview, were based on his own ideas. In fact, only one teacher described step six where students initiated their own design. This was Cassandra. She explained,

Every group did their own thing. They were just turned loose and it was just complete, general idea design, trial and error. They were saying things like, “Oh that string’s not going to work. We need something like more of a yarn or it won’t be strong enough.”
She described three artifacts that students created,

One group had a ‘put the toothpaste on the toothbrush without your hands’ machine, one had an automatic tomato slicer, and one group developed a pants-puller-upper that was hands-free for someone’s grandmother whose back went out and couldn’t bend over. (Cassandra, *Phase 1 interview*)

This highest level of teacher implementation of technological design requires students have reached a level of content knowledge and process skills that will give them the background to be able to identify a problem, design a solution to the problem, test it, re-design it, and re-test it.

The possible impediments that could account for only one teacher able to provide an example of step six are perhaps obvious. All pose potential pitfalls and include, amongst others: (1) the time it takes to get students to this stage; (2) the open-ended nature of the work can be chaotic and unproductive at first; (3) the variety of resources students might need is difficult to predict; (4) the knowledge, skill, and experience required of the teacher can be daunting; and, (5) the likelihood that the investment in time and resources would have some degree of disconnect with any prescribed or standardized curriculum. In addition, the NCASE workshops do not often approach this level during professional development, even though many of the MWM modules do include a section for student-led design projects. It is perhaps unsurprising that even within this group of highly motivated, well trained, confident, articulate, and professional teachers; only one teacher discussed her experiences at this level of technological design.
Pedagogical:

Classroom Implementation of Technological Design and the Role and Responsibilities of the Teacher and Perceived Outcome for Students

The third category is a collection of pedagogical roles and responsibilities, identified by the teachers that take into account how student learning is impacted in a technological design lesson (Ball et al., 2008; Shulman, 1986). The six themes that emerged from the data help to further explain how teachers implement technological design in their secondary science classrooms. Each of the teachers discussed at least two of the six themes. There was consensus that technological design has enabled them to become more effective practitioners. The six themes are outlined below.

Table 3. Pedagogical Category: The Role and Responsibilities of the Teacher
Classroom Implementation of Technological Design and Perceived Outcomes for Students

<table>
<thead>
<tr>
<th>Teacher Role or Responsibility</th>
<th>Outcomes for Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instruction</td>
<td>increased motivation</td>
</tr>
<tr>
<td></td>
<td>heightened interactions with teachers</td>
</tr>
<tr>
<td>Facilitative role in the classroom</td>
<td>opportunities for self-directed learning</td>
</tr>
<tr>
<td></td>
<td>equality and collaboration with teachers</td>
</tr>
<tr>
<td>Classroom discourse</td>
<td>improved questioning and researching skills</td>
</tr>
<tr>
<td></td>
<td>highlighting of strengths versus weaknesses</td>
</tr>
<tr>
<td>Resource allocation and limitations</td>
<td>environmental and economic awareness</td>
</tr>
<tr>
<td></td>
<td>shared responsibilities</td>
</tr>
<tr>
<td>Curricular considerations</td>
<td>cross curricular topics</td>
</tr>
<tr>
<td></td>
<td>interrelated nature of science subject matter</td>
</tr>
<tr>
<td>Assessments</td>
<td>working at their own pace and ability level</td>
</tr>
<tr>
<td></td>
<td>individual sense of success</td>
</tr>
</tbody>
</table>
All are pragmatic concerns similar to those confronting secondary science teachers in any school. However, during the interviews the participating teachers brought up these themes in relation to how their technological design based strategies enabled them to respond to the needs of individual students. Therefore, the table above is organized to examine the outcome for student learning within each pedagogical consideration.

Individualized Instruction

Every teacher discussed the importance of individualizing instruction to meet the emotional, intellectual, and/or academic needs of their students. Most of the teachers made a connection between individualized instruction and student motivation to learn, and saw this as a high priority in their pedagogical approach. Jack, for example regarded individualized instruction as a motivational tool, and he explained how he got to know his students through the initial research and presentation assignment. Bethany provided an example of meeting the emotional needs of her students. She explained,

I’ve done my best to make sure that my foundation of knowledge is as superior as it can be. And then my biggest task is to make sure to apply it in as much sensible detail to whatever student enters my door. I try to individualize my instruction, no matter who walks in that door. If they happen to learn science in the room, that’s a wonderful thing. I focus on sentence structure, I focus on implementation of mathematical skills as they relate to the science, I focus on good manners, I focus on politeness, I focus on attention. When these kids, these general kids come into the room, they’re broken. They’re broken. They’re so used to education as a punishment. And perhaps my saving grace is that I’m not a traditional educator. I don’t say “No. You don’t do this, and you must do that, to get through my class.” Because I’m more like, “Thank you for doing that, and let’s try to do some more.” So I think my attitude has a lot of influence on helping the kids want to be successful. (Bethany, Phase 1 interview)
Bethany discussed her nurturing approach, and the troubled students she has in one of her classes. She explained that once she has gained their trust she is able to improve their self-esteem and their sense of being able to do well in science. This is how she motivates many of her students.

Karen’s lessons are highly active and engaging, and yet highly structured. Karen represents the teacher whose lessons are most closely based on MWM mechanisms learned through the NCASE workshop. She was the only teacher who mentioned having her students keep journals for example. She connects personally and privately with each student through their journal writing, but also has them share their entries with the rest of the class on occasions. Karen follows the MWM sequence of lessons, but tries to remain completely flexible. In this way she allows her students to follow their own path, but with clearly defined boundaries. This is an effective strategy for her particular students.

Karen explained the importance of remaining open-ended and flexible in her teaching, “I try to leave it open ended because it is interesting to watch as the kids will gravitate towards whatever is their best mode of learning.” She continued, “I like just walking around and seeing what they come up with. I was tickled with the telephone that a couple of them did. It’s interesting, when you make it open-ended, I find they will revert to what they already know, and then I can get them to take it just a little bit further.” This is exactly what individualized instruction should accomplish.

