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Green Pedagogy: How STEM Teachers Understand and Enact

Environmental Projects

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Abstract

This dissertation study examined the implementation of STEM education policy by comparing teachers' understanding and enactment of environmental projects at two STEM high schools. This study found a mismatch between the goals of STEM education policy and the realities faced by teachers in STEM schools. It raised questions about what policy measures will be required for pubic school teachers to sustain a project-based and integrated STEM curriculum. It raised serious questions about the restrictions placed upon STEM schools and teachers in poor communities. It also raised hopes, indicating that teachers can find spaces for innovation amidst these constraints, particularly in courses and pathways that remain uncoupled from state testing policies. Based upon the findings, a vision for a greener, more democratic, and more equitable STEM education is presented in the concluding chapter.

In response to economic and vocational data, federal and state policymakers in the United States have urged reforms to K-12 STEM education. The general vision among policymakers is that a project-based and integrated STEM curriculum will prepare students who can compete in a global knowledge economy. Empirical research on teachers' ability to implement STEM education policy remains scarce, however. The literature on educational reform, project-based learning, and environmental education suggests that teachers will experience significant challenges. To clarify this situation, the idealist aspects of STEM education policy must be combined with empirical evidence drawn for real-world classrooms.

Data sources included in-depth interviews, classroom observations, and classroom artifacts and were drawn from a sample of 17 teachers and administrators. Data were analyzed using a conceptual framework related to project-based learning, environmental discourse, and environmental education. By adopting a phenomenological and ethnographic approach, this

study explored the interactions among policy levels, school and classroom cultures, and teachers' experience, including their life histories.

Both schools in the study—Central STEM High School and Capital STEM Academy—were awarded a seed grant by the state. The findings revealed that teachers used instruction as a culture-building strategy. In this way, project-based learning (Central) and the engineering design process (Capital) were revalued for the skills and dispositions they required of teachers and students. Over time, these cultures of instruction were negatively impacted by larger-than-expected class sizes, teachers' emotions, time pressures, relational tensions, and state/district policies related to testing and curriculum. As a result, projects at both schools were compromised.

This study found that teachers who participated in environmental projects at both schools were driven by childhood nature experiences. In several cases, these experiences were connected their adult interests in science and environmental issues. Teacher at both schools felt free to address the moral, social, and political aspects of environmental problems. Their teaching reflected a range environmental positions, including survivalism, prometheanism, economic rationalism, and democratic pragmatism. Generally, the projects took the liberal capitalist political economy for granted. A comparative analysis of the findings indicated that the project curriculum prepared students for very different roles in the world economy.

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Chapter One

Introduction to the Study

This dissertation study examines the implementation of STEM education policy by comparing teachers' understanding and enactment of environmental projects at two STEM-focused high schools.

Statement of the Problem

The Soviet Union's launch of the Sputnik satellite on October 4, 1957 initiated a crisis in the United States concerning our status as innovators of science-based technologies. Sputnik became an "instant metaphor" (Ravitch, 2000, p. 361) for the failure of American schools and helped close the door on the progressive education movement. Since Sputnik, policymakers have consistently interpreted student achievements in science and mathematics as issues of economic and national security. The current interest among policymakers in reforming K-12 science, technology, engineering, and mathematics (STEM) education continues this tradition.

It is true that the United States faces significant economic and educational challenges. A prolonged recession has amplified the poor performance of American students on international benchmarks of science and mathematics achievement, subjects believed to foster economic competitiveness (Drew, 2011). Such statistics provide a baseline rationale for STEM education, a rationale strengthened by projections for exceptional growth in STEM careers and higher-than-average wages for STEM workers (Drew, 2011; Georgetown University Center on Education and the Workforce, 2011; National Governors Association, 2007) This combination of economic and educational imperatives underwrites an annual federal investment in STEM education of over $3 billion as well as plans to create one thousand STEM-focused schools, produce one million additional college graduates in STEM fields, and train one hundred thousand new STEM teachers—all within the next ten years (National Science and Technology Council, 2011; President's Council of Advisors on Science and Technology, 2010, 2012). A number of states have begun implementing these policy recommendations by funding new STEM schools and public/private partnerships (Popkewitz, 2003).

STEM education policy works to reform teachers' instruction in fundamental ways. The general vision among policymakers is that 'hands-on' and 'real-world' experiences with an integrated STEM curriculum will prepare students with the knowledge and skills to solve twenty-first century problems, including problems related to energy and the environment (President's Council of Advisors on Science and Technology, 2010). To this end, policymakers would break the tradition of teacher- and subject-centered instruction so that students' creativity can be unleashed across the disciplines. Many in the STEM education community have adopted project-based learning as a means of achieving these ends. In addition to meeting the demands of policymakers, project-based learning draws together STEM's conceptual undercurrents, all of which 'speak' the project idiom in one form or another. These include "design thinking" and pedagogy (Dym, Agogino, Eris, Frey, & Leifer, 2005; Razzouk & Shute, 2012), engineering and science education reforms (Bybee, 2011; National Research Council, 2012), the 21st Century Skills framework (Bell, 2010), project management and problem-solving methodologies from business and industry, and constructivist research in the "learning sciences" (Krajcik & Blumenfeld, 2006; Sawyer, 2006b). As a result, project-based learning has become part of the "cultural logic" of STEM education (Enfield, 2000).

In sum, STEM education policy pressures teachers to adopt constructivist approaches to instruction and address complex problems related to energy and the environment. The ideal is that STEM teachers will create learning environments in which collaborative problem-solving is a common occurrence and students conduct their own authentic inquiries (Dewey, 1933). Research evidence suggests that such radical departures from traditional practice are difficult for teachers to sustain because most schools are not organized to support progressive education (Blumenfeld, Fishman, Krajcik, & Marx, 2000; Cuban, 2013; Elmore, 1996; Stevenson, 2007; Tyack & Cuban, 1995).

The problem is that STEM education policymakers have yet to account for the constraints experienced by STEM teachers, and until the idealist aspects of STEM education policy are combined with empirical evidence drawn from real-world classrooms, STEM is unlikely to succeed as an educational reform movement.

Instructional aspects of the problem.

Regarding instruction, project-based learning is historically imbued with multiple interpretations and methods (Alberty, 1927). While this complexity has helped incorporate diverse stakeholders around the project *idea*, it has also inhibited the type of shared understanding among teachers and administrators necessary for an instructional innovation to take root in a school. In addition, the conceptual confusion around projects has made it difficult for teachers and administrators to determine the educational value of different approaches. Although researchers in the learning sciences have improved this situation by aligning project-based learning with constructivist learning theory (Blumenfeld, et al., 1991; Krajcik & Blumenfeld, 2006), these models do not easily translate into pedagogical practices and require teachers to rethink their basic beliefs about teaching and learning (Howe & Berv, 2000a; Prawat, 1992). This gap between theory and practice is not new. Prior to the rise of constructivism, science educators struggled to translate Dewey's ideas about problem-solving into science education practices (Champagne & Klopfer, 1977).

In addition to these conceptual and theoretical barriers, there are personal and professional risks involved. Adopting a project-based approach involves a radical redistribution of classroom power and authority, runs counter to an entrenched "grammar of schooling" (Tyack & Cuban, 1995), and puts one at odds with the dominant educational culture of high-stakes testing and teacher accountability systems, both of which drive teachers (and students) towards *less* innovation, not more (Au, 2011; Meier & Wood, 2004). Finally, although existing research indicates that project-based learning requires peer collaboration, professional development, university support, and technical training (Barron, et al., 1998; Blumenfeld, et al., 1991; Krajcik & Blumenfeld, 2006), it remains unclear the extent to which STEM teachers experience these supports.

Environmental aspects of the problem.

Considering the potential for STEM education to construct the next generation's vision of "sustainability," it is also important to examine how environmental problems and solutions are represented in STEM schools. Although STEM dovetails nicely with technocentric discourses such as sustainable development, and ecological modernization (Dryzek, 2005), it remains unclear how STEM teachers are addressing the moral, social, and political aspects of sustainability (Davison, 2001; Orr, 1992) or the extent to which their work resists, reproduces, or modifies the dominant notions of environmental problem-solving embedded in STEM education discourse and policy. It is important, for example, to know whether or not the social studies teacher working in a STEM-focused school is invited to join an environmental project and, if so, what role they are given. If they are not involved, researchers need to understand the barriers that exist to their future participation. Although a project-based approach to environmental issues has become common in higher education (Lehmann, et al., 2008; Nation, 2008; Savage, Chen, &

Vanasupa, 2007; Steinemann, 2003; Thomas, 2009), researchers have yet to interpret this approach in the context of elementary and secondary STEM schools.

Study Purposes

The primary purpose of this study is to examine how teachers implement STEM education policy *in context*. This purpose is achieved by comparing teachers' understanding and enactment of environmental projects at two STEM-focused high schools. This study proposes that these projects represent an enactment of policy.

This study is also designed to provide a compelling, evidence-based rationale for increasing STEM teacher supports. As a former classroom teacher and someone who has worked for several years with STEM policymakers and STEM teachers, I have observed the gap between policy and what teachers are able to achieve in their classrooms. To improve STEM education, policymakers must attend to the real-world constraints affecting teachers' work and create innovative policies to remove some of these obstacles. Evidence for doing so is included in this study. This evidence is compelling because the *teachers* are compelling—as are their stories.

Research Questions

This dissertation study examines the implementation of STEM education policy by comparing teachers' understanding and enactment of environmental projects at two STEM-focused high schools. The main research questions are as follows:

1. How do STEM teachers understand and enact project-based learning?
2. What challenges do they experience when teaching environmental projects, and how do they negotiate these challenges?
3. How do these projects represent environmental problems and solutions?

4. How do these projects reflect teachers' previous educational and environmental experiences?

Conceptual Framework

There are instructional and environmental components to the conceptual framework, which includes literature on project-based learning, environmental discourse, and environmental education. This literature provides models for analyzing and interpreting participants' understanding and enactment of environmental projects.

Project-based learning.

A central paradox involved in this study is how project-based learning can be claimed by diverse and competing interest groups as central or antecedent to their work. For example, project-based learning has been claimed by those interested in science education (Krajcik & Blumenfeld, 2006; Marx, Blumenfeld, Krajcik, & Soloway, 1997), engineering education (Dym, et al., 2005; Savage, Chen, & Vanasupa, 2007), environmental education (Judson, 2010; Smith & Sobel, 2010), organizational studies (Sydow, Lindkvist, & DeFillippi, 2004; Waks, 1997) and sustainable development (Lehmann, Christensen, Du, & Thrane, 2008; Nation, 2008). What accounts for this remarkable flexibility? Kliebard (2004) suggests an origin in the American progressive movement, when projects served competing interests related to industrial education and vocational agriculture (Snedden, 1916; Stimson, 1915). This dialectic expresses an ongoing conflict between industrial and pastoral visions of society (Marx, 1964/2000; Williams, 1973). This dissertation study situates project-based learning at the intersection of two competing visions of the sustainable society—STEM education and environmental education.

As a former classroom teacher who 'did' projects in his class but knew little of constructivist learning theory, I am particularly interested in how teachers' perceptions of project-based learning compare to theoretical models (Blumenfeld, et al., 1991; Krajcik & Blumenfeld, 2006). As a result of my graduate studies, I now understand project-based learning as an attempt to create classroom environments faithful to constructivist learning theory—a challenging undertaking requiring significant teacher supports (Blumenfeld, et al., 2000; Blumenfeld, et al., 1991; Howe & Berv, 2000a; Prawat, 1992).

Environmental discourse.

This study uses environmental discourse as a framework for examining how environmental projects represent environmental problems and solutions. Dryzek (2005) defines discourse as "a shared way of apprehending the world" (p. 9) and argues that environmental discourse "conditions the way we define, interpret, and address environmental affairs" (p. 11). Dryzek's (2005) work suggests that a particular view of environmental affairs is embedded in STEM education discourse and policy, a view which may or may not be shared by STEM teachers. Dryzek demonstrates how environmental discourses are "bound up with political power" (p. 9) as they move through government policies, institutions such as schools, and cultural practices. From this perspective, the environmental projects and pedagogies included in this study are the effects of environmental discourses and can be interpreted as such.

Environmental education.

Readers who are unfamiliar with environmental education may be surprised at the depth and breadth of its pedagogies (Sauve, 2005). In America, environmental education dates back to the 1890s, when "nature study" advocates introduced science (and school gardens) to elementary schools (Kohlstedt, 2010; Kohlstedt, 2008). Today's environmental education has much in common with STEM education traditions such as socio-scientific issues education (Zeidler, Sadler, Simmons, & Howes, 2005) and context-based science education (Fensham, 2009).

Environmental education also offers alternative approaches for teachers interested in critical theory and political action (Huckle, 1983; Kahn, 2010). These more critical approaches question the basic assumptions undergirding STEM education.

In this study, environmental education serves as a framework for interpreting the environmental aspects of teachers' experience with environmental projects. The primary typology I have used distinguishes between education *about* the environment, education *in* the environment, and education *for* the environment (Huckle, 1983). Education *about* the environment is subject-centered, quite common in secondary schools, and strongly scientific. Education *in* the environment is topic-centered, often community-based, and involves "safe" action projects such as recycling initiatives (p. 105). Education *for* the environment is issue-centered and designed to prepare students to "participate in environmental politics" (p. 105). To participate in a democratic society, students must be introduced to a wide range of environmental positions (Stevenson, 2007).

Significance of the Study

The two STEM schools in this study are located in a state that is a national leader in STEM education policy. As such, the findings indicate what lies ahead for elementary and secondary teachers in other states. By indicating a number of real-world constraints, the findings will be useful for revising the idealist aspects of current policy (Dryzek, 1992). Most importantly, this study's "bottom-up" approach—which takes STEM teachers' lived experience to be the primary phenomenon of interest—empowers teachers to comment on this situation (Darling-Hammond, 1990).

This study adds to the literature on educational reform, educational innovation, educational policy, curriculum and instruction, and environmental education. It will be of interest to researchers and practitioners in these areas, including those interested in STEM education. This study is innovative and explores new areas, including the instructional and environmental politics of STEM education. The findings of this study will be particularly significant to researchers and practitioners who are dually-concerned about the demands placed upon teachers and the general failure by those within mainstream education to address the social and non-technical aspects of environmental problems.

The general attitudes toward nature in any society are enacted in its classrooms. Classrooms in which order and control are valued over diversity, participation, and spontaneity indicate a hierarchical and anti-ecological cosmology (Bateson, 1996). If one accepts this argument, then an inquiry into teachers' understanding and enactment of environmental projects is also an inquiry into the educational foundations of an ecologically-sustainable and democratic society—a green democracy (Arias-Maldonado, 2000).

Structure of the Dissertation Study

Chapter Two provides a political context for STEM education by examining official policy documents, including *Rising Above the Gathering Storm* (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2007) and *Prepare and Inspire* (President's Council of Advisors on Science and Technology, 2010). This chapter demonstrates how policymakers have interpreted the relationship between STEM, innovation, environmental problems, economic growth, and classroom instruction. Alternative perspectives on STEM education are also provided, including an environmental discourse perspective.

Chapter Three provides a review of the literature on project-based learning. This review includes both historical and contemporary discourses. The chapter explains how and why educational reformers have so often turned to projects as a means of implementing their visions.

The history of projects in engineering education, vocational agriculture, industrial education, manual training, and nature study are addressed. A review of the contemporary literature of project-based learning, including project-based science, suggests the challenges of sustaining educational projects in public school settings.

Chapter Four discusses the research methodology and methods, beginning with my general approach to inquiry, which positions educational policy as a "quest for certainty" (Dewey, 1929). The chapter also provides a rationale for combining phenomenological and ethnographical methods. Data sources, methods of data collection, and analysis are discussed in detail. Chapter Four ends with an introduction to the two STEM schools compared in the study.

Chapters Five and Chapter Six present the findings related to the two schools—Central STEM High School and Capital STEM Academy. Each of these chapters begins with an account of the school's design process, including how instruction was used as a culture-building strategy. Each chapter then presents findings related to teachers' experience with the school's environmental projects. These findings are organized around central themes, tensions, and metaphors. A narrative approach is used to maintain the context of teachers' experience.

In Chapter Seven, the findings from both schools are analyzed and compared using frameworks for project-based learning, environmental discourse, and environmental education. The chapter concludes with recommendations related to the political, instructional, and environmental aspects of STEM education. These recommendations provide a vision for a greener, more equitable, and more democratic STEM education.

Chapter Two

The Politics of STEM Education

Introduction

This chapter addresses the instructional and environmental politics of STEM education. These politics are considered in the context of social theories and discourses on educational globalization and the knowledge economy. The chapter suggests how federal policymakers have interpreted the relationship between STEM, innovation, environmental problems, economic growth, and classroom instruction. The chapter ends with an environmental discourse perspective on STEM education.

Educational Globalization

The educational policies within national and local school systems, including the STEM education movement in the United States, reflect the politics of globalization (Spring, 2009). In addition to increasing the uniformity of educational ideas and practices across nations, educational globalization has increased the influence of intergovernmental and nongovernment organizations on educational policy (Spring, 2009). One important example is the Organization for Economic Cooperation and Development (OECD), which has developed a common assessment tool (PISA) used by its member countries, which represent 90 percent of the world's economy (p. 64). Another example is the United Nations Educational, Scientific, and Cultural Organization (UNESCO), which has introduced the environmental discourse of sustainable development. International assessments such as PISA and environmental discourses such as sustainable development have had a significant effect on the development of STEM education policy in the United States.

The Knowledge Economy

Social theorists have suggested that the world has transitioned towards a global society in which knowledge and innovation are the key economic drivers (Beck, 2004; Castells, 1996; Drucker, 1993; Powell & Snellman, 2004). In their view, the rapid rise of information technologies at the end of the twentieth century has had a disruptive and revolutionary effect on social, economic, and environmental systems, including traditional forms of employment. In response to this radical uncertainty, it is argued, new approaches to work and governance must be developed that are more adaptive, inclusive, and flexible than ever before (Franklin, Bloch, & Popkewitz, 2003b; Hajer & Wagenaar, 2003b; Sydow, et al., 2004).

Beck (2004) has dubbed the knowledge society the "risk society"—a society in which environmental hazards are experienced by an increasing number of people and are no longer predicated on one's class position or geographical location. Such a society develops when the "spell of the invisibility of risks" is "broken by personal experiences" (p. 11). This situation creates the need for policy experts to manage the social perceptions of risk. Beck was primarily concerned with the social perceptions of environmental risk. Environmental politics are central to this social work of risk management (Dryzek, 2005; Lejano, Ingram, & Ingram, 2013).

In accord with the suggestion that *knowledge*—a non-tangible resource—is a nation's most important commodity, policymakers in the world's most developed countries have turned their attention to industries, organizations, and institutions directly involved in knowledge work, including those involved in education (Powell & Snellman, 2004). The role of governors and managers in the knowledge economy is to develop systems and environments that facilitate the generation and transmission of knowledge.

The politics of STEM education can not be understood apart from these theories. STEM education is a political effort to create “knowledge-society schools” (Hargreaves, 2003).

Networks and Partnerships

The politics of STEM education incorporates knowledge society concepts related to learning and governance, including the “network” and the “partnership.” These concepts are used to suggest how the educational sector of society might adapt to social, environmental, and economic uncertainties.

In a landmark study, Castells (1996) argues that the forces of globalization sparked by innovations in information technologies had created a “network society” in which organizations and institutions have been driven by uncertainty to form new alliances. For Castells, these networks have replaced the individual and collective as the basic unit of economic organization (p. 198). Castells is particularly interested in how global competition and technology have led to increasing interdependencies among different labor segments across national boundaries.

Theoretically, interdependence is a liberating aspect of governance in the network society (Hajer & Wagenaar, 2003a; Powell & Snellman, 2004; Torgerson, 2003). However, as Castells (1996) notes, the traditional certainties of work are in steady decline, with fewer workers experiencing a lifetime of full-time employment in one career track (p. 68). This uncertainty necessitates flexibility among workers and explains the importance of “lifelong learning” within educational globalization (Spring, 2008). An important social justice concern is whether or not the capital gains of networks are equally distributed or are “skimmed off by those at the top of the flatter hierarchy” (Powell & Snellman, 2004, p. 210).

In addition to the network, the partnership is a key concept among policymakers, particularly in education (Franklin, Bloch, & Popkewitz, 2003). Like the network, the partnership suggests interdependencies among stakeholders and is a direct response to the insecurities of globalization.

> Seen as an antidote for historic battles between left and right and public and private, partnerships are to bring government, business, the voluntary sector, and citizens together around issues of public policy. It is in other words—in appearance—a mechanism for cooperation and consensus (Franklin, et al., 2003, p. 7).

As Popkewitz (2003) notes, when integrated into educational reform movements, the partnership carries particular implications for both teachers and students. From his perspective, the reformed teacher is "one who enters partnerships" (p. 37) and the expert teacher is one who can sustain such partnerships amidst changing pedagogies and standards. Popkewitz (2003) reads a "new child of pedagogy" in the language of educational reform through partnerships. This child is adept at "working flexibly as a problem solver in uncertain contexts" and "constructing knowledge in communities" (p. 37). In the current language of educational reform, he or she is "an active, self-reflexive problem-solver and lifelong learner" (p. 38). This ideal of the constructivist, problem-solving individual is also to be found in the post-industrial workplace, which is increasingly organized around projects (Sydow, et al., 2004).

Education has been interpreted as a specific sector of knowledge production. This is the view, for example, of the Organization for Economic Cooperation and Development, who argue that for education to contribute to economic growth, the educational sector must undergo a transformation similar to that experienced by health care and microelectronics (Organization for Economic Cooperation and Development, 2004). To this end, the OECD recommends "pumping" education with additional research dollars, collaborative cultures, horizontal networks, and information technologies (2000). The OECD's faith in the progressive power of technology is a central aspect of educational reform in the United States (Cuban, 2001; Ferneding, 2003). This remains true within STEM education discourse and policy.

The Schools of the Future

These theories and concepts provide a strong rationale for reforming schools. Within STEM education, this rationale is combined with political will and a disciplinary focus (STEM) and strengthened by support of learning theorists, cognitive scientists, and instructional designers who have designed pedagogies to develop knowledge society skills. The schools of the future, including STEM schools, include all of these attributes.

Arguing that educational researchers have paid little attention to the shift from an industrial economy to a knowledge economy, Sawyer (2006a) suggests that schools turn their attention to knowledge creation. For Sawyer (2006a) this involves replicating in elementary and secondary classrooms the same collaborative cultures and social processes that have spurred innovations in other areas, including jazz, improvisational theater, and the corporate world. The complexity of the world's "most pressing problems" (p. 42) requires this collaborative and improvisational approach, Sawyer argues. In Sawyer's model classroom, effective instruction involves "disciplined improvisation" by teachers and "collaborative discussion" among students (p. 47). As evidence for the influence of his thinking, Sawyer was chosen to edit *The Cambridge Handbook of the Learning Sciences* (Sawyer, 2006b), a book which draws from research in educational technology, instructional design, cognitive psychology, cognitive neurosciences, and educational psychology. This book argues strongly for the creation of constructivist learning environments in elementary and secondary schools. In the book's conclusion, Sawyer rationalizes constructivist classrooms by suggesting the following alignment among educational stakeholders and their purposes:

> Leading thinkers in business, politics, and education are now in consensus that schools have to be redesigned for the new economy, and that the learning sciences are pointing the way to this new kind of school—a school that teaches the deep knowledge required in a knowledge economy (Sawyer, 2006c, p. 567).

Sawyer recognizes the severity of the task ahead, which involves replacing "the entire instructionist system" with "new learning environments…based on the learning sciences" (p. 578). Initiating such a major transition will require large initial investments in "computers, software, and network infrastructure—perhaps even new buildings with as-yet-undetermined architectural designs" (p. 578) in addition to new textbooks, curriculum, assessments, school cultures, teacher education programs, learning networks, and educational partnerships.

Addition perspectives on education in the "knowledge age" (Bereiter, 2002) and "knowledge society" (Hargreaves, 2003) suggest a similar process of radical restructuring. Bereiter (2002), a cognitive and educational psychologist, argues that the knowledge society is distinguished by its dependence upon "conceptual artifacts" rather than material artifacts. For Bereiter (2002), the purpose of education in the knowledge society is to develop students' ability to understand conceptual artifacts by creating and using them. This sounds simple enough, but much of Bereiter's argument is meant to disrupt our initial acceptance of such an idea, and Bereiter is at pains to show how common ideas such as inquiry, hands-on science, and project-based learning have distracted teachers from considering the deep understanding he is after, which may or may not involve problem situations or project deliverables (p. 260). After considering what an educational system in tune with economic uncertainty might look like, the educational alternatives currently available, and several pitfalls, Bereiter (2002) argues that school designers should concern themselves exclusively to enculturating students to the world of knowledge, and to the skills and dispositions involved in knowledge work, leaving the mundane aspects of teaching to computers and other educational technologies.

Andy Hargreaves (2003) has taken perhaps the closest look at what teaching for the knowledge economy entails. While arguing that the knowledge economy demands increased "creativity and ingenuity" (p. 1) from school systems, Hargreaves (2003) notes that teachers are faced with a number of competing priorities. At the same time that they are expected to be "catalysts" for knowledge economy opportunities, they are expected to serve as "counterpoints" to the knowledge society by teaching students the moral and democratic aspects of social life. In order to survive, argues Hargreaves (2004), teachers must also avoid becoming "casualties" of the knowledge society, encouraged to leave the profession by unprecedented public pressures and the standardization of classroom practices.

Educational globalization, the knowledge economy, networks, partnerships, and schools of the future provide a discursive foundation for STEM education policy in the United States. An examination of official policy documents and legislation related to STEM education makes this clear.

Rising Above the Gathering Storm

In response to a Congressional request for recommendations related to American science and technology policy, the National Academies' Committee on Prospering in the Global Economy of the 21st Century undertook a wide inquiry. The committee's recommendations were published as *Rising Above the Gathering Storm: Energizing and Employing American for a Brighter Future* (National Academy of Sciences, et al., 2007). Although *Rising Above the Gathering Storm* was proceeded by a number of reports and legislative actions related to K-12

STEM education, this report remains the most detailed summary of policymakers' thinking and represents the dominant public discourse on STEM education.

The charge to the Committee on Prospering in the Global Economy of the 21st Century was to recommend concrete policy actions "to enhance the science and technology enterprise so that the United States can successfully compete, prosper, and be secure in the global community of the 21st century" (xi). In order to meet this charge, the Committee reviewed research literature and conducted focus groups related to K-12 education, higher education, science and engineering research, innovation and the workforce, and national security (p. 249). *Rising Above the Gathering Storm* suggests that a combination of progressive public policies and educational reform will be necessary to meet the economic crisis sparked by globalization. Although economic policy recommendations play a leading role in the report, the Committee makes clear that global competitiveness will be "purchased largely in the K-12 classroom" (p. 129).

Committee proposals for reforming K-12 education.

In regards to education, the Committee suggests that a "revolution in the study of the mind" has occurred that "will lead to very different approaches to the design of curriculum, and assessment from those generally found in schools today" (p. 66). The Committee also states that research undertaken by social scientists and cognitive and developmental psychologists has led to new understandings about knowledge organization, problem-solving behavior, and learning environments (p. 66). As evidence, the Committee cites the National Research Council report *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown, & Cocking, 2000).

The Committee reserves its deepest concerns for the United States' K-12 education system, which when compared on international benchmarks such as the Program for International Student Assessment (PISA) and Trends in International Mathematics and Science

Study (TIMMS) fails to engage students in STEM. The Committee also laments the lack of content knowledge and expertise among elementary and secondary teachers, and the overall quality of the science and mathematics curriculum, although it notes that new standards that "emphasize inquiry and detailed study of fewer topics" are a hopeful sign on the horizon (p. 98). The Committee emphasizes that the "unique hierarchical nature" of science and engineering requires that students be prepared for advanced study in the middle school years. The Committee is pleased that more schools are moving towards an "integrated science curriculum" and coordination among grades 7-12 (p. 102).

In Chapter Five, the Committee presents action steps for reforming K-12 education. In rationalizing their recommendations, the Committee draws a straight line between classroom instruction, workforce development, and global competitiveness.

> The critical lack of technically trained people in the United States can be traced directly to poor K-12 mathematics and science instruction. Few factors are more important than this if the United States is to compete successfully in the 21st century (p. 114).

This focus on instruction, rather than curriculum, is explained by the Committee's goal to make science and mathematics more engaging to students. This work also involves building a "natural constituency for science" (p. 112) within society, otherwise

> young people will have no motivation to become the next generation of scientists and engineers who can address persistent national problems, including national and homeland security, healthcare, the provision of energy, the preservation of the environment, and the growth of the economy, including the creation of jobs (p. 113).

The Committee's recommendations are specific. First, the Committee recommends recruiting 10,000 elite college students to become STEM teachers. Through a competitive process, these teachers would be awarded a full scholarship. As a collaborative venture in teacher education, these persons would earn a major in a STEM department and pedagogical training from a college or department of education. Second, the Committee recommends remedial training and professional development for 250,000 active teachers. This would involve summer institutes, master's programs with an emphasis on content, and training to deliver Advanced Placement (AP) and International Baccalaureate (IB) courses.

In an effort to increase the overall rigor of curriculum and teaching materials, the Committee also recommends that the Department of Education collect the best of what currently exists as well as creating new materials matched to international standards. The Committee highlights Project Lead the Way (PLTW) as a model program for middle and high schools, claiming that students who participate in PLTW courses are "better prepared for college engineering programs that those exposed to the more traditional curricula" (p. 129). Third, the Committee recommends a dramatic increase in the number of students who take AP and IB courses, which have been demonstrated to retain students in the STEM pipeline as well as increasing their performance on international assessments.

As a final recommendation, and one most germane to this study, the Committee recommends that the states develop specialty high schools devoted to science and mathematics education. As an example, they cite the North Carolina School of Science and Mathematics (NCSSM), a public and highly-selective residential high school. The Committee also recommends summer research programs devoted to inquiry-based learning. It strongly encourages programs "that involve several institutions or pubic-private partnerships" as well as programs designed to impact low-income and minority students (p. 133). The two schools that participated in this dissertation study—Central STEM High School and Capital STEM Academy—are examples of this type of specialty school.

America Competes Act of 2007

The America Competes Act of 2007 mandated many of the public policy and educational reform recommendations of *Rising Above the Gathering Storm*. At a general level, the act created the President's Council on Innovation and Competitiveness (Title I, Sec. 1006). This council was designed to oversee public laws and programs promoting innovation and included representatives from a wide range of federal departments and agencies such as the Department of Education, the Department of Energy, the Department of Homeland Security, and the Environmental Protection Agency. Although this council was never established as named, President Obama established in 2010 the President's Council of Advisors in Science and Technology to serve the same purpose.

The American Competes Act of 2007 also enacted several educational provisions from *Rising Above the Gathering Storm*, including establishing a competitive grant programs for STEM teacher education and STEM master's programs. The act also established a panel to identify "promising practices" in K-12 STEM education and funded a pilot grant program housed within the Department of Energy for states to develop new STEM-focused public secondary schools. The act stated that these schools must offer students a "high quality, comprehensive" curriculum designed to increase "experiential, hands-on learning opportunities" and "hands-on laboratory experiences" for students (Title V, Sec. 3171). The Department of Energy was given $7,500,000 for the fiscal years 2008 through 2010 to develop "experiential-based learning projects" and summer internships for middle and high school students at the National Laboratories (Title V, Sec. 3175). Finally, the act provided funds for the Department of

Energy to develop a national energy education program available to K-12 teachers. Program materials were to focus on the intersections of energy, society, and the environment (Title V, Sec. 3191).

President's Council of Advisors on Science and Technology

The President's Council of Advisors on Science and Technology (PCAST) is comprised of prominent scientists and engineers and is charged to provide the President with advice concerning the United States' science and technology policy, including K-12 STEM education policy. In 2010, the Council submitted to President Obama a report called *Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future* (President's Council of Advisors on Science and Technology, 2010). Compared to the National Research Council's *Rising Above the Gathering Storm*, *Prepare and Inspire* is entirely focused on reforms to K-12 STEM education and provides detailed policy recommendations for enacting several of the action steps recommended in the earlier report. An analysis of the Council's recommendations provides a sense for the current policymaking climate in regards to K-12 STEM education. In several important respects, which are detailed below, this report extends more deeply—and is designed to more directly impact—the practice of STEM teachers, teacher educators, school administrators, and school partners.

In *Prepare and Inspire*, the Council identifies four major goals for K-12 STEM education: training a STEM-literate citizenry, training a STEM-proficient workforce, training an elite cadre of STEM experts, and closing the achievement and participation gap. In order to meet these goals, the Council expresses strong support for the state-led standards movement. The Council also recommends training 100,000 new STEM teachers, including a STEM Master Teacher Corps to serve as school and district teacher-leaders, developing new technologies to drive innovation in the K-12 education sector, and creating 1,000 STEM-focused schools to serve as "laboratories for experimenting with innovative approaches" (p. ix), including STEM-focused elementary and secondary schools designed to serve "minority and high-poverty communities" (p. 101). Similar to *Rising Above the Gathering Storm*, the Council's recommendations for educational reform are rationalized by referring to research conducted by social scientists and cognitive and developmental psychologists (National Research Council, 2000a). The council suggests that this research points to "cooperative, collaborative, active, and inquiry-based methods" as the most effective pedagogy for STEM education (p. 60).

As the title of the report implies, the Council is particularly interested in methods, programs, and experiences designed and proven to *inspire* students. Thus, the bulk of the council's recommendations—including those directly related to pedagogy, instruction, and curriculum materials—are designed to inspire students to pursue degrees and careers in STEM. The priority to inspire students extends, too, to the work of educational partners (i.e., colleges and universities, business and industry partners, museums and zoos) whose key value to the Federal STEM enterprise is their potential to provide inspiring STEM experiences to secondary students and secure the STEM pipeline. Considering this potential, the Council recommends that every STEM middle school and high school have a "partner in a STEM field" that can "bring STEM subjects to life" and help students "learn about STEM in the workplace" (p. 102). Building these connections is a critical piece of the Council's inspiration strategy.

> By making abundantly clear to students how many discoveries remain to be made and the role young people can play in solving important problems, schools and school systems can excite and motivate students to learn science and mathematics and to pursue careers in STEM fields (p. 97)

Although the Council recognizes that “efficient and effective” programs will have to be developed in order to engage the STEM professional community in these ways, the Council places the burden of innovation on the shoulders of school and teachers, requiring that they “maintain direct connections to appropriate STEM expertise” (p. 97).

The Council’s recommendations for reforms to K-12 STEM education are very much in line with the recommendations of previous policymakers (Ferneding, 2003). Their social vision is dependent upon what they call “technology-enabled educational innovation” (p. 76) and the “transformative potential” (p. 77) of educational technologies. In recommending the creation of an Advanced Research Projects Agency for Education (ARPA-ED), the Council hopes to speed the development of educational technologies to provide students with individualized, customized, and differentiated learning experiences and assessments and provide teachers with a constant stream of student performance data. The Council claims that these technologies would “support teachers in doing what they do best such as leading discussions and evaluating student work” (p. 80). Although the Committee recognizes that a lack of market incentives has handicapped educational innovation, they suggest that the new standards being developed has created a need for “new instructional materials, new professional development materials, and new kinds of assessments” (p. 74). In other words, an emerging market.

Committee on Highly Successful Schools or Programs for K-12 STEM Education

In order to determine best practices in K-12 STEM education—a key expectations of the policy recommendations and legislation addressed above—the National Research Council formed the Committee on Highly Successful Schools or Programs in K-12 STEM education. This committee held a workshop in May 2011 in which a number of papers were presented by leading experts and panels were held. The Committee’s workshop summary (National Research

Council, 2011b) and formal report (National Research Council, 2011a) demonstrate the difficulty of determining successful schools or programs due to the lack of conceptual agreement about the core practices of K-12 STEM education (Breiner, Harkness, Johnson, & Koehler, 2012; Bybee, 2010b; Roehrig, Moore, Wang, & Park, 2012; Zollman, 2011).

In keeping with previous policymakers' goals, the Committee suggests reforms to K-12 education as a way to expand the number of students with advanced degrees in STEM fields, including women and minorities, expanding the STEM workforce, and increasing scientific and technical literacy for all citizens to inform personal and societal decisions. Although the Committee is hesitant to recommend specific STEM education practices, due to the lack of available research on STEM integration in schools and the context-dependent nature of success, they identify three categories of STEM-focused schools. In the absence of a shared understanding of K-12 STEM education, these categories—and the schools mentioned under each category—serve as models for those hoping to design STEM-focused schools, including the persons charged to design the two schools that participated in this dissertation study.

First, the Committee notes highly-selective STEM schools such as the North Carolina School of Science and Mathematics, a school which includes a strong foreign language requirement and a significant research and mentorship experience for each student. Second are inclusive STEM-focused schools such as High Tech High in San Diego, the Denver School for Science and Mathematics, and Manor New Technology School in Austin, Texas. As the name implies, inclusive STEM schools are designed to serve a broad student population. In describing Manor New Technology High School, the Committee notes its "student-centered, collaborative, project-based community" as well as its "project-based instructional approach" (National Research Council, 2011a, p. 12). The Committee also notes the school's Think Forward Institute, which trains educators in "best practices for project-based learning, leadership, and 21st century skill applications" (p. 12). The third major category includes STEM-focused schools that offer career and technical education (CTE). The Committee describes career academies, career pathways, and career clusters as common ways for this type of school to organize the curriculum. James Stone, a faculty member at the University of Louisville who presented a paper on STEM-focused CTE at the Committee's 2011 workshop, recommends "project-based learning" and "work-based learning" as two promising pedagogical approaches for enhancing STEM learning in CTE settings although Stone notes the lack of available evidence for both approaches (National Research Council, 2011b, p. 17).

In regards to specific practices that support effective STEM education, the Committee focuses primarily on instruction and leadership practices to support instruction. Citing a number of previous National Research Council reports—including *How People Learn: Brain, Mind, Experience, and School* (Bransford, et al., 2000)—the committee argues that effective STEM instruction "actively engages students" in STEM practices and allows them to carry out their own "scientific investigations and engineering design projects" (National Research Council, 2011a, p. 19). Although the Committee notes that this type of instruction is rare in schools, facilitated only by "extraordinary teachers who overcome a variety of challenges" (p. 19), they recommend reforms to professional development, teacher assessment, and accountability systems as ways to incentivize teacher change. The Committee also calls attention to partnerships between schools and external organizations as an effective approach although they note that partnerships are more likely to be sustained when "the interests of both parties are served" and that that corporations will expect measurable and replicable impacts from their investments, objectives which are more easily achieved with non-profits than with public schools and districts (National Research Council, 2011b, p. 52)

Additional Perspectives on STEM Education's Purposes and Practices

Several scholars have been critical of the dominant purposes and rationales for K-12 STEM education. For example, writing from an Australian perspective, Williams (2011) argues that the STEM movement was designed by policymakers to serve economic and vocational goals. In other words, a "non-educational rationale" (p. 31). He writes:

> Spurred on by the global financial crisis, it is hoped that coordination and integration of STEM activities will better equip a workforce for dealing with the contemporary nature of business and industry, and encourage more school leavers to seek further training and employment in areas of engineering and science (Williams, 2011, p. 31)

Considering the lack of clarity around "what STEM education might look like in schools" (p. 28), Williams is wary that STEM integration will position engineering and technology as "a tool to achieve the goals of science and mathematics" (p. 28). Williams (2011) also criticizes the attempt by policymakers to fuse the general education goals for STEM (e.g. STEM literacy for all) and the vocational education goals for STEM (STEM for workforce development) into one policy package. This is bound to create implementation conflicts, Williams argued, considering that general and vocational education involve very different histories, goals, assessments, teaching methods, and methodologies.