Facilitative Role in the Classroom

All the teachers considered themselves to be facilitators. Many discussed their techniques for engaging their students in higher order thinking through effective questioning (Johnson & Johnson, 1994; Shor, 1989; Shor & Freier, 1987). As
facilitators, they saw themselves as being flexible and responsive to their individual students, and could adapt their own thinking to match with the divergent thinking and activities taking place within the classroom at any one time (Johnson & Johnson, 1994). Technological design lessons require students to be self-directed, and the learning to be student-centered (NRC, 1996, 1999, 2000, 2001). Karen exemplified this in her classroom. She was adept at finding the customized key into each of her students’ locked up interests and intellect. Karen described her pedagogical approach, “I would say my role is to facilitate. I am here to help facilitate their learning. I am here to question their learning. I’m here to guide with questioning into a little bit deeper thought process. That questioning is how I facilitate. It makes a difference. I know it’s cliché but it makes a huge difference.” Lydia also defined her role in the classroom as that of a facilitator. Lydia explained, “I am definitely a facilitator – a starter – I get them started. For some of them I am a reminder to stay on task. I am there to kind of lead them in a direction. I really try not to give them answers. I make them look because they have the ability to find the answers themselves.” These facilitative behaviors acted to scaffold learning for their individual students in a variety of different ways (Vygotsky, 1978). As facilitators, the teachers engendered a non-threatening environment supportive of student-centered learning, where students could test their own ideas, and answer questions that they themselves had formulated, rather than answer questions and solve problems generated by the teacher (Roth, 1995).

Classroom Discourse

Classroom discourse includes verbal interactions between students and between teachers and students. Questioning techniques are an important part of effective
classroom discourse. In the post observation interview, Karen discussed one example
of a discovery that was made by a student during a physical science lesson where
students were investigating tuning forks. Karen explained how this interaction affected
her,

And then I got tickled because they took that 2 liter bottle and they filled
it with water - they had it empty at first, and they were doing the tuning
fork on the side. Then they filled it completely with water and they put
the tuning fork on the side and they said, “Look, Miss, I don’t get any
sound.” I said, “Well, is that the same tuning fork?” They said, “Yeah.”
I said, “What do you think?” They said, “I think the sound is trapped in
the bottle.” So then Valerie said, “Can we put a microphone in there and
see if the sound is trapped in the water?” And I thought, “Perfect!”
(Karen, Phase 2 post observation interview)

In this example, once Karen had encouraged her student to verbalize her observations, the
student’s questions began to come into focus, and resulted in a question that could then
be tested (Johnson & Johnson, 1994; Shor, 1989; Shor & Freier, 1987). If the classroom
environment and the teacher can encourage discourse such as that exemplified by Karen
in this example, verbalization of such a question inevitably leads to further, more
sophisticated questions and observations, and ultimately to testing, re-designing, and re-
testing until an answer is found.

Karen gave another example of a different type of classroom discourse,

When they’re done with their labs I ask them to share their “aha”
moment – or what they learned from this activity. They will usually
come up with the connections themselves when they are sharing what
they learned. That’s where the largest number of connections occur,
which is kind of funny because I think one of the big things we, as
teachers, don’t do - is, we don’t allow for, or set up for, free dialogue
within the scope of a topic. (Karen, post-observation interview)

Karen explained that she uses these verbal interactions as an effective summation at the
end of a lesson or topic.
Resource Allocation and Limitations

Resources are always a concern for science teachers. Technological design lessons can require more and unconventional types of resources than traditional science lessons because students are ideally supposed to be drawing upon their own innovative skills and ideas to build and design artifacts. In response to these pressures, the teachers involved with the NCASE workshops are all in contact with their local DoD base, and for many of the teachers this has meant additional resources, usually in the form of teaching materials, have been allocated to them. Seven of the ten teachers brought up ways they had been positively impacted by the MWM and NCASE involvement with the DoD. All four of the teachers who took part in Phase 2 of this research study have benefited from having S&E’s working in their classrooms with their students. Karen discussed one aspect of how the S&E’s had helped her,

In order to do your job as a teacher there are two types of frustrations you have; one is from having a steep learning curve, and not having enough time to learn some of the new technologies. The S&E’s come in and help reduce that learning curve for you. They’ll come out into the classroom and help you with that. The other frustration that you have is funding for the tools and resources that you need to do the job for teaching. The DoD runs space symposiums and other contests that provide funding for kids to design their own STEM. This money helps offset that a lot. Even coming out to the workshops to get the modules helps offset the frustration of not being able to have the tools because I love the modules and they give me the tools to teach with. (Karen, Phase 1 interview)

Karen, Angela, and Lydia have all won grants to support their technological design work, usually offered by large corporations; they have entered their students into various contests and won prizes; and, they all maintain close contact with their PoC’s and S&E’s. Of all the teachers, Rodrigo’s resource base is by far the poorest, but he has not been able
to secure any additional funds through grant writing. He does receive support from his S&E who comes to his classroom when asked, and advice from the PoC at the local DoD base, but not in the form of actual materials or technologies. Others have been given white boards, computer software and hardware, and provided with MWM kits when they attend the NCASE workshops. Irrespective of their individual circumstances, each of the teachers has had to look beyond their own school for the resources they needed.

Of all ten teachers, Rodrigo was the only one to mention a lack of resources as a limitation to his implementation of technological design. His concerns were certainly justified as witnessed during the observation. His classroom had one yardstick, and one triple beam balance for his twenty students to share. There were no meter sticks, digital balances, or computers. The room was stark, with no posters on the walls, the desks were original to the building, and bolted to the floor in a large square pattern around the periphery of the room. He explained, “I’ve been working on creating a budget with the school district for three years and they say they have money for projects in science, but only up to $150 or $200, which is pretty useless.” The disparity of resource allocation is somewhat mitigated by the DoD involvement with the schools and teachers in this research study; which is not the case with all schools around the country.

Curricular Considerations

Several teachers talked about their approach to technological design leading naturally into cross-curricular integration. The best illustrative example came from Lydia. On the day of the classroom observation, Lydia’s environmental science students were designing fish that had to survive in a certain habitat that each group had described. Students first drew a picture of their fish with the physical characteristics necessary to
survive in that environment, and then designed and built a model of their fish. Lydia had prepared her students by taking them to the Gulf Coast, which is only a block from the school, several times, to collect and observe the plants and animals there. She had given them a limited number of simple but informative and beautifully illustrated books that pictured real fish and included many different statistics about their bodies and behaviors, and from which the students could choose which body parts, such as teeth, fins, colors, shapes, eyes, sizes, etc., their habitat would require the fish to have. Lydia explained that “this project is my pathway to the next topic, which is genetics.” Lydia’s introduction to the complex and abstract concept of genetics was to invest her students’ “energy and interest in understanding the outcome first, and then work backwards to cellular structure and DNA.” She continued, “I think this approach will help them understand it better because they always have trouble with this topic.” When she was deciding how to introduce the biology topic, Lydia turned to the familiar sequence of the MWM methodology. She had incorporated the field trip as the hook and the hunt, she had provided resources for research purposes, and had then given them freedom to design their own fish.