This tension between liberal/general education and vocational education is an old one. It sparked a very public and spirited debate between John Dewey and David Snedden one hundred years ago, when Dewey used democratic concepts to argue against Snedden's proposals for vocational education (Dewey, 1977; Drost, 1977; Snedden & Dewey, 1977). Unlike the majority of STEM education policymakers, Williams (2011) is attuned to lessons from the past. Thus, his recommendation that educators be wary of supporting “a STEM approach to curriculum design” is based upon his understanding that “school curriculum structures are very resistant to change” (p. 27). This is an essential reservation and one supported by long line of research on educational reform (Alexander, Murphy, & Woods, 1996; Cuban, 1982, 1990, 2013; Goodman, 1995; Tyack & Tobin, 1994)

Although Williams (2011) recommends that technology and engineering educators be wary of the STEM integration, others have recognized STEM integration as a unique opportunity to secure the status of their respective professional communities (National Academy of Engineering, 2009; Sanders, 2009). Sanders (2009), for example, argues that “STEMmania” is an opportunity for technology educators to demonstrate that technology education deserves a permanent place in the school curriculum because it builds technological literacy and increases students’ interest and motivation. Similarly, the STEM movement has brought to the foreground concepts, skills, and practices germane to engineering and engineering education such as project-based learning and design challenges. In line with the official policy documents, Barakos, Lujan, and Strang (2012) suggest that “[p]roject-based curricula focused on team-oriented engineering challenges and contests are well-suited to prepare students to enter the workforce in STEM-related” (p. 16). With the importance of engineering and design practices to the Next Generation Science Standards (NGSS) being developed by the National Research Council, pedagogies and methodologies from engineering and engineering education are likely to appear in more and more K-12 classrooms (Dym & Little, 2008; Edelson & Reiser, 2006; National Research Council, 2012; Razzouk & Shute, 2012).

Considerable questions remain about how STEM education policy is to be implemented in schools although there is some common ground. STEM education is clearly an attempt at curriculum integration (Beane, 1997). STEM integration is most commonly understood as being purposed towards "solving real-world problems" (Breiner, Harkness, Johnson, & Koehler, 2012, p. 5). In this sense, STEM is closely related to other efforts to provide a real-world context for the teaching of science (Fensham, 2009; Mansour, 2009; Solomon & Aikenhead, 1994; Tinker & Krajcik, 2001; Zeidler, et al., 2005). Regarding instruction, there is a general consensus that STEM education involves replacing "traditional lecture-based teaching strategies with more inquiry and project-based approaches" (Breiner, et al., 2012, p. 3). Thus, STEM education puts additional emphasis on reforms to instruction already underway in STEM professional communities (National Council of Teachers of Mathematics, 2000; National Research Council, 1996). In official policy documents, including national standards documents, this move towards constructivist approaches to instruction has been rationalized by reference to emerging research in the cognitive sciences (National Research Council, 2000a; Sawyer, 2006b).

It has been common in education history for thinkers to distinguish the benefits of a new approach by creating a dichotomy between their approach and the 'traditional' way of doing things. Positioning tradition in this way is an essential aspect of progressive movements in culture and education (Bowers, 2000; Shils, 1981). Examples are widespread and include Dewey's distinction between conservative and democratic education (Dewey, 1916/1966), Freire's distinction between banking and problem-posing education (Freire, 2007), Papert's distinction between instructionism and constructionism (Papert, 1993), and Sterling's distinction between transmissive and transformative approaches to education and sustainability (Sterling, 2001). For each of the above thinkers, social progress requires progressive education. STEM education is no different. For STEM education policymakers, the move from traditional practice to constructivist practice is required by the demands of the knowledge economy and the complexity of twenty-first century problems. In this sense, STEM education is *primarily* a movement to reform instruction—an effort to create constructivist learning environments in order to meet the demands of a global economy. Underneath is a global discourse among the world's leading economies that meeting these demands involves rapid cycles of innovation in the educational sector (Organization for Economic Cooperation and Development, 2004).

STEM Education as Environmental Discourse

A deep understanding of STEM education requires a critical analysis of how STEM education works as environmental discourse. At the highest levels, STEM policymakers in the United States have integrated energy and environmental problems into their vision for STEM education. As a result, STEM education offers a particular view of environmental problem-solving having serious implications for both policy and practice.

A few examples provide a context for this analysis. The first is from the introduction to *Prepare and Inspire*, the recommendations to President Obama from his Council of Advisor's of Advisors on Science and Technology (PCAST). In introducing the importance of STEM, the council suggests the following:

> STEM education will determine whether the United States will remain a leader among nations and whether we will be able to solve immense challenges in such areas as energy, health, environmental protection, and national security (2010, p. v).

These claims are central to other key policy documents and social science research suggesting links between resource scarcity and political violence (Homer-Dixon, 1999). The claims of PCAST are significant because they represent the dominant cultural view. For example, Thomas

Friedman suggests in his popular book *Hot, Flat, and Crowded* (2008) that green is the "new red, white, and blue" and that America's future prosperity depends upon understanding—in order to solve—complex problems related to climate and energy. In line with STEM education policymakers, Friedman recommends that American companies invest in high-risk research into "clean power and energy efficiency innovation" (p. 255). From Friedman's perspective, innovations in the green energy sector will secure our economic prosperity:

> I am convinced that the best way for America to solve its big problem—the best way for America to get its "groove" back—is for us to take the lead in solving the world's big problem. In a world that is getting hot, flat, and crowded, the task of creating the tools, systems, energy sources, and ethics that will allow the planet to grow in cleaner, more sustainable ways is going to be the biggest challenge of our lifetime (2008, p. 5).

In this book, Friedman constructs American children as the "Energy-Climate" generation, a concept which dovetails nicely with STEM policy by placing students (and teachers) at the service of the economy and the state.

A third example comes from Roger Bybee, one of America's most prominent science educators, the Writing Team Leader for the Next Generation Science Standards project, and a leading thinker concerning the role of STEM in K-12 schooling (Bybee, 2010a, 2010b, 2011; National Research Council, 2012). In presenting a vision for the future, and attempting to clarify the purpose of STEM education, Bybee suggested that "STEM could mean an integrated approach to studying grand challenges of our era" such as "energy efficiency, resource use, environmental quality, and hazard mitigation" (Bybee, 2010, p. 31). As part of this particular rationale for STEM education, Bybee positions the social sciences in relation to the STEM disciplines in the following manner:

> the competencies that citizens need in order to understand and address issues such as these are clearly related to the STEM disciplines, which should be understood before addressing other disciplines (p. 31)

Reorganizing the curriculum around these “grand challenges” will be a challenge in itself, requiring a new educational approach that “places life situations and global issues in a central position and uses the four disciplines of STEM to understand and address the problem” (p. 32).

What is particularly striking about Bybee’s comments is the extent to which he positions the STEM disciplines as providing the tools necessary to “understand” and “address” environmental problems. Although his primary purpose may be to provide a clearer rationale and purpose for STEM education, when considered in the context of alternative views on education and environmental problem-solving, Bybee’s proposition represents a particularly technical, reductionist, and optimistic view of the situation at hand (Davison, 2001; Dryzek, 2005; Ehrenfeld, 1978; Jickling, 1991; Kahn, 2010; Orr, 1992).

Although the dominant discourse on STEM education suggests a consensus in regards to the right relationship between the STEM disciplines, society, and natural systems, this is far from the case. Environmental educators suggest cultural, political, economic, and social solutions to environmental problems and tend to be suspicious of institutionalized science and large-scale technologies. It would not be surprising to find some STEM teachers who share these same views. For this reason, the remainder of this chapter presents alternative views on environmental problems and solutions that might be represented in STEM teachers’ pedagogical practices.

Alternative Views on Environmental Problems and Solutions

John Dryzek is a political scientist who has taken a keen interest in environmental politics. His book *The Politics of the Earth* (2005) is helpful for interpreting STEM education as environmental discourse. Dryzek defines discourse as “a shared way of apprehending the world” (p. 9) and demonstrates how humans have developed different and shared ways of apprehending environmental issues. Dryzek also demonstrates how these shared understandings are “bound up with political power” (p. 9) as they move through policies and institutions such as schools.

Survivalism and prometheanism.

Drykek (2005) draws a primary distinction between survivalism and the “promethean response” to survivalism. As an environmental discourse, survivalism depends upon metaphors of doom and collapse and suggests that the carrying capacity of the planet has been overshot. Survivalists believe that there are natural limits to economic growth. In contrast to other discourses, survivalism suggests that environmental issues such as climate changes are best addressed by “elites operating on a coordinated global basis” (p. 46), a group of experts that includes scientific ecologists with expertise in systems modeling and other tools of statistical forecasting. In response to survivalism, prometheans have adopted a more optimistic stance, believing that human ingenuity will devise solutions to the environmental problems of the day. For this to happen, prometheans believe, policymakers must incentivize innovation and leave the rest to the market and to rational individuals. Compared to survivalists, prometheans view natural systems as being resilient and adaptive.

Problem-solving discourses.

Survivalism and prometheanism represent two very different ways of understanding environmental problems and solutions. In addition to these major discourses, Dryzek details three major approaches to environmental problem-solving: administrative rationalism, democratic pragmatism, and economic rationalism. What these three approaches share is the belief that current environmental problems can be solved without changing the liberal capitalist political economy. Where they differ is their approach to organizing problem-solving activities. Whereas administrative rationalists would rely on a hierarchy of technical experts and managers, democratic pragmatists would rely on a decentralized form of governance in which policy decisions are "legitimated through participatory procedures" (p. 103), a process which involves both cooperation and conflict. Economic rationalists would rely on market forces and consumer preferences—rather than politics—to change the behavior of individuals and institutions. Things such as pollution taxes, cap-and-trade policies, and environmental impact statements on consumer products are ideas germane to economic rationalism, the most prominent perspective on environmental problem-solving in developed countries, including the United States. These concepts can easily find their way into the curriculum, classroom discourse, and organizational culture of schools, including STEM schools.

Sustainable development and ecological modernization.

Under the influence of globalization, sustainable development is now the "leading transnational discourse of environmental concern" (p. 160). Sustainable development is a reassuring discourse, suggesting that social, economic, and environmental goals can be achieved simultaneously. Due to its focus on dissolving the tension between these three goals, Dryzek (2005) calls sustainable development an "imaginative" discourse. Compared to the other environmental discourses mentioned, sustainable development is roomy and inclusive—sensitive to the need to consider both social and natural systems, global and local concerns, international actions and grassroots efforts. Through its emphasis on networked governance, decentralized decision-making, social innovation, and the role of private-public partnerships, sustainable development has eased environmental issues into institutional discourses on globalization (Franklin, et al., 2003b; Innes & Booher, 2003; Spring, 2009).

In addition to sustainable development, Dryzek (2005) suggests ecological modernization as an imaginative discourse. Like sustainable development, ecological modernization suggests that environmental and economic goals can be met simultaneously. Key to its success is convincing businesses that environmentally-sound practices, although expensive in the short term, are more efficient in the long term. For this to occur, businesses must be persuaded that pollution is wasteful, costly, and a sign of inefficiency, and that there are unmet demands among consumers for green products and services (Dryzek, 2005, pp. 167-168). Ecological modernization depends upon a "corporatist" system in which "government, businesses, moderate environmentalists, and scientists" work together to restructure the political-economic system to be more reflexively environmentalist (Dryzek, 2005, p. 170). Due to the lack of corporatist values in the United States, ecological modernization can find no purchase here, although there is certainly a growing interest in green consciousness and politics, which is different in important ways.

Green consciousness and politics.

Dryzek (2005) suggests that green consciousness is a discourse whose proponents share a belief in changing how people think about and experience the world. Dryzek places deep ecology, ecofeminism, and lifestyle greens under this category, many of whom have expressed a romantic uneasiness towards science and technology. Dryzek finds the impact of green ideas in various cultural changes such as the increasing value of recycling, monitoring one's carbon footprint, taking up bicycling, and reading food labels. Although, as Dryzek notes, these changes may support and resemble the process of ecological modernization, the lack of attention to structural change among lifestyle greens keeps this a cultural approach. This is not the case with green politics, which involves "hardheaded analysis of social, political, and economic structure and practice” in addition to changes in consciousness (p. 205). This is the discourse of green political parties, whose visions of the sustainable society include political programs for how to get there (Dobson, 2007). Many concepts and behaviors of the green lifestyle are evident in today’s STEM schools, including recycling, school gardens, composting, energy audits, and environmental-awareness campaigns.

Chapter Three

Historical and Contemporary Perspectives on Project-Based Learning

Introduction

The purpose of this chapter is to provide a framework for interpreting STEM teachers' instructional practice. This framework is project-based learning. In designing this chapter I have drawn on two primary sources. The first is Kincheloe (2001), who argues that the rigor of contemporary qualitative research depends upon an interdisciplinary framework. In the context of this study, constructing such a framework involves connecting theoretical and empirical studies with data related to teachers' practice and school culture. The second source is "reconceptualist" work in the field of curriculum studies. Since the 1970s, reconceptualists have moved curriculum studies beyond its traditional focus on curriculum development to understanding curriculum from multiple perspectives (Pinar, Reynolds, Slattery, & Taubman, 2008). Inspired by the reconceptualist movement, this chapter approaches project-based learning from a number of historical and contemporary perspectives.

Although STEM schools and teachers identify with a number of approaches to instruction such as problem-based learning (Barron, et al., 1998; Hmelo-Silver, 2004; Savery, 2006), inquiry-based learning (Minner, Levy, & Century, 2010; National Research Council, 2000b), and design-based approaches (Dym, et al., 2005; Edelson & Reiser, 2006; Lehrer & Schauble, 2006), my experience in STEM schools, as well as the literature, suggests that project-based learning most accurately represents the instructional arm of STEM education discourse and policy. This chapter is an argument for how this is so. As such, I propose that *projects* are how STEM education is understood and enacted in the context of schools, classrooms, and educational partnerships. Having said this, all of the approaches above are closely related, attempts to create classroom environments faithful to constructivist learning theory (Blumenfeld, Kempler, & Krajcik, 2006; Howe & Berv, 2000a; Kirschner, Sweller, & Clark, 2006; Sawyer, 2006b). Their relatedness is clearly evident in the contemporary literature, where key terms overlap in a complex of ways. (Eris, 2004; Krajcik, Blumenfeld, Marx, Fredricks, & Soloway, 1998; Lehmann, et al., 2008; Polman, 2000). These practices are also related historically, as this review will make clear.

Historical Perspectives on Project-Based Learning

Project-based learning is a curious practice. On one hand it represents the leading edge of instructional theory, one of several innovations developed by researchers in the learning sciences (Krajcik & Blumenfeld, 2006; National Research Council, 2000a; Sawyer, 2006b). Contemporary models position project-based learning as a way to build knowledge society skills and engage today's digital natives (Bell, 2010; Bender, 2012; Boss & Krauss, 2007; Larmer, Ross, & Mergendoller, 2009; Moursund, 2003). These contemporary models reflect the widespread belief among many educational reformers that 'traditional' teaching practices (e.g. lecture, textbook learning, rote memorization, worksheets) are insufficient preparations for a global economy in which creativity and innovation are the key economic drivers (Sawyer, 2006a).

On the other hand, the idea of student projects has a long history in American and European education (Kliebard, 2004; Knoll, 1997; Morgan, 1983; Waks, 1997). In fact, advocates for educational reform have repeatedly turned to the project method as a way to implement their programs (Knoll, 1997, p. 1). In America,

> [w]henever constructivist concepts, inquiry-based learning, problem-solving, design are discussed in vocational and industrial education as well as in other field of education, the

"project" is considered the best and most appropriate method of teaching (Knoll, 1997, p. 1).

From this perspective project-based learning is an enduring concept and practice, part of our "pedagogical past" (Anderson, 2009; Cohen & Ball, 1990, p. 334). As an approach to instruction, it is the most traditional of innovations.

The machine in the garden.

The history of the project idea in American education reflects ongoing tensions between pastoral and industrial visions of American society. In America, the metaphors of *garden* and *machine* have often served to represent the two, with the garden serving as a "metaphor of the ideal society" (p. 85)—agrarian, pastoral, self-sufficient—and the machine representing social progress through technology and industry (Marx, 1964/2000, 1993). In America, the industrial revolution of the nineteenth century was accompanied by a complex set of feelings concerning what was lost along the way, a complexity evident in different interpretations of educational projects. In this sense, the project looks both backwards, towards a simpler time when Americans lived closer to soil, and forwards, to the twenty-first century and beyond. The idea of the project in America reflects this historical and cultural dissonance and explains why, still today, the project can be claimed by advocates for ecological and technical visions of the sustainable society (Orr, 1992).

This tension between past and future is helpful for interpreting the historical literature related to educational projects. For example, as John Dewey noted in *The School and Society* (1900), the center of industry in America had moved from the household to the factory quite rapidly, in "one, two, or at most three generations" (Dewey, 1990, p. 10). Concerned with what had been lost with the transition to a society based upon industry, Dewey incorporated “occupations” into his Laboratory School at the University of Chicago in an effort to *conserve* the educative benefits of household activities. According to Dewey, these occupations involved “the close and intimate acquaintance got with nature at first hand, with real things and materials” (p. 11) as well as building “discipline” and “character” (p. 10). Although Dewey recognized that industrialism had brought material advantages, he framed these as “consolations” for what had been lost (p 12). In the middle of sweeping social changes, Dewey designed a school and a curriculum in which the “actual world of hard conditions” played a leading role (Dewey, 1990). The conservative and somewhat nostalgic aspects of Dewey’s critique—as well as his emphasis on the educative value of nature and experience—remain central themes for today’s environmental and experiential discourses on project-based learning.

Charles S. Peirce and the role of doubt in human inquiry.

In an article published in the November 1877 issue of *Popular Science Monthly*, American philosopher and scientist Charles S. Peirce (1839-1914) suggested the “struggle to attain belief” as a motivating factor in human inquiry (Peirce, 1958, p. 100). As Peirce described it, “The irritation of doubt causes a struggle to attain a state of belief. I shall term this struggle *inquiry*” (1958, p. 100). In this manner, Peirce suggested where inquiry comes from—an irritant, a question, a doubt. Peirce argued that inquiry is activated by a doubt *experienced*, something a person felt. Although Peirce’s realism seems antiquated in our postmodern times, the idea that inquiry is initiated by a doubt experienced explains why contemporary approaches to inquiry are so focused on student engagement. Among models for project-based learning, for example, the ideal project is one in which the “driving question” is experienced by students as exciting, interesting, relevant, meaningful, and important—in other words, irritating enough to be pursued (Blumenfeld, et al., 1991; Krajcik & Blumenfeld, 2006). Similarly, a popular model for inquiry in science education invites teachers to "engage" students by asking questions and posing problems designed to "mitigate cognitive disequilibrium" and reveal student misconceptions (Bybee, et al., 2006, p. 13). Scientific inquiry, leading to conceptual change, can proceed on these grounds. How can inquiry proceed if not irritated by doubt? A number of guided approaches to inquiry have been designed to help teachers answer this question. Peirce's work (1958) suggests that the authenticity of an inquiry reflects the extent to which the irritation of doubt is experienced by students themselves, regardless of a teacher's role in establishing that irritation.

Due to a number of personal and professional circumstances, Charles S. Peirce never secured a stable academic position and spent much of his life in desperate circumstances, which makes more remarkable his impact on leading thinkers of his time, including John Dewey (Wiener, 1958). Although Peirce did not publish widely on educational topics, he strongly believed the purpose of higher education was to develop students' general desire to learn more about the world rather than preparing them for a future achievement (Wiener, 1958, p. xvii). In this sense, Peirce foreshadowed a tension that would soon follow between advocates for general and vocational approaches to elementary and secondary education, a tension most evident in the debate between John Dewey and David Snedden in the pages of the *New Republic* (Drost, 1977).

John Dewey and the role of problem-solving in everyday thinking.

Although Charles S. Peirce located doubt as the source of inquiry, it was John Dewey who introduced this idea to a general audience. In *How We Think* (Dewey, 1910; Dewey, 1933) Dewey presented a general theory of thinking as well as providing teachers with methods for training thought. Dewey's primary purpose was to distinguish "reflective thinking" from other types of thought and suggest its superiority. In doing so, Dewey borrowed heavily from Peirce, suggesting the origin of reflective thinking as "some perplexity, confusion, or doubt" (p. 15). Like Peirce, Dewey believed that the "state of doubt…is the stimulus to thorough inquiry" (p. 16). In a turn that has proved significant in educational thinking and practice, Dewey argued that the term "problem" was the most accurate name for the type of doubt that initiated reflective thinking. As a result, for the next sixty years, science educators worked to facilitate reflective thinking and "innovative problem-solving" among their students, believing these things should be the primary outcomes of good instruction (Champagne & Klopfer, 1977, p. 438). Dewey's philosophy did not easily translate into science education practices, however, although problem-solving did receive considerable attention in the science education literature, both as a method of instruction and student outcome (p. 444). By the late 1930s, a number of experimental studies had compared the problem method of science instruction to more traditional methods (p. 446). The current interest in problem-based learning among educational researchers and practitioners, in both STEM and non-STEM disciplines, demonstrates the enduring impact of Dewey's thought (Asghar, Ellington, Rice, Johnson, & Prime, 2012; Ravitz, 2009; Strobel & van Barneveld, 2009; Uden & Beaumont, 2006; Wirkala & Kuhn, 2011).

Following Dewey, the relationship between problems and projects became so intertwined that the two were often used in tandem. For example, in an article published in 1918 in *The English Journal*, James Fleming Hosic suggested the "Problem-Project" method as a way to combine the "thinking" involved in problem-solving with the "doing" then associated with project work (1918, p. 600). As such, Hosic's method combined intellect and activity. Writing that same year, Branom (1918) argued that teachers could energize themselves and their students by addressing "project problems." Branom anticipated the current interest among educational reformers to build the curriculum around 'real-world' problems as well as the hope that such problems might integrate the disciplines.

> A general aim of education should be to develop an ability in the pupils to interpret the factors—political, economical, social, and physical—involved in problems of timely moment. The most effective way of developing this ability is to give training in the interpretation of worth-while problems (p. 618).

For Branom, interpreting "worth-while problems" that are "of timely moment" developed in students a critical skill—how to make sense of problems that have political, economic, social, and physical aspects. As such, Branom's key rationale for studying such problems is that the process builds students' skills of interpretation. Although Branom noted that some students might become better at interpretation than others, he believed that "most of them, as a result of problem studies, will be able to follow intelligently and discriminatingly the statements of leaders, emanating from the pulpit, platform, and press" (p. 618). Branom was not alone among his contemporaries in putting problem-solving to social uses. By then, problem-solving was no longer relegated to science laboratories or science classrooms.

Reforms to architectural and engineering education.

Foundations scholars have not taken much interest in the conceptual nature of educational projects since the late 1920s (Waks, 1997). Michael Knoll, a German scholar, is a notable exception (Knoll, 1996, 1997; Knoll, 2012). Knoll (1997) has suggested that the project method began much earlier than is typically thought, with reforms to Italian architectural education undertaken in the late 16th century. At that time, projects provided a vehicle for architecture students to demonstrate to their instructors that they could work independently, solve problems common to the profession, and apply the knowledge learned in lectures (Knoll, 2012, p. 4). Architectural competitions, modeled after the professional and juried proposal process, became a feature of training academies in both Italy and France. Student submissions to these design competitions were knows as "progetti" in Italy and "projet" in France (Knoll, 1997, p. 3). By the end of the 18th century, the project idea had expanded from architecture into the field of engineering, both design-based professions, and into American technical colleges and universities, including the Massachusetts Institute of Technology (p. 3). The idea of projects as a way for students to demonstrate mastery, and project-based learning as a way to reform undergraduate and professional education, remains strong in the fields of design and engineering as these fields reconsider the social aspects and environmental impacts of their professional practice (Dutson, Todd, Magleby, & Sorensen, 1997; Dym & Little, 2008; Mills & Treagust, 2003; Savage, et al., 2007)

The project comes to America.

In the early twentieth century, the project method was integrated into American secondary and elementary schools. In the process it developed a more pragmatic flavor and mixed with progressive theories and ideologies (Kliebard, 2004). In contrast to Europe, where a sharp line had been drawn between design professions and applied professions, student projects in American technical colleges and universities involved both design *and* construction. Manual training—also known as *handwork*—became integrated into the curriculum of leading institutions such as the Illinois Industrial University at Urbana (1870) and the Manual Training School of Washington University (1879). In order to meet the program requirements of each institution, students had to demonstrate through project work that they could successfully design and construct a machine or other technical artifact.

Calvin M. Woodward, who started the Manual Training School in St. Louis, became a national champion for manual projects. As the manual training movement rapidly expanded, “hands-on” learning was seen as a means to move the American curriculum away from its humanist origins (mostly literary) and towards a more accurate reflection of practical life (Kliebard, 2004, pp.111-112). In addition to emphasizing the value of manual labor, from which the majority of American citizens gained their living, Woodward argued to include natural science and sense experiences into elementary and secondary curriculum (p. 112). Woodward’s adjustments to traditional education were more moderate than some of his contemporaries. For this reason, his ideas appealed to a wide variety of social and educational reformers (p. 112). The manual training movement, led by Woodward, opened the door for secondary and elementary teachers—the majority of them female—to incorporate nature and sense experiences into classroom projects.

Nature study and handwork in American elementary schools.

Only recently have educational researchers reconstructed the important role that nature study played in the history of American education. Recent historical studies suggest that the nature study movement was responsible for nothing less than introducing science to the public schools of North America (Kohlstedt, 2010; Kohlstedt, 2008). Although at the time there was considerable debate among advocates as to the purpose of nature study, and on what grounds it was justified, the rapid growth of nature study in American schools demonstrates what can happen when the goals of scientists, psychologists, educational theorists, and political and business interests are aligned (Kohlstedt, 2010, p. 36). In ten year’s time, from 1890 until 1900, outdoor outings and field studies gained widespread acceptance as a method for instructing students in basic science skills, including observation and interpretation. In both field and laboratory settings, instruction focused on natural objects. Although educating from “nature’s own book” (Kohlstedt, 2010) was more challenging for teachers than remaining indoors, nature study offered teachers a way to be innovative (p. 35). In response to the need for teacher training and professional development in nature study, many women with a scientific background were able to secure administrative and supervisory positions, and some rose to national prominence (Kolstedt, 2010, p. 146). The idea of basing instruction on tactile objects taken from students' local environment, and venturing into the field to observe objects and animals in their natural context, was the centerpiece of nature study's pedagogical philosophy. Leaders such as Wilbur Jackman—who began nature study programs at Cook County Normal School and the University of Chicago—suggested nature study as "an integrative project readily connected to other subjects and related to pupils' lives" (p. 47). In contrast to traditional education, nature study placed the center of gravity in nature and in the curious child.

Nature study and handwork were integrated into efforts to professionalize teacher education through the development of education departments, schools, and colleges at new research universities. The national interest in manual education and natural science had created the need for teachers trained to teach such courses and for educational leaders to reconstruct curriculum and instruction in order to incorporate these innovations. Like the Laboratory School at the University of Chicago, the Horace Mann School (1887) at Columbia University functioned as a research and demonstration site, a place for "testing theory through practice and modifying theory to accord with practice" (p. 11).

At Horace Mann, the elementary curriculum combined English, nature study, and manual training. These three areas were quite consciously integrated. The "projects" undertaken during "handwork" provided students with opportunities to paint, model, and build things related to their studies in English and nature study. Charles R. Richards, professor of Manual Training, argued that all human beings had an "instinctive tendency towards self-expression" (Richards, 1900b, p. 3). In the concrete word of childhood, this involved "expression through the hand" (p. 6). Perhaps anticipating common criticisms at the time, Richards' argued that learning involved both expression and impression and that "constructive design" (p. 5) and other acts of expression worked to "deepen and vivify" (p. 7) the impressions made by more formal activities and texts. By suggesting that material "representations" were integral to the learning process, Richards' foreshadowed a key element of constructivist teaching and learning (Blumenfeld, et al., 1991; Hmelo, Holton, & Kolodner, 2000; Hmelo-Silver, 2004; Krajcik & Blumenfeld, 2006).

In this same inaugural volume of *Teachers College Record*, Lloyd (1900) introduced nature study as a central aspect of the elementary curriculum at Horace Mann. Recognizing that the vast majority of students would not become professional scientists, Lloyd (1900) presented the value of natural science in more general terms.

> The chief end of such study is to enable the average person to understand and have a share in that scientific spirit which ought to be the common heritage of all; to have a faith in the results of proper scientific investigation which makes for clean living; and finally to have and to posess an abiding satisfaction in the things of nature which will attract the mind at times away from the strife of modern living to a quiet contemplation. (62)

Lloyd argued that "conservation of our natural resources…is dependent on an enlightened public opinion" (p. 63). At the level of curriculum, Lloyd urged teachers to "correlate the nature studies with the other studies of the curriculum" (p. 64). The same perspective is expressed by Professor Baker, who detailed the English curriculum at Horace Mann in the same volume (1900). Baker explained that Longfellow's *Hiawatha* was chosen for the second grade not only for its literary value but because "it affords so much opportunity" to connect with "modeling, drawing, etc." (p.

129). Baker noted that literature dealing with nature, which was prominent in the curriculum, would "open the eyes of the children to the beautiful or literary aspects of nature" (p. 129).

A closer look at the curriculum demonstrates how handwork, nature study, and English were seen as working together at Horace Mann. In English, a large portion of the year was spent on *Hiawatha.* Their reading was correlated in handwork class through the theme of "primitive life and occupations" (Richards, 1900a, p. 267). The major project was "the planning and making of an Indian village" (p. 267) and involved, among other tasks, making canoes of bark or paper, setting up a frame for curing skins, and weaving a blanket with "Indian decorations" (p. 267). Correlated to their nature study class, students built a replica beaver dam and house, as well as chicken-coop and pigeon house for the school garden, which had by the become a common site for nature study in the public schools (Kohlstedt, 2008; Trelstad, 1997).

The above snapshot from 1900 indicates the importance of handwork and nature study to educational thinking and practice at that time. It is striking the extent to which constructive design, both indoors and outdoors, remains a key feature of American education, particularly in the elementary school. The traces of this early history are everywhere, including "the special corners, tables, and window ledges of elementary school classrooms devoted to natural objects" (Kohlstedt, 2010, p. 9). Students re-enact this history whenever they express themselves through modeling, building, painting, or drawing. Teachers do the same whenever they plant a school garden, correlate science with literature and art, take a field trip to a local museum, or focus their class on issues in the local community.

Projects in American agricultural and industrial vocational education.

By 1900, the project had become a common term for educational practice in American schools. Although handwork and nature study were popular, particularly at the elementary level, manual training quickly grew into a movement to bring vocational training into the secondary schools. Nature study and handwork were vocationalized and overtaken by interests in funding agricultural education in rural areas and industrial education in urban areas. It was the economic value of these educational innovations that appealed most to the public (2004, p. 115). Led by the lobby of the National Association of Manufacturers and the National Society for the Promotion of Industrial Education, policymakers and educational leaders debated the role of vocational education in the school. The manufacturing lobby was particularly interested in the German system of technical training. By then the idea of educational projects had become widespread, and the project became the ideal for instruction in both vocational agriculture and industrial training (Moore, 1988; Snedden, 1916, 1918; Stimson, 1915). For advocates in these areas, the project had become "the chief pedagogical unit of organization" (Snedden, 1916, p. 421).

This would not have happened without the leadership of Rufus W. Stimson, who studied philosophy at Harvard under William James and eventually became President of Connecticut Agricultural College, which would later become the University of Connecticut. In 1908, Stimson left his university post to become the director of Smith's Agricultural School in Massachusetts (Moore, 1988, p. 51). Concerned for the lack of active participation among students of agriculture, Stimson devised a new instructional method. Through "home projects" students would apply on their family farms what they were learning in school classrooms. Stimson's idea of home projects attracted the attention of David Snedden and Charles Prosser, two state leaders who would soon become major advocates for social efficiency. Snedden appointed Stimson as supervisor of agricultural education for the state of Massachusetts. From this post, Stimson refined his project method and shared it widely through committee reports and presentations, including the 1915 Panama-Pacific International Exposition, where the state of Massachusetts earned the grand prize for their exhibit on the use of student projects in agricultural education (Moore, 1988, p. 52).

As a student of philosophy and literature, Stimson advocated a balanced approach to project teaching at the secondary level. Writing in 1915 for an audience of general educators, Stimson recognized two different types of secondary training—“cultural” and “vocational” (Stimson, 1915, p. 475). In a slide show that accompanied his presentation, Stimson represented the cultural aspects of his approach as a lowercase *c* and the vocational aspects as an uppercase *V* (p. 475). For Stimson, this represented the proper balance of “direct preparation for the career” and “cultural or civic values” (p. 475). In explaining the method of instruction, Stimson (1915) noted “kitchen gardening” as an introductory project for “boys of fourteen or so” and “fruit growing” and “market gardening” as more advanced “plant projects” undertaken during the third year (p. 477). The fourth year included “advanced projects in animal husbandry…and agriculture as a business” (p. 478). It is important to note that these were year long projects and quite different than what was happening in many urban elementary schools. Projects were supervised by instructors, who were on duty through the summer, riding farm-to-farm to supervise students’ work. Similarly, in cities such as Cincinnati, Philadelphia, and New York, large school garden programs developed through the work of school garden coordinators who, like their rural counterparts, worked throughout the summer to supervise students’ “home gardens” (Kohlstedt, 2008). In this way, school garden advocates were able to shift the burden away from classroom teachers, many of whom resisted the extra work involved in garden maintenance and supervision (Kohlstedt, 2008).

Although both were vocational, industrial education and agricultural education reflected two very different sets of values. One was urban and progressive and the other was primarily rural and nostalgic. Although in 1917 it became politically expedient to join the two through the Smith Hughes Act, which provided federal funding for vocational education, this was an uneasy union. A the level of culture, the "garden" and "machine" represented a deep social unease about the effects of rapid industrialization and urbanization (Marx, 1964/2000). As Kliebard (2004) explained:

> one was framed in terms of simply meeting the needs of the new industrial society by training a skilled labor force in schools, while the other had its origins in the effort to preserve certain values associated with rural living in the face of that new society (p. 130).

In addition to representing different sets of values, these two versions of vocational education carried different conceptions of educational projects. Within agricultural education, projects were embedded within the workplace of the family farm, a world which students experienced directly. By contrast, industrial projects involved training students for a "real world of manufacturing" that they would experience after school (Kliebard, 2004, p. 131). Considering the centrality of the "real world" to STEM education discourse, this is a critical distinction. Whose real world are we talking about? The real world of the soil, of the present, of students' experience? Or the real world of the future, of the post industrial workplace, of the energy efficient society? The project, it appears, remains implicated in both.

Tensions between democratic and vocational purposes.

In late 1914 and early 1915, John Dewey and David Snedden carried on a public and spirited debate in the National about the role of vocational education in American society. At the time, Snedden was the leading national advocate for social efficiency. For Snedden, the most efficient use of educational resources involved training students for their adult role, which he believed was predetermined. Snedden would have students counseled towards a specific occupation during junior high school (Drost, 1977, p. 24). By contrast, Dewey would have students participate more generally in a wide range of "occupations" as a way to make sense of the manufacturing process itself, which had moved from the household to the factory in just a few generations (Dewey, 1990). Dewey, whose general philosophy was rooted in the natural world, believed that industry was educative not because it provided ends for socially efficient curriculum-making but because it demonstrated the many ways in which communities of people had learned to satisfy their basic human needs (Dewey, 1958). From this perspective, human vocations served as lessons in history and geography—how particular peoples at particular times wrested security from particular environments. For Dewey, the purpose of education in a democratic society was to provide students with tools to interpret and reconstruct the world, a purpose which Dewey would extend to vocational education (Drost, 1977, p. 20).

In his initial critique, Dewey noted the "undigested medley" (Dewey, 1977, p. 54) of rationales for vocational education then being offered.

> The need of a substituted for the disappearing apprenticeship system, the demand of employers for more skilled workers, the importance of special training if the United States is to hold its own in international competitive commerce, figure side by side with the educational need of making instruction more "vital" to pupils (p. 54).

Dewey critiqued those who would hold Germany as a model for industrial education. Dewey argued that Germany's nationalism rationalized a narrow form of technical training that was "extraordinarily irrelevant to American conditions" (p. 54). Dewey argued that in America the problem of how to adjust to industrialization was an "educational" problem and not a "business" or "technical" problem (p. 56).

In an article that followed several months later, Dewey continued his critique of narrow vocational education by focusing on recent legislation from Indiana, which included a number of provisions designed to ensure that state funds for vocational programs in schools were not diverted by local interests to serve general education programs or activities. Dewey argued that policymakers efforts to "put a fence around industrial education" served only to build distrust among school teachers and administrators (p. 57). For Dewey, this Indiana law was wrong-headed because it disregarded "actual conditions" (p. 57).

In May of 1915, Snedden and Dewey responded to one another in the pages of *New Republic* (Snedden & Dewey, 1977). Snedden took the opportunity to argue that in the absence of an apprenticeship system, the state must provide vocational training in the public schools. Snedden responded to Dewey's critique of industry's involvement in education. Snedden explained that "dual control" of vocational education represented

> an attempt to put in immediate charge of a special form of education a group of persons who are primarily interested in its successful development, and who may be able to bring it to the point of view of practical men in that field. Business men are suspicious of the so-called academic mind in connection with vocational education. They feel assured neither of the friendliness nor of the competency of our schoolmasters in developing sound industrial education. For that reason they often favor some form of partially separate control, at least at the outset of any new experiment (p. 37).

Although this debate happened a century ago, the central tensions and themes discussed by Dewey and Snedden are present in STEM education discourse and policy, although not always revealed or made so public. The economic and vocational goals of STEM education, and the role of business and industry leaders in STEM education policy and partnerships, make STEM education an effort at social efficiency. Were he able to, Dewey would argue that STEM education should give students the tools to *create* a knowledge society rather than adapt to it. Due to its service to business interests, Dewey would be wary of STEM's democratic and educational credentials.

The project method goes viral.