Types of Assessments

It is often difficult to create a meaningful assessment that fairly reflects student achievement in a technological design based assignment. Students are expected to work at their own level, work collaboratively, and create products that will all be unique. When asked what should be in place to make technological design lessons successful, five of the teachers included assessments as being important, and that the assessment tool should be made available to students before the start of the lesson. Most often teachers
described some form of a rubric. Jack discussed his technique of using rubrics together with student to student critiques as his assessment tools. Two teachers allowed their students to write their own rubrics. Karen described her use of rubrics,

I love rubrics. You can make your own rubrics online using RUBISTAR. It’s awesome. You can choose anything you want. You can make it very specific for any assignment that you’re giving. I find the students need to know before they start working. If you have it in writing, it’s a lot easier for them to gauge what it is you’re looking for instead of them saying, “I’m not sure what I’m supposed to be doing.” You can make it as open ended as you want. You can include questions like “Does your design help to answer the question?” That works really well for design lessons. It’s a fair assessment then, not connected to any other parameters. And then your can base your points on that alone if you want. (Karen, Phase 1 interview)

Rubrics that are customized or any other form of individualized assessment help to foster a non-threatening classroom environment for students; one where they know exactly what is expected of them.

Two teachers discussed how they conduct ongoing assessments through classroom discourse. Angela explained how she can monitor and assess her students’ progress, in a formative sense, by observing their behavior. She said,

They told me they didn’t want any introduction at all, they just wanted to do it. So, I was really just listening to what they were saying to each other because by listening to their questions, if they had been able to question each other better, I would know that they actually knew what they were doing and they just needed more time. But I could see that they weren’t even really able to formulate questions for each other. Only one kid was able to ask me questions, but even then he wasn’t asking me full questions. He had an idea of what he wanted to ask me, but he can normally formulate a much more detailed specific question; so even he was a little bit iffy on the whole situation. So I knew that they actually did need more direction, that’s why we had our little chat at the end of the period. I knew we were going to lose a day when they insisted they did know what they were doing when they said, “No we already know how to program, just let us go.” So it was their decision. (Angela, Phase 2 post observation interview)
Cassandra gave an example of how she allows her students to create their own rubrics and assess their fellow classmates and themselves. Authentic assessments are difficult to create. Rubrics can come close to satisfying the requirements of being flexible and responsive to individual student needs, assessing creativity and communication skills, and to allowing teachers to focus assessment on the aspects they want to emphasize from year to year.

**Conclusions**

The common opinions and behaviors related to the teachers’ understanding and implementation of technological design that emerged from the data as categories and themes form the basis of the analysis in chapter five. The conclusions that can be drawn from this research and data analysis will be considered with respect to the teachers’ beliefs and practices.

**The Teachers**

Most of the teachers who participated in this study had begun their professional careers in industry, but found themselves drawn to science education and then to technological design. The reasons for this could be due to many factors, which were not pursued as part of this research, but do constitute a valuable insight into these teachers’ beliefs and behaviors. For example, the teachers could have been attracted to technological design based lessons because: (1) they recognized the importance of using science in a real world sense, and technological design meets that requirement; (2) their appreciation for science, as adults who hold degrees in the subject, has influenced or empowered their lives so greatly that they want to pass this on to the next generation; (3)
they enjoyed the ongoing and ever changing challenge of teaching the subject, or; perhaps it is a combination of all of these emotions and altruistic behaviors. Whatever the reasons, these ten teachers were a purposeful sample who had a lot in common with each other.

Teachers’ Goals

The teachers repeatedly stated that their goal was for their students to love science, and for them to be able to use science to solve problems in the world and in their personal lives. Conclusions to draw about the learning goals for their students include the surprising finding that almost all of the examples of technological design lessons discussed in the teachers’ narratives were actually traditional physics experiments that had been left more open ended than in the past, or made to become more collaborative amongst groups of students. There was very little mention of teachers extending any form of technological design into chemistry and biology. There were several examples where environmental science was the subject matter being studied. The safety issues associated with chemistry and biology might account for the rarity of these examples. In addition, not many teachers described instances when their students conducted testing, redesigning, retesting in their examples, even though this is an aspect of MWM methodology, and an important part of the NSES description of technological design.

Other commonly held goals that all the teachers shared related to their own understanding of pedagogy. Many of the examples recounted by the teachers involved their attempts to induce metacognitive experiences for students, where content and process found a balance, although they never identified it themselves as metacognition. One of Jack’s examples included the culminating exercise in his AP physics class, to
build a Rube Goldberg device, was so that Jack could assess their learning, and in turn reflect on his own performance as the teacher.

Teacher Achievements

Other striking similarities shared amongst the participating teachers include how each interpreted technological design based science lessons, and that they expressed very few doubts or regrets about their practice. These teachers are sure of their approach, and enjoy a high level of confidence and support within their schools. All provided evidence of their innovative ability, their broad range of skills, and their dedication to improving their teaching when possible. They all believe that using a technological design based pedagogical approach allows them to remain flexible, and responsive to the individual needs of their students. All described instances of their teaching of the same topic changing from one year to the next or, most commonly, from one hour to the next. In several cases, even as the teachers discussed a lesson they had experienced in the interviews, he or she would be reinventing or reassessing the lesson being discussed.