In America, project work was introduced to a general audience by William H. Kilpatrick, a philosopher of education at Teachers College of Columbia and a colleague of John Dewey (Kilpatrick, 1918, 1925). The appearance of Kilpatrick's essay "The Project Method" in late 1918 attracted significant attention among teachers, leading to requests for 60,000 reprints from the Teachers College Bureau of Publications (Kliebard, 2004, p. 135). Kilpatrick's major achievement was to translate the project idea, which had taken hold in vocational education (Snedden, 1916), agricultural education (Stimson, 1915), and home economics (Charters, 1918), into a general method for teaching and learning applicable—at least theoretically—in every classroom (Kliebard, 2004, p. 135). Most importantly, by integrating Dewey's (1910) conception of thinking-as-problem-solving into his method, Kilpatrick provided a psychological rationale and assured that future conceptions of the project method would incorporate problem-solving as a key component. The project method also aligned well with American's practical temperament and its native philosophy of pragmatism, a philosophy committed to democracy, community, and unfettered inquiry (Bernstein, 1998; Dewey, 1916/1966; Peirce, 1958). Hosic (1918) declared the "project-problem" method "the method employed by the nation" (p. 602).

Although Kilpatrick (1918) introduced the project method to a general audience, his alignment of project work with student "purposes" had an unfortunate effect. By such criteria, any classroom activity (e.g., building a boat, sewing a dress, making a kite) could be considered a project so long as it emerged from the interest of students. Much of the literature that followed Kilpatrick's reconstruction involved attempts to delimit the concept and method (Alberty, 1927; Branom, 1919; Horn, 1920; Stevenson, 1921). For example, Stevenson's (1921) definition of the educational project as a "problematic act carried to completion in its natural setting" (p. 43) clarified the boundaries of Kilpatrick's method, keeping in tact the primary focus on problem-solving while making more explicit the importance of context. Although Stevenson's idea of the "natural setting" was perhaps ambiguous (Alberty, 1927), his focus on 'real-world' situations as a way of bringing schooling and life closer together remains a key rationale for problem- and project-based learning (Barron, et al., 1998; Blumenfeld, et al., 1991). Krajcik and Blumenfeld's (2006) desire to situate learning in an "authentic, real-world context" (p. 319) echoes Stevenson's earlier desire to do the same.

Michael Knoll's reconstructive historiography.

In a recent paper, Knoll (2012) challenged the project's historiography, suggesting that William Kilpatrick, who is typically regarded as the father of the "project method" (1918), had merely radicalized an existing practice and done so to suit his professional interests. Drawing from a detailed analysis of archival sources, including Kilpatrick's diaries and correspondences, Knoll (2012) argues that Kilpatrick developed the "project method" as an academic posture, an attempt to distance himself from the "problem method" introduced to general education by Frank McMurry, a colleague of Kilpatrick's at Teachers College, and vetted by John Dewey's psychological interpretation. Knoll (2012) suggests that Kilpatrick was well aware of the power of the term *project*, which "possessed an openness that permitted it to be filled with new ideas and concepts" (p. 13), and the term *method*, which satisfied progressive educators' desire to increase students' activity, interest, and freedom (p. 13). Knoll's (2012) argues, quite convincingly, that Kilpatrick's project method became an international success *not* because it was successful in real-world classrooms, but because it met many educators' visions for what classrooms *should* and *could* look like.

The enduring promise of projects.

As evidence of the enduring promise of the project idea, consider the following excerpts. The first appeared in the winter of 1921, when William Kilpatrick was invited by the Milwaukee Teachers Association to speak to teachers about his project method. The local press advertised the event as follows (cited in Knoll, 2012, p. 25):

Can you imagine –

A school room without desks and stiff-backed seats?

Where you don't have to sit with folded hands?

Where you can whisper and pass notes, if you feel like it?

Where you won't have dull things like reading, 'riting, and 'rithmetic?

No more examinations?

Where you actually like to go?

Well that's the school of the future, according to Dr. William Heard Kilpatrick.

The seminar was a huge success, attended by sixteen hundred participants, and led to considerable but short-lived enthusiasm for the project method in Milwaukee (Knoll, 2012, p. 25). Now consider a second excerpt, taken from a paper published in 2010 in which an elementary educator argued for project-based learning as a way to build twenty-first century skills (Bell, 2010). The article begins with the following vignette, a glimpse into an ideal classroom:

> *Mrs. Regent was erasing the board, getting prepared for the next lesson, when the new assistant principal walked in. Introductions were made as the assistant principal perused the room. He stood for a minute or two, just looking at the classroom. Finally, he spoke. "They are all so. . . engaged," he said with astonishment. The teacher paused for a moment, not sure what to say. She looked around, and it was evident that each child was immersed and focused on his or her work. The only thing that the teacher could respond to the assistant principal was, "Aren't they supposed to be?"* (p. 39)

Here, eighty-nine years later, the project idea continues to tug at teachers' deepest aspirations—a classroom so engaging and interesting that observers are left speechless. Following this vignette, which the article implies can be achieved through project-based learning, Bell (2010) credits project-based learning for building numerous skills and dispositions among students, including responsibility, discipline, accountability, communication, negotiation, and collaboration. Bell's (2010) article includes excerpts such as the following:

> PROJECT-BASED LEARNING is a key strategy for creating independent thinkers and learners. Children solve real-world problems by designing their own inquiries, planning their learning, organizing their research, and implementing a multitude of learning strategies. Students flourish under this child-driven, motivating approach to learning and gain valuable skills that will build a strong foundation for their future in our global economy (p. 39).

From a teacher's perspective, these claims are quite persuasive. Not only can project-based learning help your students to "flourish" it can also help you meet the demands placed upon you by policymakers, administrators, and professional organizations. These include the professional mandate that your students will "solve real-world problems by designing their own inquiries" as well as the political mandate that your students will develop "a strong foundation for their future in our global economy." In this sense, project-based learning is a problem-solving practice.

In fact, the project idea has a history for solving educational problems. These problems are both general and specific, theoretical and practical. As Alberty (1927) noted in a dissertation supervised by Boyd Bode, who at the time was a leading critic of Kilpatrick, the project method was an attempt to solve a problem endemic to complex civilizations: How can the accumulated experience of a society, which is arranged logically and systematically, be transmitted to young persons, who are involved in experiencing the world directly and who learn in response to a "felt need or difficulty" (p. 1)? Alberty (1927) recognized the gap that the project method attempted to fill, between facts as they are arranged by adult specialists and facts as they are experienced by children (p. 3). Alberty appreciated Kilpatrick's attempt to fill this gap, but he did not believe that "psychologizing" the curriculum into "immediate and individual experiencing" could teach students the basic facts and principles necessary for understanding and applying complex fields of knowledge such as science. Instead, Alberty (1927) argued for a balanced approach. Rather that relying entirely on "the *immediate* experience of the child" (p. 106), Alberty recommended that teachers combine the project method with "other procedures which will provide for logical organization" including direct instruction (p. 107).

Contemporary Perspectives on Project-Based Learning

In many ways, all of the major themes from the history of project-based learning remain active today. For example, hands-on learning remains prominent in the fields of science and engineering education. Also, problem-solving—as both a method of instruction and as a student outcome—remains at the center of practice. Fields such as environmental education (Huckle, 1983; Sauve, 2005), science technology studies (STS), and socio-scientific issues depend on a foundation laid by nature study advocates over a century ago. Despite this stability, several things are very different about today's project-based learning. In addition to the more traditional meanings associated with project exercises and components, project-based learning now also describes the philosophical or methodological orientation of an educational institution (Morgan, 1983). Project-based organizations are a common way for industries to remain flexible and responsive to customer needs in the knowledge economy (Powell & Snellman, 2004; Sydow, et al., 2004; Waks, 1997).

Theoretical and empirical research on project-based learning.

A qualitative review of the literature on project-based learning in post-secondary education (Helle, Tynjala, & Olkinuora, 2006) suggests that while the central components of project-based learning may remain stable (student initiative in solving a driving question or problem organizes classroom activity leading to an end product) the use of projects varies widely depending upon the "pedagogical, political or ethical reasons for its adoption" (pp. 288-289). The authors of this study locate four major motives adopting project-based learning: a professional motive to orient students to professional practice; a humanitarian motive common to service learning; a critical thinking motive common to science education; and a pedagogical motive to increase student understanding of subject matter (p. 290). Their review of thirty-seven empirical articles on project-based learning within post-secondary education found that the majority of articles were descriptive rather than evaluative. Challenges to implementation were rarely addressed in detail. The authors concluded that "serious theoretically-grounded research" on project-based learning remains rare within the context of higher education (p. 306). This situation may be changing, as indicated by a recent article locating project-based learning and social constructivism within a "theoretical mid-ground" between critical theory and behaviorism (Roessingh & Chambers, 2011).

The general lack of theoretical and evaluative interest in project-based learning among researchers in higher education makes more problematic the promises made of project-based learning by publishing practitioners. For example, in her (2010) article linking project-based learning to the 21st Century Skills framework, elementary school teacher Stephanie Bell claims that project-based learning teaches responsibility, independence, and accountability; promotes social learning; provides intrinsic motivation; enhances creativity through technology use; and engages students in real-world tasks. While these promises are consistent with the dominant design frameworks for project-based learning (Barron, et al., 1998; Blumenfeld, et al., 1991), the lack of a strong empirical base for project-based learning leads Bell (2010) and STEM practitioners (Cole, 2011) to appeal to a similar utopian vision—a "classroom of the future" in which technology facilitates the successful implementation of project-based learning. Empirical evidence suggest that a core component of this vision, the social component of a problem-based approach, may have little impact on student learning (Wirkala & Kuhn, 2011). This will come as bad news to engineering educators hoping that problem-oriented and project-based approaches will train future engineers in the collaborative aspects of sustainable development projects (Lehmann, et al., 2008) It remains to be seen which core components of project-based learning similar models will be validated by future research. Discursive tensions beneath the "consensus" on project-based learning indicate future disruptions to the utopian vision (Moje, Collazo, Carrillo, & Marx, 2001).

Project-based science.

The main stream of existing research on project-based learning comes out of a long-term partnership between the University of Michigan and the Detroit Public Schools (Blumenfeld, et al., 2000; Blumenfeld, Krajcik, Marx, & Soloway, 1994; Fishman & Krajcik, 2003; Krajcik, Blumenfeld, Marx, & Soloway, 1994; Ladewski, Krajcik, & Harvey, 1994; Marx, et al., 1994; Marx, et al., 2004; Marx, et al., 1997). This research locates project-based learning within the theoretical field of constructivism, the academic field of science education, and the practical field of middle school science teaching. Project-based learning is constructed as a technologically-enhanced "curricular innovation" (Fishman & Krajcik, 2003) informed by research in the cognitive sciences. Through this literature, the enactment of project-based learning as project-based science (PBS) is closely linked to ongoing reform efforts within science education (Marx, et al., 1997) and urban school systems (Blumenfeld, Fishman, Krajcik, & Marx, 2000; Marx, et al., 2004).

This research addresses the significant challenges to teacher implementation and the importance of meeting these challenges if project-based learning is to "change school learning fundamentally" (Marx, et al., 1997). At the level of individual teachers, successful implementation requires significant alterations to a teacher's "stable and well-practiced repertoire" (p. 347), to their pedagogical assumptions, and to their theories of learning. Qualitative studies of teachers' understanding and enactment of this particular model of project-based learning indicate that teachers face challenges related to time, classroom authority, order and control, and the use of technology (Ladewski, Krajcik, & Harvey, 1994; Marx, et al., 1994). The researchers suggest peer collaboration, strong partnerships with university personnel and technology experts, and time set aside for teacher reflection as potential ways of meeting these challenges (Blumenfeld, et al., 1994; Krajcik, et al., 1994).

Conclusion

As a whole, the research base on project-based learning suggests significant opportunities for theoretical work and the need for empirical studies exploring the real-world barriers to implementation and the effects of implementation on teachers. The utopian rhetoric surrounding project-based learning the general lack of engagement with theory, the number of learning outcomes project-based learning is suggested as achieving, the extent to which project-based learning is tied to systemic reform efforts, and the lack of research attention to the role of teachers *all* suggest a rigorous and qualitative approach with teachers' voices, experiences, and practices at the center.

Chapter Four

Research Methodology and Procedures

Introduction

This dissertation study examines the implementation of STEM education policy by comparing teachers' understanding and enactment of environmental projects at two STEM-focused high schools. This chapter provides a detailed rationale for my methodology and methods, including a description of my general approach to inquiry. This chapter is designed to serve as a guide for other doctoral students who are trying to find their way through the messy particulars of postmodern qualitative research (Atkinson, Coffey, & Delamont, 2001; Lather, 2006).

Study Context

This study was conducted as a sub-study involving modifications to an IRB protocol for a National Science Foundation Innovative Technology Experiences for Teachers and Students (ITEST) project. I was a graduate research assistant for the ITEST study, which investigated the effectiveness, innovativeness, and sustainability of integrated science projects at Central STEM High School. My dissertation added a second site to the ITEST study—Capital Design Academy. All of the projects in my dissertation were designed by teachers and partners to address problems related to climate, energy, water, and food. As such, they mirrored STEM education discourse and policy as well cultural discourses concerning climate change, energy, and the economy (Friedman, 2008).

General Approach to Inquiry: Dewey's Naturalism

My general approach to inquiry has developed in conversation with John Dewey's thinking and writing. Dewey is often misunderstood as being overly concerned with the scientific method. This is inaccurate. For Dewey, science represents the success of a particular epistemology, evidence that human knowledge of the world involves taking actions, having certain experiences, and reflecting on those experiences. Dewey's approach to social reconstruction is a result of taking this experimental/experiential method and applying it to the social world. As such, Dewey does not distinguish between actions undertaken in a laboratory setting and actions undertaken in a socio-political setting. Both are inquiries resulting from a problem situation. Both are valid and necessary ways of knowing. Both involve educative situations. Taking Darwin seriously, as Dewey does, involves abandoning a teleological idea of nature and society—the idea that either are headed towards a more accurate representation of an ideal that transcends our experience of the world (Rorty, 1989). This sort of abandonment is what allows Richard Rorty, a postmodern pragmatist, to reject the "priestly function" of the scientist and to recommend the poet as "vanguard of the species" (1989, pp. 20-21). The work of the social scientist in this regard is to investigate interactions among persons, language, and environments. These interactions are situated, context-bound, and as complex as any in nature. This understanding frames my approach to social phenomenon.

In my approach to this dissertation study, I have been particularly interested in two books not commonly read in education courses: *Experience and Nature* (1958) and *The Quest for Certainty* (1929). In each of these books, Dewey suggests that our primary experience of the world is one of risk and contingency. As evidence that the world is in fact "precarious and perilous" (1958, p. 41) Dewey points to a number of enduring cultural phenomenon, including idealist philosophies. Dewey is critical of such attempts to claim a certainty and security that our experience of the world recommends as false. I would include idealist educational policies and instructional models in this same category. Both seek a level of certainty and security that teachers' classroom experience recommends as false. This dissertation study explores the terrain between risk and security in the context of STEM education.

Research Questions

This dissertation study examines the implementation of STEM education policy by comparing teachers' understanding and enactment of environmental projects at two STEM-focused high schools. The main research questions are as follows:

1. How do STEM teachers understand and enact project-based learning?
2. What challenges do they experience when teaching environmental projects, and how do they negotiate these challenges?
3. How do these projects represent environmental problems and solutions?
4. How do these projects represent teachers' previous educational and environmental experiences?

Research Design and Methodology

Answering these questions involves the collection and analysis of qualitative data. A qualitative approach allows me to investigate teachers' practice, and the meaning teachers attribute to their practice, in the context of teachers' life histories and school cultures. A qualitative approach also answers the call by the National Research Council for additional research into the "organizational and instructional practices" that exist in STEM schools and classrooms (2011a, p. 7). As project-based learning and STEM education become integrated into a comprehensive model for educational reform (Blumenfeld, et al., 2000; Bybee, 2010a; Krajcik & Blumenfeld, 2006; National Research Council, 2011a) researchers will need additional studies that examine how teachers are implementing this model. Qualitative methods have proven to be good tools for this type of investigation (Erickson, 2009; Siegel, 2005; Supovitz & Weinbaum, 2008).

Three theoretical propositions are central to my study design and methodology. First, I propose that teachers' experience reflects their life history, a history which includes significant educational and environmental experiences (Chawla, 2006; Raymund, 1995; Sebba, 1991; Seidman, 2006). Second, I propose that teachers' life histories frame their understanding and enactment of environmental projects—providing certain possibilities and constraints. Third, I propose that the history and culture of schools provides additional layers of possibilities and constraints. As such, this study examines both experience and culture and involves combining two traditions in qualitative research: interpretive phenomenology and ethnography (Maggs-Rapport, 2000). Interpretive phenomenology provides a methodology and methods for interpreting teachers' experience, including their life history. Ethnography provides a methodology and methods for interpreting the cultural context of experience. On both accounts, this study is situated within the interpretive tradition of philosophy and educational research (Delanty & Strydom, 2003; Erickson, 1986).

This study is a comparative case study. Initially, I considered a case to be an individual teacher's experience. I held firm to this idea through the process of adding a second site to my study. It wasn't until well into data analysis that I realized the true consequences of having introducing a second site. By introducing a second site, I had also introduced a second level of cases—the schools themselves. As I considered different ways to represent this complexity, it became clear to me that the experience of the teacher participants made sense only within the context of the schools where they worked, each of which had adopted a different interpretation of STEM education during the school design process. As such, I now identify this dissertation as a comparative case study involving two STEM schools: Central STEM High School and Capital Design Academy. This is why my findings are presented in two chapters—one for each school case—before being compared in the final chapter. This organization has allowed me to be more clear and confident when suggesting what aspects of being a STEM teacher are context-dependent and what aspects of being a STEM teacher are primary to the experience itself.

There are two categories of participants in this study. Primary participants include classroom teachers at each school. Secondary participants include teachers, administrators, and partners involved in school design. At the time of this study, each primary participant was attempting to implement two key aspects of project-based learning: using a problem situation to organize classroom activities and requiring students to create project artifacts (Blumenfeld, et al., 1991). Interview data were triangulated against classroom observations, curriculum documents, official school documents, and participant-provided documents related to school design.

Philosophical framework for interpretation.

As a philosophical framework for interpretation, phenomenology orients a researcher towards two intersecting levels of meaning: the meaning given to an experience by research participants—their "self-explication" (Schutz, 1967, p. 100)—and the meaning given to these same experiences by the researcher. Within the context of a phenomenological study, participants express themselves through language, and the process of their *speaking* facilitates the construction of their *meaning*. The researcher relies on participants' linguistic descriptions of experience, and their own experience with the phenomenon, to create a written representation of the experience that inspired the investigation. The success of the interpretation will depend on the extent to which the written description strikes "a responsive chord" among others, including the participants themselves (Aoki, 2005, p. 104). The intersubjective nature of phenomenological inquiry confers both personal and social validity to a researcher's interpretation (Moustakas, 1994).

Although phenomenological research seeks to interpret things and experiences "in themselves" (Moustakas, 1994, p. 27) environmental education research often adopts a more critical approach. Paul Hart's (1996) notion of a "critical interpretive methodology" (p. 61) helps elaborate the ways in which this study—as an inquiry into an *environmental education phenomenon*—foregrounds the gaps that exist between teachers' sense-making and the possible worlds suggested by environmental educators. The methodological tensions involved reflect deeper tensions between "intersubjective" (e.g., phenomenological) and "interobjective" (e.g., ecological) conceptions of knowledge, teaching, and learning (Davis, 2009). If, as many ecological thinkers and educators argue, the more-than-human-world is a co-participant in the construction of knowledge, this involves a recalibration of methodology and methods. Dewey's naturalism provides a general approach to interobjective inquiry grounded in experience and nature. This dissertation further accounts for interobjectivity by interpreting educational policy as environmental discourse, collecting data specifically related to environmental experiences and projects, and analyzing this data in light of its environmental implications.

Researcher positionality and ethics.

My positionality related to this study is complex. As a graduate assistant at one of my research sites, I have had access to information that does not fall directly under the IRB protocol for this dissertation, including many informal conversations with teachers, students, state-level policymakers, and educational partners. This experience has shaped my understanding of STEM education considerably. I have used this experience as a guide to the research literature, being careful to ground my opinions about STEM education in published academic work and in the empirical data I have collected.