One of the interesting conclusions drawn from the data is that although all the teachers had numerous examples of their students working on technological design projects, according to MWM methodology, the level of the students’ work was most often representative of step five, and not step six. The MWM six-step methodology has in-built structure and the suggestion of a sequence of steps of increasing complexity, leading to the most complex step being student-initiated design. Even for these teachers, it seems that finding ways to engage students themselves in self-defined technological design project work was a stretch. The reasons why this happened are likely to involve various resource based limitations or constraints, such as, time, money, materiel, or
expertise, although these were not often discussed by the teachers. In fact, with one exception, the teachers expressed no understanding or awareness of the existence of step six or student-initiated design as an option. This may be related to the fact that NCASE rarely gets teachers to this point in its professional development sessions, even though most of the MWM modules do include it in the teaching materials. This may be an area that requires further development and practice, and leaves a gap that can be addressed in the future.
CHAPTER SIX

IMPLICATIONS OF THIS STUDY

Introduction

This chapter considers the implications that can be drawn from this study, with regard to how the teachers understand and implement technological design in their secondary science classrooms. These implications include how the data, MWM, professional development, and technological design have, to this point in time, interacted to meet the standards for effective science education set out in NSES (NRC, 1996).

At this point it also appropriate to introduce the latest iteration of national science standards, presently known as A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2011). Since the initiation of this research study, NSES standards, used to describe technological design for the purposes of this research, have evolved into a new standards document. Technological design has been renamed, expanded upon, and clarified, and will be known as engineering design in the future. In order to examine how the implications drawn from this study will play out in the future, it is necessary to examine how the old standards of NSES compare with the new standards as they are described in the Framework document. A brief comparison will be included in this chapter as will a discussion about the limitations of this study.
This Study

This study examined the beliefs and practices of a select group of science teachers whose approaches to teaching have been influenced by NSES (NRC, 1996) and MWM, but whose passion for their work has taken them beyond these bounds. Despite the fact that the teachers were confronted with different challenges on a daily basis, such as teaching different science subjects to middle and high school aged students of all ability levels, in urban, suburban, and rural settings, all relied on their own interpretation of technological design to motivate and engage their students in learning science. They all sought increased responsibilities and more effective experiences for themselves, and in turn, for their students. As such, the implications that can be drawn from this study examined in this chapter will focus on aspects other than those associated with the teachers.

The Data

The data that was collected in this study was analyzed using a phenomenological approach. Each of the teachers who took part in this research interpreted the semi-structured interview questions in different ways, and hence responded in different ways. The initial categories that emerged, the theoretical, methodological, and pedagogical were a starting point, but were obviously too broad. Once the data had been sifted and teacher responses had been more discreetly interpreted, the various themes that fell within each category began to take shape. Even so, teacher “understanding” and “implementation” were not always separate entities that could be discussed in isolation. The teachers all used examples of their teaching experiences, or their beliefs about their teaching responsibilities to answer the interview questions. These richly textured
narratives had to be interpreted, with the intention of remaining faithful to the original intent of the participants (Kvale & Brinkman, 2009; Geertz, 1973).

Because the research question delineates between understanding and implementation, the analysis is separated to respond to these two ideas. However, in reality, during data collection and analysis it was evident that the teachers could not explain how they understood technological design. The concept of understanding technological design was not a static reality for any of the participating teachers. Rather, understanding and implementation are dynamic and interdependent. The two evolve together, and teacher interpretations changed even as they discussed their ideas during the interviews. Teachers’ experiences of taking part in the Phase 1 and Phase 2 interviews for this research project affected how they came to understand the role of technological design and ways to implement it in their classrooms. Several teachers even described the actual interview experience as being a professional development experience that affected their plans for implementing future lessons.

MWM

MWM has been the most influential source supporting the propagation of technological design around the country, with respect to both its teaching materials, and its role in the professional development of teachers. Although there was little evidence of the crossover of the actual content based on materials science, upon which MWM and the NCASE workshops focus, into the actual classrooms, all the teachers gained a significant understanding of how to conduct a technological design based lesson thanks to the methodology of MWM. Its role in providing a forum within which these likeminded teachers could form a knowledge community (Craig, 1995; Seaman, 2008), in providing
a platform upon which NCASE could function, not least because of the financial and technical support from the Department of Defense (DoD), and setting a high standard for the quality and nature of this approach to science education can not be underestimated.

Professional Development

The unique professional development program from which the study sample was drawn implies the need for such ongoing support in the future. All the teachers had been to several NCASE summer workshops, and all had a close connection with their local DoD bases through their points of contact (PoC’s) and scientists and engineers (S&E’s). All expressed the high value they placed on the quality and effectiveness of the professional development they had received. They all expressed some example of how their teaching continually evolved because of their involvement, and that their repeated attendance at the workshops was the key to its impact on their teaching. This research highlights the importance of supporting teachers like these, who are innovative, creative, and who seek to primarily influence the next generation to love science and science learning. There are very few similar opportunities for professional development, and this is unfortunate. The cost is high, and without DoD funding and manpower, the NCASE program would not be able to function to such a high standard.

Technological Design

The data analysis has revealed that the teachers who use technological design do so because they appreciate its potential to engage and motivate students to love science. According the teachers, the reasons for this are not always cut and dried. It does provide a forum within which a real world approach to science can flourish; where real problems can be tackled, and where failure becomes a positive learning experience, as in the real
world. It makes science relevant. All ages and abilities of students can be successful. It provides students an experience where their intellect and physical dexterity are developed in conjunction. So, then, why are there so few adherents, and so few possibilities for teachers to learn about it and become adherents? Perhaps this is because the drawbacks are in the difficulties it poses for teachers. It may be the reason why only one of these committed teachers could discuss getting her students to design their own products. Technological design requires a lot of precious time to prepare and then allow students to do design work. To teach technological design, the teacher must be extremely confident in his or her science and technical knowledge and classroom management skills. The teacher must be experienced enough to remain infinitely flexible and responsive to each student as an individual. The teacher must be willing to consider all kinds of ideas that students might want to pursue, and have a lot of resources available for them to do so. The teacher must have a sense of how to assess learning both academically and socially, and to continually be questioning and encouraging and pushing students to think in a different way, or to perhaps try another approach. It is clear that all the teachers who took part in this research study have these qualities; they found technological design because they have these qualities and it has served its purpose for them.