As a former classroom teacher and environmental educator, I have considerable experience with the types of projects that my participants are attempting. I know how hard this work can be. This explains, perhaps, why I have chosen to conduct a teacher-centered study in a field that has focused on measuring student outcomes, developing policy, and securing external funding. As a former classroom teacher, I have serious reservations about the demands being placed upon teachers by STEM policymakers. Having said this, there are no gains to be had in identifying a villain in this type of study. It is far more productive to recognize that groups and individuals are doing the best they can to reform a system that has proven very resistant to change. This approach is an ethical imperative in studies such as this one where participants have shared so much of their practice and themselves. I have drawn on two main sources to help me calibrate this position. The first is educational researcher Sarah Lawrence Lightfoot, who in her book *The Good High School* (1983) provides a template for conducting field research that is both "generous" and "critical" (p. 14). The second source is educational ethnographer Frederick Erickson, who has identified ways to engage a policy audience when presenting findings (2009). Recognizing that policymakers are a primary audience, I have tried to represent the "relative frequency" and "full range of variation" (p. 73) among teachers' experience and not to generalize from specific excerpts and instances.

In the rush to produce educational innovations, common classroom events such as lecturing, note-taking, and leading student discussions have been categorized as "traditional" practices in need of reform. Although this false dichotomy represents a stereotype (Brown, 1992) and inhibits a clear-headed examination of teaching practice (Ravitz, 2009), it is more common than I first imagined, having found its way even into my observation protocol. I know from having taught school myself that more traditional practices complement more progressive or student-centered practices in a complex of ways. The confusion around tradition and innovation in regards to instruction reveals a “looseness of fit” between constructivist epistemology and constructivist pedagogy (Howe & Berv, 2000b). One can be a constructivist and still use traditional practices in the classroom. What matters are the beliefs behind the behavior, which can not be accounted for by observation alone. As a result, I have adopted a position of neutrality in regards to teachers’ practice. I have chosen not to adopt an operational definition of key concepts in this study (e.g., STEM education, project-based learning, sustainability) as a way to measure participants’ practice.

In considering this position, I have returned to readings in environmental ethics (Light & Rolston, 2003), a field which argues for the moral stranding of non-human species. From these readings, I have developed a sense for how an environmental ethic can lead to a general disdain for the human species. The moral pessimism resulting from such a position might explain why some of the brightest researchers in environmental education have declined to collect data from human subjects, choosing instead to construct new theories and pedagogies (Bowers, 2001; Gruenewald, 2003; Kahn, 2010). While I find this work invaluable, I am also troubled by how distant these frameworks are from practicing teachers. I also find a troubling assumption underneath too much work in environmental education, that the practice of most teachers is morally suspect when judged from an environmental perspective. In order to avoid this pitfall, my ethical position is that teachers and their practice—like that of any natural kind—carry an intrinsic value deserving full moral consideration.

Research Procedures

Below is a detailed account of the research procedures used in this study. This discussion includes a description of site selection, selection of participants, data collection, data analysis, reporting of the cases, and trustworthiness.

Site selection.

A detailed description of Central STEM High School and Capital STEM Academy is included in Chapters Five and Six, where I report my findings. Here, I detail the criteria for selecting each site. This study was made possible by my employment at Central STEM High School, where I served as a part-time, doctoral-level assistant. The study was conducted as a sub-study under the ITEST protocol, to which I have added a second site, Capital STEM Academy. Each school is within a short drive from a large city center, with Central being the more urban of the two. Central and Capital are two hours away from each other by car. As such, my visits to Capital involved most of a day, and on several occasions I stayed over at a hotel to make a two-day visit possible.

I conducted the interviews and observations at both sites between March, 2012 and June, 2013. Throughout this time period, I had regular contact with teachers at Central, where I was working part-time, and less frequent contact with teachers and administrators at Capital. Although I built a strong rapport with teachers and both schools, and came to understand the culture of each school quite well, my engagement with Central was more prolonged and intensive.

This study began with my interest in the ITEST projects at Central STEM High School, projects which were anchored by teachers in the biological and physical sciences. I was attracted to these projects because they were related to environmental problems. After reviewing official policy documents related to STEM education, it became clear that this environmental focus reflected the highest levels of policy concern. Upon further study, I became quite confident that these projects were instances of a larger effort to incorporate environmental problem-solving into school curriculum, including STEM education. Guided by this understanding, I chose Central for a research site not for its convenience but because it represented one case of a STEM high school where teachers were attempting projects related to environmental problems. In addition, Central represented a particular type of STEM school trying to do this—an inclusive school with a career focus that served a poor community (National Research Council, 2011a, 2011b).

Capital made for an interesting comparative case for a number of reasons. In contrast to Central, Capital identified itself as an environmental STEM school and had more consciously incorporated the social and political aspects of sustainability into its curriculum. In addition, teachers and administrators at Capital had rejected the project-based culture of Central in favor of a design-based approach borrowed from engineering. Capital had far less of a career focus than Capital and its curriculum included various high-status markers, including advanced placement (AP) courses. In addition, its geographic location, in the capital of the state, facilitated partnerships with state-level policymakers. Finally, in contrast to Central, which was housed in a renovated, century-old building, Capital was built from the ground-up with close collaborations among the school's design team, curriculum developers, and building architects. As such, Capital represented a new model in a new building, a building which reflected dominant visions of what twenty-first century schools should look and feel like. Thus, Capital provided a contrast to Central in terms of setting, student demographics, building design, instructional design, and approach to environmental issues.

Selection of participants.

Pseudonyms were used for all participants in an effort to maintain their anonymity. The participants included teachers at each school as well as teachers and administrators who were involved in the design process of each school. Informed consent was gathered for each participant. Through a process of face-to-face meetings, and phone/email communications, each participant was provided with detailed information about the purpose of the study and what was expected of them as participants. I made clear that participation was voluntary and made every effort to reach potential participants directly and without the mediation of school administrators. Finally, each participant was informed by me that they could withdraw from the study at any time and for any reason.

At Central, the initial participants were drawn from the group of teachers who were already participants of the ITEST study, the protocol that this dissertation fell under as a sub-study. This sub-study, which added a second site and new interview protocol, was approved by the district. Potential participants at Capital were approached in person, by me, and asked if they would consider joining a sub-study to the ITEST project. I chose potential participants to maximize the variability of experience within the school's context. I invited individual to join who were of different races, who taught different courses and grade levels, and who were at varying stages in their careers. I invited teachers who had taught, or were currently teaching, projects related to climate change, renewable energy, and global water sustainability. One of these teachers had designed the school's garden. All of the teachers I invited to join considered themselves to be doing project-based learning or inquiry-based learning. Following a modification to my study protocol, I added a second round of participants, inviting four of the five teachers who were involved in the initial design of the school related to curriculum and instruction. These persons included a graduate student in mathematics, Central's current principal, a veteran teacher in the district, and one of Central's strongest teacher-leaders. In total, I invited nine participants to join the study from Central, all of whom accepted.

At Capital, I first contacted the principal, who invited me to present my study and recruit participants at a faculty meeting in August, 2012. I met all of the school's teachers at this meeting, several of whom I already knew through my work with the state's network of STEM schools. I connected with one of my participants at this time, a teacher who teaches a capstone course on engineering and design. Three other teachers, who were collaborating on a separate project-based course related to economics, energy, and the environment, were recommended by the school principal following this meeting. These teachers were then contacted by me and invited to join individually. As was the case at Central, a second round of interviews invited teachers and administrators to join the study who were involved in the building and program design of the school. This second group included the first and second principals of the school. In total, I invited eight participants to join the study from Capital, all of whom accepted.

Methods of data collection.

My methods of data collection—semi-structured interviews, classroom observations, and the collection of classroom artifacts—were designed to provide data sources related to teachers' *understanding* and *enactment*. In choosing these three methods, I considered that interpretation involves a consideration for what people say, what they do, and the things they make and use (Spradley, 1980). By including observations and artifacts, I hoped to generate grounded theories to balance the culture-bound theories contained in my framework. As was mentioned in the methodology description, a phenomenological approach to in-depth interviewing was used to account for teachers' experience and an ethnographic approach to observations and artifacts was used to account for the cultural context of teachers' experience.

Teacher interviews.

Research in the human sciences requires methods that allow participants to explore the meaning of their actions through humane interactions with a researcher (Mischler, 1986; van Manen, 1990). With this in mind, my interviews with teachers and administrators offered many opportunities, through initial and follow-up questions, for participants to share their feelings, attitudes, and values related to STEM education, project-based learning, and environmental issues (Anderson & Jack, 1991).

I consider my primary participants to be the nine teachers at Central and Capital who were originally invited to join the study. These teachers participated in an interview process tailored to their experience as STEM teachers who have adopted a project-based approach to environmental issues. Using Seidman's (2006) phenomenological interview method as a guide, I interviewed each of these nine teachers two time for sixty to ninety minutes each time. Although Seidman's model suggests three interview with each person, I have found this more than necessary and a potential burden to participants. I piloted a modified, two-interview approach during a study that I conducted at a school garden program in 2011, and I found that this approach yielded rich data while allowing time and resources to interview additional participants. The first interview with each teacher adopted Seidman's life history approach, which Seidman based on the work of French sociologist Daniel Berteaux. This interview invited participants to share their past experiences from early childhood through teacher training, with an emphasis on educational and environmental experiences. The second interview invited teachers to reflect on these same topics related to their current practice and in the context of their life history.

In designing the interview questions, I drew from both Seidman (2006) and Spradley (1979). Consulting Seidman (2006), I defined my main focus area: the experience of STEM teachers who have adopted a project-based approach to environmental issues. Questions for the life history reflected this focus, inviting teachers to reconstruct their early experiences related to formal/informal education and the outdoors. Teachers were asked if they could remember their own teachers using a project-based approach and how they were trained to use a project-based approach themselves. Through primary and follow-up questions, teachers were invited to reflect on the social and collaborative aspects of these experiences, as well as to explore their interest in STEM, however they defined STEM. During this interview, several teachers recalled a primary interest in the natural world, an interest which led them to study physical and ecological science as adults. Teachers also recalled informal inquiry activities they had undertaken, both inside and outside, as well as a variety of design projects. Mothers and fathers were *very* present in these interviews.

Interview questions, particularly for the second of the two interviews, were also inspired by Spradley's (1979) work on ethnographic interviewing. Spradley describes the need to ask "native language questions" in order to determine what language participants themselves use. This need became clear during my pilot study on school gardens, when I learned that the term "outdoors" rather than "nature" was the appropriate "folk term" used by the participants (Spradley, 1979). As such, I made sure to ask each teacher if the term project-based learning was what the term that they themselves used, which it typically was. If not, we discussed new folk terms such as "design-based learning" which had been adopted by some teachers as a replacement for project-based learning. Other questions asked teachers to describe project-based learning to a hypothetical parent, and to describe for me a typical class period when they are doing project-based learning. Both of these questions functioned as “grand tour” questions (Spradley, 1979) designed to elicit teachers’ understanding of their practice by asking them to describe it across lines of identity (p. 90). These questions often elicited from teachers a project ‘ideal,’ particular at Capital where teachers were struggling to manage projects under exceptionally challenging conditions. The second interview ended with questions designed to elicit how teachers understood particular environmental problems as they related to project design and instruction such as student outcomes and project artifacts.

The second round of study interviews were context interviews and included eight teachers and administrators who had been involved in the design of each school. Each of these persons was interviewed one time for about sixty minutes. These interview questions asked participants to recall the design process from their perspective, with an emphasis on how decisions related to curriculum and instruction were made. Key design constraints were addressed as well. The final questions asked teachers to reflect on how closely each school, and they now observed it, matched the vision they had for the school during the design process. These interviews providing a critical context for interpreting the interview data gathered from the primary participants.

Classroom observations.

In total, I conducted fourteen observations of the primary teacher participants in this study. During these observations, I attended to what teachers and students were saying and doing. I wrote down “jottings” (Emerson, Fretz, & Shaw, 1995) during each observation, turning these descriptive fragments into expanded fieldnotes later on that same day (Lightfoot, 1983). I considered this routine a data management tool (Richards, 2009). Themes, ideas, issues, and topics that emerged from these evening sessions informed my later observations and interviews.

The first observation in each classroom, I attended closely to my initial impressions, to key classroom events, and to my personal reactions to these events (Emerson, et al., 1995). Following Spradley (Spradley, 1980), later observations focused on speech acts and behaviors related to project-based learning and environmental issues. Focused observations were designed to add to my understanding of how environmental problems and solutions were constructed in these classrooms, one of the study's main research questions. Established models for project-based learning (Barron, et al., 1998; Blumenfeld, et al., 1991) and existing research on teachers' enactment of project-based learning (Blumenfeld, Krajcik, Marx, & Soloway, 1994; Marx, et al., 1997) provided categories for narrowing the scope of my observations.

The most significant observation I conducted was at Capital, at the invitation of the participants, a mock debate between liberal and conservative politicians. This debate, a key component of their energy, economics, and environment project, was related to biodiversity and wildlife management, and was designed as an opportunity for students to hear their policy concerns addressed by two persons holding very different views on the environment and animal species. This observation was particularly useful in helping me understand how this group of teachers understood the variation among environmental positions and how they presented this variation to their students. Observations at Central provided similar opportunities for me to hear how teachers understood and represented environmental problems and solutions. These opportunities included a climate change assembly presented to students, an assembly which was incorporated into several projects.

I initially planned to use the Reformed Teacher Observation Protocol (RTOP), which was designed at Arizona State University and was used by other researchers in our ITEST study. This protocol is an attempt to operationalize a variety of reform suggestions embedded in science and mathematics documents. I quickly became disillusioned with this protocol. One, I felt that the observation criteria were idealistic and seriously inattentive to the constraints affecting teachers work. Second, as a social science practice, I felt that the protocol was more positivist and behaviorist than interpretive. The idea that one could evaluate a teacher's practice simply by observing their classroom behavior, without giving them a chance to explain the meaning of their behavior, seemed absurd and unethical. Third, I became convinced in my literature review that someone could be committed to constructivism and still display more traditional practices when observed.

Classroom artifacts.

I also collected classroom documents related to each of the projects. These artifacts included project curriculum, timelines, lesson plans, syllabi, handouts, and artifacts. Curriculum at both schools included renewable energy curriculum from Project Lead the Way (PLTW), a leading provider of "project-based" and "hand-on" STEM curriculum (Handley, Coon, & Marshall, 2012; Rogers, Wright, & Yates, 2013). Classroom observations helped identify artifacts and provided an opportunity to observe artifacts in use. During interviews, several teachers referenced additional artifacts such as books, movies, advertisements, policy papers, and teacher training course syllabi that they believed were important to understanding their own practice, and I consulted these as well. In addition, teachers and administrators involved in the design of each school provided unofficial documents related to their decision-making process.

These documents included early versions of curriculum and school missions and visions, all of which were useful in interpreting each school's particular approach to STEM education.

Data analysis.

In my experience, there is a lack of theoretical guideposts to help novice qualitative researchers during the data analysis phase. I was pleased to find the work of Maxwell and Miller (2008), which provided me with a theoretical rationale for my procedures, which are described below. According to Maxwell and Miller (2008), structuralist theories of language suggest that ideas are related either because they are similar to one another or because they are near to each other (contiguous) in space and time. Maxwell and Miller (2008) argue for combining similarity-based and contiguity-based strategies during the process of qualitative data analysis. Whereas similarity-based strategies work *across* cases and contexts (e.g., coding) contiguity-based strategies work *within* cases and contexts (e.g. narrative analysis). What is lost through the decontextualizing process of coding is returned through a narrative account of participants' experience. For this study, data analysis combined categorizing and connecting strategies related to interview transcripts and field notes.

Narrative analysis within cases.

All interviews were transcribed by a professional with whom I had worked during a pilot study. Upon receiving each transcript, I listened to the interview again in full, correcting the paper transcript in the process. During this listening, I also noted any passages that struck me as particular significant or representative of participants' experience.

I then returned to each interview transcript with the intention of conducting a narrative or contextual analysis. I decided to base this analysis on the Listening Guide approach developed by Carol Gilligan, which I had used in a doctoral-level seminar on feminist qualitative methods.

(Gilligan, Spencer, Weinberg, & Bertsch, 2003) The Listening Guide was also recommended by Maxwell and Miller (2008). For this study, I chose to conduct a “first listening” of each interview (Gilligan, et al., 2003, p. 160). Guided by the following description of what a first listening entails, as well as my previous experience with the method, I was confident that this step would generate key tensions, themes, and categories that might function as codes during my next step of analysis. The text says:

> We begin by first getting a sense of where we are, or what the territory is by identifying the stories that are being told, what is happening, when, where, with whom, and why. Repeated images and metaphors and dominant themes are noted as are contradictions and absences, or what is not expressed (Gilligan, et al., 2003)

I took this as a directive and created what I call a “listening sheet” to fill in while I listened to each interview. This sheet had sections marked for Stories (which became a numbered list), Conflicts and Tensions, Moral Language, Repeated Words and Themes, Key Images and Metaphors, and Reader Response. My attention to moral language during this listening was inspired by additional work in feminist psychology (Anderson & Jack, 1991; Gilligan, Brown, & Rogers, 1989; Jack, 1991) and confirmed by the many instances in which teachers judged themselves, and their practice, by cultural norms and other ideals.

For the first listening, I sat down in front of my computer, with a my listening sheet to one side, and a paper copy of the transcript to the other. While listening to the interview, I took notes on the listening sheet under the respective headings as well as marking, on the interview transcript, major passages associated with each. When the interview was complete, I sat down to flesh-out the listening sheet, using my notes to construct a narrative and analytic account of the interview, which included large and small data excerpts. Although first listenings typically describe the data, the fact that I knew there would be no further listenings led me to analyze as well. Looking back at these pieces, those sections read like analytic memos in which I followed key themes and tensions a bit further. In one section, for example, I analyzed one participant's sense of fairness related to differences in workload among teachers in the building as representing his sense of distributive justice. Overall, this process was both time-consuming and productive. These listening generated key findings related to individual teacher's experience. The next step of analysis was designed to determine the extent to which these findings varied across the teachers.

Coding across cases by machine.

In addition to constructing narrative accounts, qualitative data analysis involves grouping textual data into categories containing similar concepts (Maxwell & Miller, 2008). In order to function analytically and not just organizationally, these categories must provide insight into the meaning of particular experiences and events. In this study, I used coding as my primary categorizing strategy (Saldana, 2009). Following Saldana's recommendation, I decided to code broadly rather than narrowly. In order to facilitate the coding process, I turned to a computer-based program called Dedoose that I had been introduced to by a qualitative researcher from California who had been contracted by the National Science Foundation to evaluate a sample of ITEST projects from around the country. As a data management tool, Dedoose allowed me to store text files of interviews and field notes as media items and to indentify each media item with each school and participant. It also allowed me to store analytic memos and to link these memos to the excerpts that inspired them.

Initial codes were suggested by my first listenings and included autonomy, tradition, innovation, outdoor experiences, educational experiences, project challenges, ideals, and reality.

The relationships code quickly developed a number of sub-codes representing teachers' relationships with administrators, parents, students, themselves and their practice, colleagues, curriculum, family, parents, partners, community, mentors and teachers, childhood peers, and the district. This coding process generated two documents of value. The first included all excerpts from the interviews and field notes organized by each participant. This document retained the context of experience and echoed the first listenings, although without any commentary. Reading through this document provides a strong sense for each teacher's experience. The second document of value included all excerpts from the interviews and field notes organized by codes. Reading through this document suggested the extent to which key aspects of each teacher's experience, such as project challenges, were distributed across participants. This document provided grounds for considering what elements of the experience were constitutive of the experience itself (van Manen, 1990).

Moving from codes to categories.

During the third and final step of data analysis, the particular meanings gained from the first listenings, and the general survey of meanings gained through coding, were analyzed in the context of several frameworks. The first was the research questions themselves. These questions, which related to teachers' understanding and enactment of environmental projects, drew to the foreground narratives, metaphors, and tensions related to participants' environmental and educational experiences. In several cases, a representative quote from a participant served to integrate the experience of others. For example, when Philip, a science teacher at Central STEM High School, expressed his frustration with inquiry teaching by saying "there's a time and place for acting like bears" I had a strong sense that this statement represented the experience of others, several of whom had used moral language when describing the gap between instructional ideals and their classrooms. Similarly, I was attracted to the analytic effects of concepts drawn from the STEM disciplines. For example, the engineering concepts of "structure and load" became a useful way to interpret the supports and challenges reported by the teachers in this study.

As an aid to this final phase of analysis, I created several one-page summaries of concepts findings from the literature on project-based learning and instructional innovation. These frameworks incorporated issues related to implementation (Blumenfeld, et al., 2000; Blumenfeld, et al., 2006; Krajcik & Blumenfeld, 2006). In addition, I created a one-page framework of Dryzek's (2005) work on environmental discourses. By reading the first listening documents, codes, and excerpts against these frameworks and my research questions, an outline for a narrative representation of the participants' experience began to emerge.

Generalization and validity.

The generalizations suggested by this study are what Eisner (2003) calls "naturalistic generalizations" and "canonical events" (p. 24) both of which function as heuristics for understanding cases beyond those addressed in a study. This study is generalizable to the extent that the lived experiences of these three teachers suggest an anticipatory framework for understanding the experiences of teachers working in similar situations. I have attempted to establishing the validity of my conclusions through attention to Eisner's (2003, pp. 25-26) three criteria for validity in qualitative research. According to Eisner, for a work to be valid it must be structurally corroborated, with a preponderance of evidence leading to strong conclusions, and referentially adequate, organizing a reader's perception in such a way that they "see the qualities described in the work" (p. 26). In addition, the work must rise to a standard of consensual validation in which it is demonstrated that two or more qualitative researchers would have similar conclusions when presented with the same data. In addressing criteria one, I have left a trail of evidence leading back to the raw data that represents the lived experience of my participants. In addressing criteria two, I have used my narrative and rhetorical skills to illuminate the reader to my findings, sharing with van Manen (1990) the belief that phenomenological research and writing are intertwined (p. 7). In addressing the criteria of consensual validity, I have depended upon a critical friends group consisting of several qualitative researchers. This group met on a weekly basis during the course of this study to share data excerpts and discuss the multiple interpretations that emerged during these readings. With this said, my final interpretation remains one among many possible interpretations.

Chapter Five

Findings from Central STEM High School

Introduction

Central STEM High School is an urban public high school serving approximately 1,100 students, grades seven through twelve. Its century-old building sits on high ground within walking distance from a large public university, one of the Central's major partners. The setting is vibrant, a mix of small businesses and residential housing. The school was originally commissioned by city leaders as a "defense against ignorance" at a time when the arts and sciences were a teacher's primary weapon. Following a major renovation, the building now faces forward—towards futures in science, technology, engineering, and mathematics—its library converted into a professional development and practice lab, its classrooms equipped with computers, interactive white boards, and LCD projectors. As such, Central is a mix of tradition and innovation, a school sensitive to its legacy and open to the opportunities of a new century. Central's students are predominantly African American, with a very high percentage qualifying for free and reduced lunch. Nearly one quarter are identified as in need of special education and intervention services. The guiding hope among Central's teachers and administrators is that STEM will help change the outcome for the school's students.

Before discussing the environmental projects at Central STEM High School, and the work of the project teachers, it is important to place the school in a larger policy context. This is the purpose of the next two sections, which discuss policy at the state and district levels.

State Policy: Legislating Spaces for STEM Innovation

Although all states have identified their approach to K-12 STEM education, this particular state is unique in having created a category for STEM schools through legislation. This legislation—signed into law by the governor is 2007—set aside funds to establish several new STEM high schools and established a subcommittee to oversee the process of awarding grants. As one member of the subcommittee explained, this legislation "allowed for an innovation space" by releasing school planners from a number of constraints, such as where they could site a new school. Although the purpose of this legislation was to fund innovation, the language used in the bill and in the call for proposals provided an explicit framework for curriculum and instruction. For example, those applying for a STEM school grant were asked to provide evidence that the school would feature an "integrated" and "project-based curriculum" and incorporate "scientific inquiry" and "technological design" into classroom instruction. In addition, applicants were asked to provide evidence of collaborative governance—including participation from partners in higher education, business, and industry—and the capacity to develop and share innovative practices in STEM education.

It is important to note that this legislation did not release STEM school designers, teachers, or administrators from key aspects of state education policy. For example, students in the state's STEM schools are still required to take the state's standardized tests for graduation and achievement, and STEM schools and teachers are still evaluated based upon students' performance on these tests. In addition, students in STEM high schools are required by the state to complete the same core requirements as other students, including four years of English language arts and two years of social studies. These aspects of assessment, evaluation, and curriculum policy are constraints that STEM school designers in this particular state must consider.

The state also features a strong career and technical education (CTE) program, and many schools in the state offer CTE courses and pathways alongside the state's general education core.

These programs are designed to develop students' technical skills and provide opportunities for students to earn industry credentials and college credits during high school. As a state-designated site for CTE education, Central's curriculum is organized into career "pathways" in the upper grades. For this, Central receives considerable funding from the state. Although STEM is not one of these career pathways, all five of Centrals' pathways focus on the importance of STEM knowledge and skills to career success. CTE programs are typically assessed using post-secondary criteria, and although there are federal and state standards related to CTE curriculum, no standardized assessments are linked to these standards. This situation provides CTE teachers with a level of freedom not experienced by the state's core teachers. Combining STEM and CTE in one high school is not uncommon. Educational researchers would categorize Central as an inclusive STEM school that focuses on career and technical education (CTE) (National Research Council, 2011a, 2011b).

The District Context: An Urban Innovator

Central STEM High School is situated in one of the state's largest urban districts. The district's finances have been impacted by the economic health of the state and by falling property values, which have impacted local tax revenues. In response, the district has been forced to cut positions, including teaching positions in courses not required for graduation. Base salaries for teachers are expected to remain frozen through at least 2016. Despite these financial constraints, the district has maintained its reputation as an urban innovator in regards to professional development, teacher leadership, and the use of student data to make decisions. The district is also one of the 'greenest' in the country, incorporating sustainable design into a major facilities initiative. The district currently houses as many LEED-certified schools as any comparable district in the country.

In advance of the new Common Core State Standards, the district has moved to a 7-12 high school model designed to introduce students to rigorous content at an earlier age. Recently, the district suffered the blows of a new state report card, which lowered the rating of several of its inclusive high schools. This situation was communicated to the public as a necessary precursor to higher academic standards. Documents available on the district's website appeal to "capstone projects" as the means by which students will acquire the knowledge and skills required for success in the twenty-first century, including college and career success.

Designing a Project-Based Culture and Curriculum

The sections above provide a state and district context for the work of the teachers, administrators, and partners charged to design Central STEM High School, which was awarded one of the state's initial seed grants. This context is important because it suggests that specific possibilities and constraints were embedded in the process of designing the school. This process, which is described below, indicates how the school's designers created spaces for freedom and innovation amidst the constraints they experienced. Theirs is a story of commitment, care, and resilience.

Among policymakers, Central STEM High School is considered the state's first conversion school. This conversion placed two schools—each with their own state identification number—in the same building for several years. This was a complex process as one school was phased out and another was phased in. Leading up to the STEM grant, Central had established itself as a successful urban public high school. At that time, the building housed five separate academic programs, including a science and math academy and a program devoted to teaching and technology. The teaching and technology program, in particular, had a tradition of project-based learning, conserved by the stability of its staff and by a program facilitator who understood constructivist pedagogies. According to one teacher, this person made sure that her staff "knew the difference" between project-based and problem-based learning. So, although Central now houses a new STEM program, educational innovation is a building tradition.

When the district was awarded a grant from the state to establish new STEM school, it hired a team of four teachers and one graduate student to design the school's curriculum—the curriculum design team (CDT). Each of the five CDT members had taught at Central prior to the STEM award and knew the school well. This was an unprecedented opportunity for this group of teachers, all of whom were instructional leaders. Several members of the CDT credited the local teachers' union for ensuring that teachers would play a leading role in the school's design. The CDT began the design process without a school building because the district had yet to confirm a site for the school. Many suspected Central, however, which was scheduled to be restructured due to the expense of maintaining its five programs and aging buildings. Just prior to the STEM award, Jerry, a Central veteran who had had experienced several rounds of restructuring talk, recalls saying to his colleagues during school leadership meetings, "We need to re-create ourselves or somebody's going to do it for us." Central STEM High School existence attests to the success of this effort.

Roger, a social studies teacher, believed he was hired for the CDT because his previous experience with project-based learning and co-teaching fit well with district administration's vision for a STEM school. More personally, Roger was intrigued by the 'T' in STEM and viewed the new program as an opportunity to further his use of technology to engage students with academic content. Roger described why the CDT identified with project-based learning rather than problem-based learning, which had been recommended by a university faculty member.

We decided we wanted to go project-based learning. We really felt—and it's not like the two were completely separate—but our whole thing was we wanted to design projects that students were working on. Many of them did have this overarching idea to solve a problem, but we were about doing projects.

Roger's comment demonstrates that the CDT's vision for instruction was activity-driven—with teachers designing projects and students doing them. Roger's influence on the design team is evident in the draft curriculum documents, which combined English/social studies and English/science into co-taught courses in the ninth and tenth grades. The curriculum also featured an innovative course that combined mathematics and social justice pedagogies (Gutstein, 2006). The team designed a set of projects to anchor each quarter, several of which involved external partners. In their initial vision, technology class was where students at each grade level would complete the projects they had been assigned in their core classes, and there were also plans for a semi-structured project time after lunch. Project checklists were viewed by the CDT as a project management tool and means to facilitate communications among students, teachers, and parents.

In the absence of STEM schools in the local area, several members of the CDT visited model schools across the country, including High Tech High in California and a New Tech school in a neighboring state. Both Roger and Jerry came away from these visits intrigued by the schools' flexible architecture, which included glass classroom walls and breakout spaces for project work. These aspects of school architecture represented to them visible signs of collaboration and professional excellence. Roger believed such openness provided teachers with "positive peer pressure to be doing great things."

More than the similarities, however, these visits revealed to the team the unique nature of their own vision for an inclusive STEM school to serve low income students of color, the same student population that Central had served prior to its conversion. CDT member Sheila explained, “We didn’t want to create a school that no kid could get into or be successful at.” Derrick, the graduate student member on the CDT, noted that the team wanted to avoid “hidden entrance requirements” that penalized students from low income backgrounds. He offered the example of requiring a entrance interview in the evening, with both parents presents, as an admissions requirement.

Each of the CDT members I spoke with commented on the constraints they experienced during the planning year. As Roger explained, “It’s hard to start a school when you don’t even know what building you’re going to be in or how big you’re going to be…the most basic, fundamental of questions.” This uncertainty meant that the unfeasibility of certain architectural features (e.g., glass walls, project work spaces, classroom dividers, multiple power outlets) did not become clear until late in the planning process, past the point of negotiations with the school’s architects. For teachers hoping to design a project-based school, this was a setback. When the STEM program moved into Central’s newly-renovated building, after a year spent in an attached annex, the lack of classroom dividers, as well as a larger-than-expected class sizes, made it difficult to implement the CDT’s vision for co-taught courses.

Jerry attempted to co-teach an English/social studies course in Central STEM High School’s first year in the renovated building. This course placed 60 students and two teachers in a large room with high ceilings and poor acoustics. Reflecting on this experience, Jerry noted, “If you had taken 25 kids, 50 kids, and put them in that room with a divider, it would have been night and day.” For Jerry, the stress of co-teaching that year was exacerbated by a particularly difficult group of students and the presence of a student teacher and two faculty researchers from a local university. Jerry's experience that year suggests how school architecture can constrain an instructional innovation.

A peer-reviewed publication co-authored by Central STEM High School's first principal, its first technology teacher, and a university researcher describes how project-based learning was interpreted as contributing to a much larger project—building a positive school culture around trust, community, and teacher leadership. Such a culture was viewed by teachers, administrators, and university partners as an essential aspect of restructuring and sustaining the school. Through this culture-building process, project-based learning at Central STEM High School—including the skills and dispositions it required of teachers and students—became a *core value.* The tension between project-based learning as a cultural practice, and project-based learning as an instructional practice, frames my interpretation of the environmental projects at the school.

Implementing the Vision: The ITEST Projects

The curriculum design team interpreted their work as an effort to integrate the curriculum through projects, with an emphasis on integrating the STEM disciplines. Implementing this vision became easier when Central STEM High School was awarded a federal grant ($730,000) from the National Science Foundation's Innovative Technology Experiences for Students and Teachers (ITEST) program. ITEST awards are purposed towards workforce development and designed to support K-12 educators in increasing students' interest and engagement in STEM. Central's successful proposal addressed several ITEST priorities by incorporating partners from business and industry and serving a student population underrepresented in STEM professions. The ITEST grant at Central supported four integrated projects involving science teachers, career and technical education (CTE) teachers, and technology teachers in grades 9 and 10. Three of these projects addressed an environmental issue—climate change, renewable energy, and global water sustainability. A sizeable portion of the ITEST grant funds went towards purchasing backpacks and portable technologies designed to facilitate science learning in out-of-school contexts (Tinker & Krajcik, 2001). A corporate partner was integrated into the energy and water projects, commitments secured by the CDT during the planning year.

Gardeners and Engineers: The Work of the Project Teachers

Central was designed as an inclusive STEM high school, open to any student in the district. The primary hope among Central's teachers was that the school would change the outcome for its students, the majority of whom were low income students of color. The school's culture was built to support this hope and to revitalize it when it waned. Given the school's focus on social and emotional learning, teachers assumed several different roles throughout the day, including nurturing students and managing classroom projects. In a well-regarded book on district-wide educational reform, Supovitz (2006) argues that successful reform depends as much on "gardening" as "engineering" (p. 63). These are good names for the primary roles of Central's teachers. The remainder of this chapter focuses on five of these teachers and how they worked as "gardeners" and "engineers" within the context of the school's environmental projects.

Lucas, David, Althea, Deborah, and Philip participated in the ITEST projects related to climate change, renewable energy, and global water sustainability as well as teaching about the environment in the context of other projects they had designed. Their participation spanned the first four years of the school, when Central expanded from one grade to six grades. The school's growing pains disrupted the stability of the projects, which were revised from year-to-year as teachers were re-assigned to meet the needs of the school. Explaining how and why these projects were sustained during this time period involves attending to the teachers' life histories.

As I will detail in the next three sections, the teachers' childhood experiences framed how they understood the relationship between STEM and environmental issues and provided a strong rationale for continuing the projects.

Teachers' Childhood Nature Experiences

During their life history interviews, each of the five teachers attached significance to their childhood experiences outdoors. For example, Lucas recalled growing up with a backyard that bordered a city park and in a family where "being outdoors was a family value." He remembered his mother opening kitchen windows in the middle of winter, which he attributed to her European upbringing. Another teacher, Philip, shared that he had "never lived anywhere where there wasn't a creek" and described a childhood spent "creeking" and catching "crawdads" to irritate and observe. These experiences provided Philip with significant social capital. As a Boy Scout he was elected Instructor for his troop—his first teaching position and something he valued over any leadership role he might have been given. Deborah described herself as a curious child who started camping in second grade and later became involved in Girl Scouts, where she learned to identify trees and plants and to season her food with different types of vegetation. Deborah's memories are grounded in family and a "culture of place" (hooks, 2009), and when describing childhood trips to visit her family's burial plot in Alabama and her aunt in California, Deborah uses *trees* to represent the differences between the two places, noting the oaks in Alabama and the redwoods in California.

These experiences are important findings. Research evidence suggests that such experiences can develop an environmental sensitivity among children, an affective state which prepares them to take environmental actions as adults, including teaching about the environment (Chawla, 2006; Tanner, 1980). Wells and Lekies (2006) suggest a "pathway" between childhood nature experiences and adult environmentalism. This pathway is helpful in explaining why this study's participants' were personally invested in environmental education, including David, who continued to integrate climate change into his biology curriculum the year *after* the ITEST funding and evaluation cycle had ended. Furthermore, David's commitment to teaching the *human causes* of global climate change—and not just its impact on ecological systems—resulted not from his desire to align his curriculum with the district's standards, semester exam, and textbook, all of which barely addressed human impact, but from a set of environmental values and beliefs he had developed through his childhood experiences.

As David recalled, this was a time when he felt more at home on his family's sixty acres of country farmland than in the house, where he experienced little encouragement for his interests in art and music.

> *So, here I am, where else could I go? Stay in the house where I felt personally I wasn't that welcome to a certain extent, because I wasn't being encouraged in the things that I felt I was interested in, even at that time. So, I would escape into the woods and I'd hike and explore, do this and do that. Watch the dogs and see what they're doing. Watch the great blue heron and see what he's doing. Look at the kingfishers and what they're doing. Go to the lake. And so I got very curious…I got very involved with it. And so, really, my scientific slant came from my interest in those interactions in nature.*

Although David admitted that his parents knew that he loved nature, and encouraged him to pursue a degree in agriculture, David was more interested in raising chickens, not for their eggs but because he thought that "chickens were cool" and he enjoyed observing and interacting with them. David credits several years in the military for giving him the confidence to pursue what he called his "scientific slant," which he attributed to his childhood nature experiences.

David eventually earned a graduate degree in wildlife management at a Western university. This experience provided a natural setting for David to express his creativity and passion for the natural world and formalized his interest in field science rather than laboratory science. The satisfaction David experienced in graduate school is evident in the story he shared about a research project conducted with his graduate mentor, a project which he described as solving a "real-world problem" involving birds and a golf course they had adopted as their nesting site.

> *And so, what we ended up doing was coming up, and the birds have a particular habit of space. Animals have space requirements. So, if there's a nest within a certain area and a bird lands in the tree to see if it's a fitting nesting site, and he sees that there's a nest there, he'll go somewhere else. So, what we ended up doing is making models. So, we would, we made models of these birds, with their red eye and the whole thing, the whole identification scheme, the whole, the whole color pattern, and we made nests out of sticks that looked like the nests of the bird. And we'd go up and we'd put them in the trees. And sure enough, those birds would come back from their winter breeding or the winter ground. They'd go to that tree where they would nest maybe last year. They saw oh, there's somebody here, I'd better go somewhere else. They'd go somewhere else. So we would remove them from around the greens and tees without having to poison and kill. Very interesting. So, that was field research. That was fun.*

David's graduate mentor recognized David's "need and want to create" and "desire to know why" and encouraged him to become a teacher, which he did, eventually being hired by the first principal of Central STEM High School because of his reputation for "hands-on" science teaching. David's enthusiasm for nature and ecology infused the global climate change classes I observed, where he integrated Al Gore's *An Inconvenient Truth* into a "mini-project" on the effects of global climate change on Antarctica's Adélie Penguin. During this project, David used the concept of carrying capacity to argue that the human population had exceeded the earth's natural limits, a survivalist position (Dryzek, 2005). David's experience had also inclined him to value field studies and place-based education, which he pursued during the school's intersession program each spring, when he and his students partnered with a local environmental organization to study water quality issues in the community.

Teachers' Childhood Experiences with Manual Projects

While reflecting on their childhood nature experiences, several teachers described manual and mechanical projects conducted either alone or with family members, and similar to the pathway described above, these experiences appeared connected to their adult interests in STEM. In many places, the participants' memories of nature and mechanics were intertwined. Here, Althea describes a childhood project she completed with her father.