**The New Framework Document**

The implications drawn from this study coincide with the objectives outlined in the recently circulated pre-publication of a new and updated set of national standards for science education that will eventually replace NSES (NRC, 1996). This newest iteration of standards resonates with the findings in this study because it has expanded and
intensified the role of technological design in science education. The new standards
document, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* was pre-published by the National Research Council (NRC) and the Committee on a Conceptual Framework for New K-12 Science Education Standards on July 19, 2011. Underscored by what is likely to represent another pivot point in effective science education, the findings of this research study provide data and data analysis relevant to teaching science in the future. The data collected in this study can provide insight into how the new science standards may eventually be interpreted in practice, since it focused on how teachers understand and implement technological design. As such, a brief synopsis of NSES (NRC, 1996), or the “old standards” will be compared with the “new standards” from the Framework document (NRC, 2011).

**Old Standards compared with New Standards**

In the 1996 NSES document, eight categories of content standards emerged. They are: (1) Unifying concepts and processes in science; (2) Science as inquiry; (3) Physical science; (4) Life science; (5) Earth and space science; (6) Science and technology; (7) Science in personal and social perspectives, and; (8) History and nature of science (p 104). The first content standard, called unifying concepts and processes, “transcends disciplinary boundaries” and grade differentiations (p 104), but the other seven are clustered into three groups of different grades K-4, 5-8, 9-12. The “Abilities of technological design” is the title of the main topic in the Science and technology content standard, and is listed as such for each of the three grade clusters (p 135). The most important standard is the second content standard, “Science as inquiry” or inquiry. Inquiry is defined as strategy or a fundamental approach to be used by teachers to deliver
the other content standards. In NSES (NRC, 1996), inquiry is explained as referring “to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as how scientists study the natural world” (p 23). Numerous follow-up documents were subsequently published to try to further clarify the meaning of inquiry learning (NRC, 2000a, 2000b, 2005, 2006) and how to teach using inquiry based strategies (NRC, 2001, 2002). So much attention was lavished on inquiry that the other six content standards were largely ignored (NSTA, 1990).

The new Framework document (NRC, 2011) will eventually supplant the 1996 publication of NSES, however, at the time of writing this dissertation NSES (NRC, 1996) remains the national science education standards. It is through NSES that technological design was first and most clearly described and delineated, and whose definition is at the basis of this research study. The future direction of American science education and curricula is, however, going to be determined to great extent by the new Framework document and how it is interpreted by policymakers, curriculum designers, science teachers, and professional development providers. Although still in pre-publication, it is evident that the Framework document has managed to move very far ahead of NSES in providing a vision of science education that has tangible substance, practical application, and attention to detail. This is due in large part to the fact that the Framework document pairs science equally with engineering, thus changing the objective of science education.

Many of the implications drawn from the research undertaken in this study resonate with the curriculum content, skills and processes, and methods of assessment outlined in the Framework document. This study, therefore, is a timely one. It is hoped that the conclusions drawn from this research study will help to inform, guide, and
reassure those interested parties of how to implement the new standards. In the

*Framework* document science is on equal footing with engineering. This is a monumental
departure from the past. A relevant passage from the *Framework* document reads,

> Engineering and technology are featured alongside the natural
> sciences in recognition of the importance of understanding the
> designed world and of the need to better integrate the teaching
> and learning of science, technology, engineering, and
> mathematics. (*NRC, 2011, p 1-1*)

The chapters in the *Framework* document also reflect the differences between the old
standards and the new. Chapter 3 or Dimension 1 includes the “Core Ideas in
Engineering and Technology” which are on equal footing with the “Core Ideas in the Life
Sciences”, the “Core Ideas in the Earth and Space Sciences”, and the “Core Ideas in the
Physical Sciences”. Chapter 4 or Dimension 2 is concerned with “Cross-Cutting
Elements” where science, engineering, and technology are examined as integrated
subjects. Chapter 5 or Dimension 3 is concerned with “Scientific and Engineering
Practices” where the work of scientists and engineers is compared and contrasted.
Chapter 6 or Dimension 4 is concerned with “Performance Expectations” or assessing
student progress. Chapter 7 or Dimension 5 is concerned with “Prototype Learning
Progressions” that will follow student learning progression from K through grade 12.

The *Framework* document will take American science education into a new
phase, and represents the next pivot point of change as it encompasses new content and a
new process profile. Science will be approached in a real world context that includes
engineering, design, and technology; without which science can not exist, and vice versa.
Future Implications

It is hoped that practitioners and consumers alike will embrace the new standards. It may be, however, when reviewing how NSES was disseminated and adopted, that whereas the intellectual community and educational policymakers readily accepted NSES, the teaching and K-12 education communities met NSES with trepidation, resistance, and avoidance. The Framework appears to represent a much bigger divergence from the norm than NSES called for; therefore, all involved will need to be supported in more effective ways as they face these changes. It is hoped that the conclusions drawn from this research study can help in that endeavor.

Teacher Understanding and Classroom Implementation

The new Framework document (NRC, 2011) reveals that the science lessons of the future will require transcendence of the discrepancies mentioned above. Therefore, it follows that not only should physics be part of all science teachers’ background and preparation for teaching, it should be central to all students’ science education in preparation for the new standards. In addition, the emphasis on design that is evident in the Framework suggests that technology departments and science departments will need to become more effective collaborators or perhaps even merge together. The teachers who took part in this study recognized the intrinsic importance of instilling an appreciation for design in their students. All the teachers described numerous examples of how teacher-initiated design projects, and repeated the MWM mantra of ‘design, test, redesign, retest’, but only one teacher provided one example of students initiated design projects.
Future Professional Development Model

Another implication of this study relates to the influence of really well developed and targeted professional development programs. Based on the expected demands of the new Framework, some conclusions about professional development can tentatively be made. First, the approach taken by NCASE and MWM is extremely valuable in its methodology if not in its content. There will likely be some place for materials science in the new science standards, but it appears to be more likely that the traditional subject disciplines of physics, chemistry, biology, environmental, and earth sciences will continue to exist as somewhat separate entities, even though their core content is expected to be combined with engineering, engineering design, and the cross-cutting themes described in the Framework.

One of the implications from this study is that in order to use time, energy, and resources to the best advantage, professional development models should allow teachers to build upon their existing resources and help them to adapt and ultimately adopt the new standards. According to the U.S. Department of Education Institute of Education Sciences, the future of professional development is “ongoing rather than one time events focusing on teachers' own practice rather than someone else's pedagogical formula” (http://nces.ed.gov/surveys/frss/publications/2001088/index.asp). Teachers need the skills to customize the experiments and assessments around which they have built their pedagogical content knowledge. A new professional development model could look something like this: (1) teachers bring their traditional lesson plans to work within their knowledge community; (2) teachers collaborate with others who have knowledge and experiences they lack, and; (3) teachers, as gatekeepers to their own classrooms, will
adapt these existing lessons to meet the requirements outlined in the new Framework document, in the post-technological design standard, now described as engineering design.

Technical and Financial Support Systems

The value of the technical and financial support that was enjoyed by all of these teachers represents another implication that can be drawn from this study. For Angela, Karen, Rodrigo, and Lydia, in particular, the close working relationship each was able to rely upon with their PoC’s and S&E’s impacted and enhanced their students’ classroom learning experiences. Without DoD funding, NCASE would not have been able to provide such high quality, ongoing professional development. Therefore, some type of structured, focused support network would be beneficial.

Limitations of the Study

This study was limited in that it included only ten teachers. Although they came from diverse schools in different parts of the country, they were alike in their motivation, their own science backgrounds and degrees, their philosophical beliefs about technological design, and their connections to the DoD, PoC’s and S&E’s. These results should be taken as overview, a glimpse into how these teachers think and act as they carry out their professional duties. It can not inform us about other teachers in other circumstances teaching different students.

The study was limited to only one interview with six of the teachers. The four teachers who took part in Phase 2 were interviewed before and after the classroom observation, but they were observed teaching for one day only. More reliable data could be collected using the same research method of phenomenology with ethnographic
observations with a larger sample, or with a series of recurrent interviews and additional observations. The use of field notes combined with filming would provide more accurate and more intimate data.

Additional questions might have helped to explain certain findings. For example, the interviews could have included questions asking the teachers why they had become disillusioned about working in the chemical industry. Steve and Angela discussed that it was because they found it monotonous and unproductive. The altruistic characteristics that many of the teachers hinted at could have been further investigated, possibly leading to a better understanding of how and why all the teachers discussed their objective of motivating their students to love science and science learning. The reasons why this was so prevalent in all the narratives, unfortunately, remain unclear.

My own personal experiences with technological design may have influenced the interviews and observations, and the analysis of the data. Because of my long association with NCASE and MWM, the teachers may have been more likely to discuss their work in the terminology and through the methodological approaches associated with MWM. Although I felt that the strongest connection I made with all the teachers was not because of MWM, and few of them discussed actual modules in their narratives, but as a science teacher whose experiences of technological design were common to theirs. However, there is no way to be certain of this.

In Conclusion

The teachers have remained committed to teaching technological design, and all found their way to NCASE and learned about MWM. The data shows that these teachers share certain core beliefs about their teaching practice, even though their responsibilities
vary across a range of subjects, students, and classrooms. The timely pre-publication of the new *Framework* document has provided insight into the direction science education will be taking in the future. It validates the beliefs and practices of these participating teachers, in a fundamentally powerful way that reflects positively on this research. The mainstream science teacher and classroom is likely to resemble these teachers more and more as the new standards are required. How this will happen, and how teachers will be supported as they endeavor to transition to meet the new standards is unclear. However, it is possible that the findings of this study will assist somehow. How the teachers understand and implement technological design is hopefully a little clearer in the minds of those who have read through this dissertation. As in all human endeavors, it is a complex interplay of multiple considerations.
APPENDIX A

PHASE 1 INTERVIEW PROTOCOL
PHASE 1 INTERVIEW PROTOCOL

Semi-structured interview questions

1. Please tell me about your background and your current teaching responsibilities.

2. How do you understand the idea of effective science education?

3. Please explain your understanding of these terms:
   a. Nature of science
   b. Inquiry based learning
   c. Hands on learning
   d. Technological design

4. How do you include these ideas into your pedagogy?

5. What needs to be in place in a lesson to ensure successful implementation of technological design?

6. Please describe an example of a lesson when you would use any or all of these ideas in your teaching pedagogy?

7. In this example, please describe the science content you feel is necessary for the lesson to be successful.

8. In this example, please describe your general pedagogical approach to ensure the lesson is successful.

9. What supports have you encountered in achieving success in implementing these teaching strategies?

10. Please give an example.

11. Has your teaching style changed throughout your teaching practice?

12. Please give an example.
13. Would you be interested in continuing our discussion by meeting with me for a second interview, then allowing me to observe a lesson where you incorporate technological design methods, and then talking to me again in a post observation interview?
APPENDIX B

PHASE 2 INTERVIEW PROTOCOL 1
PHASE 2 INTERVIEW PROTOCOL 1

Pre-observation interview - Semi-structured questions

Thank you for agreeing to this second interview and subsequent observation of a technological design lesson that you will be teaching.

Please describe the lesson that I will be observing. Please answer these pre-observation questions:

1. How is the lesson introduced?
2. What activities will be included?
3. How often have you taught this lesson?
4. Have you made innovations? Please explain.
5. How would you describe the students' experience and knowledge base before the lesson?
6. What scientific content do you think will be most important for this lesson to be successful?
7. What skills do you think will be most important for students to have mastered for this lesson to be successful?
8. How would you describe the learning climate in the classroom during this type of lesson?
9. How do you support students during the lesson?
10. How do you inform your students of your expectations?
11. How do you interact with students during the lesson?
12. How do you assess student learning during this type of lesson?
13. How do you manage the classroom during this type of lesson?
14. How do you characterize your role during the lesson?

15. How do you manage time constraints?

16. How do you monitor student learning during the lesson?
Description of classroom:

Classroom layout:

Teaching events during the lesson:

<table>
<thead>
<tr>
<th>Topic</th>
<th>Number of occurrences</th>
<th>Themes</th>
<th>Cultural context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addressed real world problem</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Content knowledge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process skills</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student learning objectives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assessment</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX D

OBSERVATION PROTOCOL 2
### OBSERVATION PROTOCOL 2

#### Phase II - Teacher Behaviors

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>SUPPORTING PEDAGOGICAL STRATEGIES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Does the teacher:</strong></td>
<td></td>
</tr>
<tr>
<td>Introducing the topic</td>
<td>Take the approach that the design is a challenge – intellectually and socially. Ensure that the design problem has importance and relevance to student interests.</td>
</tr>
<tr>
<td>Questioning</td>
<td>Develop student ability to ask good questions. Encourage ongoing questioning. Help students refine and focus questions in order to get to the investigation stage. Allow students to shape the project.</td>
</tr>
<tr>
<td>Collecting and analyzing data</td>
<td>Help students design good ways of collecting empirical, unambiguous data. Make empirical evidence accessible to all students. Help students reflect on prior learning. Establish a set of accepted criteria for good design ideas.</td>
</tr>
<tr>
<td>Pursuing explanatory goals</td>
<td>Help students understand how the design idea contributes to performance. Help students recognize limitations in their designs. Encourage discussion of surprising results. Help students find ways to improve through redesign.</td>
</tr>
</tbody>
</table>
APPENDIX E

OBSERVATION PROTOCOL 3
# OBSERVATION PROTOCOL 3

## Phase II - Cultural Context

<table>
<thead>
<tr>
<th>With students</th>
<th>With classroom and larger environment</th>
<th>With colleagues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evidence of encouraging recording, reflection, inclusion of interdisciplinary nature of the topic</td>
<td>Note limitations</td>
<td>Evidence of discussions and clarification of meanings</td>
</tr>
<tr>
<td>Technique of enhancing science literacy and subject conceptual matter</td>
<td>Note available resources</td>
<td>Evidence of including metacognitive processes</td>
</tr>
<tr>
<td>Use of cooperative grouping – structured or unstructured – group dynamics</td>
<td>Use of supporting technology – word processing, web based, interactive learning</td>
<td></td>
</tr>
<tr>
<td>Evidence of incorporating expectations of iterative cycle of design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evidence of questioning technique – voice of teacher – generation of questions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX F

PHASE 2 INTERVIEW PROTOCOL 2
PHASE 2 INTERVIEW PROTOCOL 2

Post-observation interview

Please answer these questions:

1. How do you think the lesson went based on what you intended?

2. What aspect or aspects of the lesson would you say were most effective?

3. What aspect or aspects of the lesson would you say were least effective?

4. Did anything surprise you?

5. Would you change anything if you conducted the same lesson tomorrow?

6. Did the lesson change your understanding of technological design?
APPENDIX G

CONSENT TO PARTICIPATE IN RESEARCH
CONSENT TO PARTICIPATE IN RESEARCH

**Project Title:** How Do Secondary Science Teachers Understand and Implement Technological Design in their Classrooms?

**Researcher(s):** Kathryn Heroux

**Faculty Sponsor:** Therese Pigott

**Introduction:**
You are being asked to take part in a research study being conducted by Kathryn Heroux for a dissertation under the supervision of Dr. Therese Pigott in the Department of Education at Loyola University of Chicago.

You are being asked to participate because you are a secondary science teacher who has participated in a professional learning program that emphasizes technological design in science, technology, engineering, and mathematics (STEM). There will be approximately five teachers who will be participating in this research project. Criteria for selection of participating teachers is based on their experience with teaching technological design, teaching science for a minimum of five years, and possessing a diverse subject specialization background.

Please read this form carefully and ask any questions you may have before deciding whether to participate in the study.

**Purpose:**
The purpose of this study is to provide empirical evidence of exemplary teaching practices and development of new strategies and methods to meet the demands of the National Science Education Standards (NRC, 1996) for technological design.

**Procedures:**
If you agree to be in the study, you will be asked to:

- Take part in a Phase I interview that will take place at Garrett College, McHenry, MD during the week long professional development session sponsored by CASE. This interview will explore your background, your beliefs about effective science education, your beliefs about technological design, and how you implement these beliefs in your secondary science classroom. The interview will take approximately one hour, and will be digitally recorded. The researcher will also take handwritten notes to supplement the recording.

- Take part in a Phase II pre-observation interview that will take place at your school. The interview will focus on details of the upcoming observation. This interview will include the problem you will address in the lesson to be observed, the intended activities, the targeted content knowledge, and the scientific process skills and learning objectives. This interview will take approximately 30 minutes, and will be
digitally recorded. The researcher will also take hand written notes to supplement the recording.

- Take part in a Phase II observation of a lesson that you have chosen to represent a technological design based science lesson. This observation will take place in your classroom and continue for the duration of the lesson. The observation will focus on the details you outlined in the pre-observation interview, including the type of practical activities used in the lesson to address a specific, real world problem by integrating and applying scientific content knowledge within scientific processes. Evidence of your role as the teacher will also be gathered through this observation. Hand written notes will be taken during the observation by the researcher.

- Take part in a Phase II post-observation interview at your school that will last approximately 30 minutes. This post-observation interview will be digitally recorded and hand written notes will be taken by the researcher. This post-observation interview will give you the opportunity to reflect on the observed lesson and allow you to link intent, action, and outcomes of the observed lesson.

**Risks/Benefits:**
There are no foreseeable risks involved in participating in this research beyond those experienced in everyday life.

There are no direct benefits to you from participation, but it is expected that results from this research will help to inform professional development providers and teachers who seek to include technological design in their science teaching.

**Confidentiality:**
Audio recordings of all interviews will be listened to and transcribed by the researcher alone. These recordings will be deleted once transcription has been completed. Hand written field notes will be transcribed by the researcher alone and then shredded. Transcriptions will be saved on a password protected computer.

**Voluntary Participation:**
Participation in this study is voluntary. If you do not want to be in this study, you do not have to participate. Even if you decide to participate, you are free not to answer any question or to withdraw from participation at any time without penalty. Your decision to participate in this research study will have not affect your current relationship with the CASE professional learning program with which you are involved.

**Contacts and Questions:**
If you have questions about this research project, interviews, or observation, please feel free to contact Kate Heroux at kheroux@lfschools.net or the faculty sponsor Dr. Therese Pigott at tpigott@luc.edu.

*If you have questions about your rights as a research participant, you may contact the Loyola University Office of Research Services at (773) 508-2689.*
Statement of Consent:

Your signature below indicates that you have read the information provided above, have had an opportunity to ask questions, and agree to participate in this research study. You will be given a copy of this form to keep for your records.

____________________________________________   __________________
Participant’s Signature                                                   Date

____________________________________________  ___________________
Researcher’s Signature                                                  Date
Dear __________________________

My name is Kate Heroux. I am a doctoral student in the Research and Psychology in Schools Program in the Department of Education at Loyola University, Chicago under the supervision of Dr. Therese Pigott. You are being contacted because you are a secondary science teacher who will be participating in a professional learning program that emphasizes technological design in science, technology, engineering, and mathematics (STEM). Your involvement with the Center for the Advancement of STEM Education (CASE) at Garrett College, McHenry, MD during July, 2010, indicates you have had experience with teaching technological design. There will be approximately five teachers from the CASE professional learning program who will be participating in this research project. Criteria for selection of participating teachers is based on their experience with teaching technological design, teaching science for a minimum of five years, and possessing a diverse subject specialization background.

The purpose of this study is to provide empirical evidence of exemplary teaching practices and development of new strategies and methods to meet the demands of the National Science Education Standards (NRC, 1996) for technological design. I am interested in how secondary science teachers understand and implement technological design in their classrooms. I want to assure you that this research has been approved by the Institutional Review Board of Loyola University. All of your responses, your identity, and the identity of your school will remain confidential. The qualitative data that is collected will be analyzed and used for a doctoral dissertation in educational research.

The research will involve two Phases. Phase I will be a general interview to be conducted during the week you are attending Garrett College in July 2010. This interview will explore your background, your beliefs about effective science education, your beliefs about technological design, and how you implement these beliefs in your secondary science classroom.

Phase II will involve a pre-observation interview at your school prior to a prearranged classroom observation. A third, post-observation interview will be the final part of this phase. The pre-observation interview will focus on details of the upcoming observation. This interview will include the problem you will address in the lesson to be observed, the intended activities, the targeted content knowledge, and the scientific process skills and learning objectives. This interview will take approximately 30 minutes.
The observation will take place in your classroom and continue for the duration of the lesson. The observation will focus on the details you outlined in the pre-observation interview. The observation will be followed by a post-observation interview that will give you the opportunity to reflect on the observed lesson and allow you to link intent, action, and outcomes of the observed lesson.

Your participation in this study is voluntary. If you do not want to be in this study, you do not have to participate. Even if you decide to participate, you are free not to answer any question or to withdraw from participation at any time without penalty. Your decision to participate in this research study will have no affect your current relationship with the CASE professional learning program with which you are involved. If you have questions about this research project, interviews, or observation, please feel free to contact Kate Heroux at kheroux@lfschools.net or the faculty sponsor Dr. Therese Pigott at tpigott@luc.edu. If you have questions about your rights as a research participant, you may contact the Loyola University Office of Research Services at (773) 508-2689.

I am looking forward to meeting you this summer and learning more about how you understand and implement technological design in your science classroom.

Yours truly,

Kate Heroux
APPENDIX I

LETTER OF APPROVAL
May 3, 2010

Rebekah Soule  
Compliance Manager  
Office of Research Service  
Loyola University Chicago  
439 N. Sheridan Rd., Granada Center, Ste. 400  
Chicago, IL 60626

Dear Madam,

Re: Approval for Kathryn Heroux

**Project Title:** How Do Secondary Science Teachers Understand and Implement Technological Design in their Classrooms?

This letter is to certify that Kathryn Heroux, a doctoral candidate from the Research and Psychology in Schools Program at Loyola University Chicago, has my permission to use the data she obtains from teachers who will participate in the July 2010 professional development workshops at Garrett College, McHenry, Maryland. This workshop is under my direction as the Executive Director of the Center for the Advancement of STEM Education (CASE).

I understand that Ms. Heroux will be interviewing and observing secondary science teachers who agree to participate in her research project. Teachers with a minimum of five years science teaching experience, who will be conducting a lesson based on technological design during the first semester of the 2010-2011 academic year, and whose school is in a geographically accessible place will be identified and invited to participate. Approximately five to seven teachers who volunteer will take part in an initial interview with Ms. Heroux at the summer professional development workshops. Of this number, three will then be interviewed again and observed by Ms. Heroux at their schools. A third interview will be conducted following the observation. I understand this research and data is qualitative in nature.
Ms. Heroux's involvement with the project is as the researcher, and, as such, she is allowed to access any data she thinks is necessary to support her work towards her Ph.D. dissertation through Loyola University, Chicago.

Yours truly,

Dr. Stephen M. Priselac

Executive Director, CASE
(724) 812-2599
BIBLIOGRAPHY


American College Testing (ACT). 2008. The Forgotten Middle: Ensuring that All Students Are on Target for College and Career Readiness before High School, ACT.


VITA

Kathryn Heroux’s background in science education was shaped by her experiences as a teacher in Manchester, England, where she began her teaching career. In England, at that time, teachers across the country were closely collaborating to define and create a National Curriculum document; one of many mandated reforms put in place by the Thatcher government during the early 1980’s. The National Curriculum document that emerged included the requirement for all primary and secondary students to design and implement their own experiments based on real world problems. Teachers in each school revised their own curricula to incorporate lessons to meet this requirement. The author’s involvement in this ongoing experience and expectation of revision and redesign of curriculum was a formative experience that had carry-over into her later career.

After returning to the United States in 1994, the author became involved as a co-author of one of Northwestern University’s Materials Science Modules (MWM). This work resonated with her personal sense of responsibility as a teacher and eventually led to the creation of a new science course at Lake Forest High School called Materials Science and Design. This course is aimed at engaging high school seniors in the experiences of technological design. It has been a popular course in the science department at Lake Forest High School since it was begun in 2001.
Because of her work with Northwestern University, the author has had the opportunity to make presentations at several conferences, work with Department of Defense representatives, and to have published a number of topical and relevant articles, and been involved with the National Center for the Advancement of STEM Education (NCASE) since its inception.

The author’s expectations for the future are to continue to work in the capacity of a teacher or as a professional development consultant or instructor whose contribution will be based on her understanding of the intricacies and the unique challenges of teaching science as it continues to be defined and re-defined. In particular, the author hopes to be involved with the latest iteration of technological design, now called engineering design, as it is represented in new Framework document. As STEM education becomes more of a common place activity in secondary science classroom and departments, there will be a need for seasoned practitioners to step up and help their colleagues make the most of the opportunity to bring American science education to the forefront. The author’s unique teaching experiences, and the work she has undertaken for this doctoral dissertation, will enable her to work with and help other likeminded teachers and science departments to meet the demands set out in the new science standards.