> *My father and I, we remodeled the basement. That's engineering all around, but I didn't consider it that. It was hands-on. It was what I liked doing. I used to um, my dad used to work on cars and I would get grunged up. I'd be right there with him, all day Saturday, working on somebody's car. But you don't consider that science or engineering as a kid, you're just like that's what I like to do. Yeah. When he was not working on things, I'd be in the garage looking at all the tools and seeing how they work. I wonder what he uses this for? I wonder what he uses this for? So, I mean, yeah. As a kid I remember doing those things, but never really putting them in the category of science until this conversation.*

For Althea, these "hands-on" experiences were supplemented by basic experiments she conducted outdoors—tasting leaves and berries in the neighborhood, pulling worms apart to see what would happen, promoting "unfortunate accidents" between snails and salt. Althea also noted frequent conversations with a next door neighbor, whose grape garden and its "little trellises" fascinated her. Her driving *need to know* is evident in the questions she recalled asking him over the fence: "What are you growing and why are you building that? And why have I never seen that before? And what's going to happen. And…can I have some?"

Philip also recalled a childhood interest in mechanics. During his life history interview, he identified himself as someone who liked to explore and investigate various technologies and designs in addition to exploring and investigating creek beds.

> *I was the guy who liked to take apart things. Took, you know, whatever it was, if it was busted, I loved to take it apart. I talk to people about that now, I was just picking up these crystal high-impedance radio ear buds, that you like can't find anywhere, but there was a dude up in [a nearby town] and he was telling me about how he took stuff apart and then put it back together into something else that then worked. My stuff never worked. I was never that talented, but I loved to explore and investigate those kind of tech things, because back then, you could really see stuff. Now it's all just a printed board and you have no idea what's going on. But back then you could really see, hey, that's a capacitor. And did I know what a capacitor was? No, but they were tangible, look at type things.*

Philip's maintained his interest in these things as an adult and admitted spending hours on a website where people shared their do-it-yourself constructions. As a teacher, Philip had invested a significant amount of money and time to design projects in which students had a similar hands-on experience. For Philip, this involved building classroom kits from scratch, which he had done for a wind turbine project one fall. Although Philip appreciated the educational value of computers and computer software, he would have preferred to have his classroom well-stocked with materials for inquiry labs, which was impossible given the resource constraints on the school and the district. Philip recalled attending a national science conference where one presenter received a standing ovation for giving away plans for a year's worth of affordable labs. What impressed Philip was that this teacher had found a way to put something in students' hands each and every day.

Connecting Experience, Nature, and STEM

Of all the participants at Central, Philip shared the most detailed understanding of how his childhood experiences—both natural and mechanical experiences—related to the methods and methodologies of STEM. To Philip, being outside and taking things apart were "all STEM." When asked to elaborate on this idea, he explained:

> *Well, it's an investigation of nature. And I'm not talking nature in the green sense, but nature in the this is how the world works sense. You can make things if you understand how the world works and, you know, because talking about physics, what is the study of, study of interactions, right? Really is what it is, um interactions of forces. That's physics.*

When I told Philip that my own outdoor experiences had turned me in a different direction—towards nature poetry and away from physics—Philip used this idea to elaborate on his distinction between different ways of knowing the natural world.

> *If I'm describing you correctly, or at least in general correctly, of having a reverence and awe, a love for the outdoors. I have those same aspects, but on top of that, there's a layer of intrigue I guess is what it is about what's really going on there..*

Philip then suggested the types of inquiries that his "intrigue" led him to pursue.

So here's a level of intrigue and so I have, because I've been intrigued about those, I've gone out and found the answers, and it's really the how things work and how things are and what they are before you figure out what, how they work.

The intrigue that Philip described is very similar to the “irritation of doubt” that Charles S. Peirce (1958) believed initiated inquiry. Philip described how his intrigue led him to inquire into “how things work” and “how things are”—basic scientific questions. Philip believed that the adults in his life, including his mother, interpreted his childhood interest in being outdoors and taking things apart as signs that he was “good at science.” Philip believed that hearing these comments encouraged him to continue exploring and constructing, things he does to this day.

In addition to providing a context for teachers’ understanding of their own practice, these findings indicate a number of pathways that educational researchers might explore. To my mind, the most significant of these is how teachers’ childhood nature experiences are related to their adult understanding of STEM education. The literature on childhood nature experiences—or what some researchers have called significant life experiences (SLE) outdoors (Chawla, 2006; Tanner, 1980)—provides some interesting starting points. For example, Louise Chawla (2006) argues that outdoor experiences satisfy children’s emotional need to identify with the natural world, an identity which motivates them to care for the environment as adults. In this way, nature experiences represent the emotional side to environmental learning, a counterforce to the rational and managerial approach of the STEM disciplines (Chawla, 2006).

The findings of this study support these claims. It is clear that the participants’ childhood experiences served as a context for their adult lives—providing the inspiration and motivation to pursue STEM careers and care for the environment. In this sense, however, the participants’ differed sharply from their students, the majority of whom had not had these experiences.

Because of this, engaging students with STEM and environmental issues was a significant challenge. Several teachers used economic and vocational appeals to meet this challenge, as described in the next section.

Teaching Towards the 'Green New Deal'

From an economic and vocational perspective, the climate crisis involves new opportunities for those who work in the energy sector. Policy analysts have called this the "green New Deal" (DiPeso, 2009) As a career and technical education (CTE) school serving low income students of color, Central's teachers were very much attuned to these opportunities, and the career pathways and courses at the school were infused with environmental content. Engaging students with these opportunities was not easy, however, and required teachers to build bridges between their students' experience, the project curriculum, and careers in the green economy. In addition, these bridges needed to be relevant to students' home and community cultures (Ladson-Billings, 1995). This work required a complex pedagogy—part gardening and part engineering. Here are several examples of how this pedagogy looked in the classroom.

During one class I observed within a month-long energy project, Althea showed her class a video on watersheds. Students were to incorporate content from the video into a proposal to protect a local watershed. These proposals would be entered into a competition with the winner receiving a grant to implement their proposal. Like the other classes I observed Althea teaching, this class started in the hallway, where Althea met her students, previewed the day's activities, and reinforced her expectations. The video on watersheds served as the day's warm-up activity. Here is a field note excerpt:

The video described the "essential" and "unique" and "distinct" features of watersheds—bouncing back and forth between common and distinct features. The voice *on the video was identifiable as that of an older, white male. Althea instructed students to write a 3-2-1 (three facts, two questions, and one career) related to the video. She instructed them to use the "common heading" and to write in "complete sentences." She asked students at one point to write down "one career that you would imagine would be responsible for any of the information you see in this video."*

After the video, the class broke into small groups, with three to seven students gathered around one of several computers in the classroom, PCs donated by one of Central's corporate partners. As students considered the questions they had come up with during the opening "3-2-1" activity, Althea moved from group to group.

Althea then stopped class and asked students to tell her what a watershed is. She said "love it, love it, love it" when a student provided a correct answer. She asked: "Does everyone live on a watershed?" and then proceeded to explain that everyone on earth lives on a watershed. She then asked, "How can we be effected by the watershed issues in other states?" She then explained how pollution was carried down rivers from it source to affect the students' local community. This was followed by the question, "What are some careers?" a brief discussion about being a "hydrologist" and what the people at the local Water Works do for a living.

These two excerpts demonstrate the complexity of Althea's pedagogy as she works to engage her students with the content of the curriculum—in this case a video whose narrator sounds not at all like them—by appealing to the common experience of living "on a watershed." She then *localizes* this experience for her students, and at this point the classroom discourse takes on moral and political overtones, which provide a fitting context for the watershed proposal. In addition to this, Althea manages to incorporate different career opportunities and add a signature of enthusiasm.

Althea was not a CTE teacher but a science teacher, and the career connections she made in her classes reflected the culture of the school and her personal beliefs rather than any policy mandate. Deborah's situation was different because she taught CTE courses, which were designed to draw explicit connections between curriculum and careers. When we spoke, Deborah was teaching CTE courses for seventh and eighth graders. Previous to this, she had taught a tenth grade CTE course. The syllabus for the tenth grade course reads:

> *[This course will] provide students with an overview of STEM careers, provides structured experiential learning, site visits, and interactions with partner organizations. Students will engage in project-based learning where they will learn about and apply information and communication technologies. There will also be a strong focus on developing the character and interpersonal skills needed to succeed in life and the workplace.*

Because the content of Deborah's CTE courses was not coupled to any standardized assessment, Deborah had considerable freedom to determine how to meet the goals described in the syllabus, but this freedom was offset by her CTE status, which placed her beyond the reach of the collective bargaining agreement. From a policy perspective, there was nothing that disqualified Deborah from teaching several hundred students in a day, which she had done previously in the district.

All of Deborah's courses incorporated environmental content related to STEM careers. A former Girl Scout, she remained interested in environmental issues. Her colleagues described her as a flexible planner who could design projects efficiently, and she was skilled at finding environmental curriculum on the internet. In her classes, Deborah told stories as a way to engage her students with environmental issues. Some of these stories touched on environmental justice themes, including the relationship between economics, culture, food, and health. In other stories, Deborah appealed to a bleak climate future in order to motivate her students to change their environmental behavior.

From a social theory perspective, Deborah's course prepared students to live in a "risk society" (Beck, 2004), a society in which environmental crises create economic opportunities. This perspective is common in the private sector, where various tools and methodologies are used to forecast environmental disruptions in order to determine new markets. In the corporate world, this is how a company builds "climate resilience." In places, Deborah's CTE curriculum involved her students in a similar process. For example, one summer homework assignment asked students to choose a natural disaster and investigate five careers involved in responding to that disaster. This assignment included a concept map in which students identified the education and training requirements of each career and the interests, values, and skills that success in each career would require.

When I interviewed Deborah, she had moved from teaching her tenth grade CTE course to teaching seventh and eight grade CTE courses. In these courses, she used a middle school curriculum from Project Lead the Way (PLTW) (Rogers, et al., 2013). Much of the curriculum for PLTW courses focuses on careers in the alternative energy sector and can be considered a form of renewable energy education (Thomas, Jennings, & Lloyd, 2008). During one project, for example, the teacher is asked to facilitate a scenario in which the class has been hired by a private firm to create an energy efficient wind turbine, which the class then does by breaking into teams, each of which sketches, builds, tests, and refines a separate model. When asked what she wanted her students to *do* with what they learned from these types of experiences, Deborah said the following:

> *I want them to get a job in it [sustainable energy] because I know it's a really hot career right now. Play some type of role in it. I mean, if you want to go into healthcare, that's fine. But figure out your niche with sustainable energy. Figure out, you know, be the person that innovates something that helps at the hospital level, helps recycle equipment. You know, the bedding sheets. How can they be environmentally safe? Or, you know, certain surgical tools that are thrown away during the first use. How can that help the hospital? Just like if they…the bottle caps, pop tabs. You know, if you save those, you can send them in and get some type of thing for your school. Start thinking outside the box. Not only what you can do in that career, but what you can do for others within that career.*

In order to draw connections between sustainable energy and students' personal experiences, Deborah encouraged her students to become more aware when they were outside of school, on the lookout for things such as recycling bins and solar panels that represented sustainability. She described how this awareness work related to students' personal energy behavior and to the moral, social, and political aspects of sustainability.

> *Well, I'm teaching the students to be aware, you know, not only to be aware about, you know, what's going on in their households but outside. You know, and how they play a part in that and how, um, our world is dependent not only, you know, on certain people but on everyone. And everyone has to work together to make sure that we have a green environment.*

Helping students draw connections the curriculum, their own behavior, and environmental problems—and placing these connections in a moral, social, and political context—was a central theme throughout the environmental projects at Central STEM High School. Althea used the concept of scientific literacy to make these connections.

> *To be scientifically literate, you have to be able to discern information, discern from what's accurate and what's inaccurate and then make a decision on your own based on your research. And so, I want them to be able to read information about global warming and then decide OK, as a result of global warming, I'm going to recycle stuff so that we don't have to spend fuel to make more things so that we can recycle, reduce, and reuse. So, I'm going to um sponsor this, this agency who doesn't use bottled water, who sends money over to underdeveloped countries to sustain clean and safe water. Um so really teaching them how to seek the information, understand the information, and then make a decision of how to act based on their understanding of that information.*

Deborah and Althea's teaching reflected the hope among Central's teachers that STEM would help change the outcome for the school's low income students of color. Deborah's CTE courses offered a pragmatic and storied approach to this. Althea perceived STEM as the basis for making rational and ethical decisions. Both Deborah and Althea stressed the communitarian aspects of environmental concern. Several times in Althea's class, I observed her using the concept of community to build bridges between students' home culture, the project-based culture of the school, and the world culture of global citizenship and environmental concern.

The Climate Change Assembly

The work of Central's teachers related to climate change and energy was informed by a special assembly featuring a representative from a climate change education organization, an organization which includes a national network of student leaders and green teams in schools. During this assembly, the speaker presented scientific evidence for climate change, and the connection between climate change and energy use, and noted a number of environmental events (e.g. wildfires, drought, heat waves) likely to become more frequent unless students took action. Recommended actions included recycling, conducting an energy audit at school, starting a recycling program, planting a garden, building community awareness, and writing a letter to a politician or local newspaper. This presentation also addressed climate opportunities and encouraged students to consider becoming a green architect, wind turbine engineer, solar panel installer, home energy auditor, or paleo-climatologist. In these ways, the climate change assembly reinforced the school's dominant discourse on climate and energy by foregrounding vocational opportunities and the need for students to change their environmental behavior.

How Teachers Educated for the Economy while Respecting Students' Autonomy

Although at Central STEM High School, career opportunities were an important aspect of teachers' understanding and enactment of environmental projects, several teachers expressed ambivalence about the vocational aspects of their work. This was the case with David, who as a child had experienced little encouragement for his interests in art and music from his parents and teachers. During a life history interview, David described his struggle to win autonomy from others' influence, which he did by joining the military. This struggle provides a context for understanding David's hope for his own students.

> *I look at each student as me just trying to encourage them to follow their path. And I'm just one of the ways to help them out. You know? Just one of the, this is part of your journey. I mean, I don't know where their life is going to go.*

David's desire to preserve his students' autonomy was shared by Lucas, who as an eleventh and twelfth grade CTE teacher was more involved than David in helping students make college and career decisions. Lucas described this as one of the most satisfying parts of his job. He talked about how he enjoyed helping each of his students "make an informed [career] decision based off of their skills, their passions, and their interests." Lucas managed to guide his students towards a STEM career while respecting their personal autonomy and the realities of their experience as low income students. Lucas' situation was particularly complex because he had originally studied to be an engineer and had worked in the field for four years. Although this career satisfied the expectations of his family, Lucas found it personally unsatisfying and went back to school to become a teacher. As a result, Lucas was placed in the unusual position of teaching in a career field that he himself had left. This experience informed his understanding of his role as a mentor and career counselor.

> *My emphasis is engineering and they've chosen the Engineering Pathway, so yes, I'm going to promote engineering and I'm going to push them for engineering or architecture or something like that. But at the same time, if they discover that after two years they don't want to be an engineer, and they hate it, that's fantastic. I'd rather them learn that now as opposed to learning it after two years of paying for it at college because they probably can't pay for it or they're going to have to go into debt. I'd just rather them figure that out before they get there or give them some kind of encouragement that yeah, maybe you can be an engineer, you know, you're pretty smart.*

Lucas' interpretation of his role is fit for the context. Although he hopes his students will pursue a career in architecture or engineering, he knows the academic requirements. He also understands the serious financial constraints on his students and their families. Unlike his students, Lucas had engineers in his immediate family and learned to ‘see’ himself as an engineer at an very early age. He had this social capital. He also had the financial means and social support to leave one profession and train for another when he became unsatisfied. His pedagogy incorporated his awareness that his students, because they came from working class and poor families, did not experience these same privileges.

Lucas had organized his course in response to his personal interests in the environment and what he perceived to be the needs of his students. For example, he had asked his students to incorporate sustainability into their capstone projects, although he said that his students were still working to understand the concept. Lucas hoped that the school would add an environmental science course in eleventh grade. If that were to happen, he could depend on a colleague to reinforce the concept of sustainability.

The Obstacles the Project Teachers Experienced

A central proposition of this dissertation study is that implementing STEM education policy involves adopting constructivist pedagogies and incorporating environmental problems into the curriculum. The environmental projects at Central STEM High School represented an attempt by teachers to meet these policy demands in the context of an urban public school serving low income students of color. For this reason, the obstacles they experienced are significant because they indicate the additional supports necessary for teachers to sustain this kind of instruction in this particular context. The sections that follow will detail how the participants experienced and negotiated these obstacles.

The literature suggests that constructivist approaches to instruction are difficult to sustain in public school settings (Blumenfeld, et al., 2000; Blumenfeld, Kempler, & Krajcik, 2006). One challenge is quite simple, the fact that constructivist approaches to instruction require more time from teachers and students than public schools are organized to provide. Other challenges are political in nature. For example, in an article that describes an effort by teachers and university personnel to implement project-based science in an urban public school, researchers noted conflicts between teachers' instructional needs and district policies for managing technology, making curriculum decisions, and approving payment for extra teacher work sessions (Blumenfeld, et al., 2000). The researchers also noted how the district's testing policies "resulted in limited instructional time for inquiry" (p. 156) and discouraged the school's teachers and administrators from continuing the projects.

Although there are different names for constructivist approaches to instruction, inquiry is central to them all, and the inquiry classroom is an ideal shared by many within the STEM education community. Managing such a classroom is the central challenge involved in meeting the instructional demands of STEM education policy. Inquiry is a complex human activity and requires a *need to know* strong enough to transcend any obstacle. Within theoretical models for project-based learning, this requirement is met by the "driving question" (Blumenfeld, et al., 1991; Krajcik & Blumenfeld, 2006). For these models to work, however, students must be motivated enough by the driving question to become cognitively engaged (Blumenfeld, et al., 2006). This process asks much more of students than most people realize.

> Students must become accustomed to new rules and new classroom norms. They need to adjust to new relationships with their teacher, who becomes a facilitator rather than the primary source of information. Students must be self-regulating as their responsibility for constructing understanding and for directing learning increases. Moreover, students must be committed to collaborating and enhancing the community's knowledge, meaning that

students must participate actively during small group collaboration and whole class discussion (Blumenfeld, et al., 2006, p. 478).

In addition to these things, inquiry requires students to have a number of "process skills, literacy skills, and numeracy skills," including knowing how to design an experiment, how to conduct a literature search, how to collect and analyze data, how to interpret different data representations, and how to write about research findings (p. 481). These skills are particularly demanding for middle school students, who are still new to science and scientific practices (Krajcik, et al., 1998). Project-based and inquiry-based pedagogies are also discursively demanding, particularly when the discourses of mainstream science conflict with students' everyday language and literacy practices, which is often the case in schools such as Central that serve low income students of color (Moje, et al., 2001).

Teachers new to inquiry teaching have described a "hot spot" of anxiety, stress, and doubt—emotions that led them to question their capabilities as teachers and the capabilities of their students. (Dreon & McDonald, 2012). Zembylas (2002) argues that positive and negative emotions play a significant role in science teachers' pedagogical decisions and their relationships to students and colleagues. Given all of the challenges above, it is clear that project-based and inquiry-based teaching are risky and demanding approaches. The remainder of this chapter presents findings related to these risks, which the teachers at Central STEM High School experienced and negotiated.

A time and place for acting like bears—the risks of inquiry teaching.

Of the five project teachers who participated in this study, only Philip experienced a teacher education program centered around constructivist pedagogies, and his introduction to inquiry was intensive. The primary textbook for one of his science methods course was Eleanor

Duckworth's (2006) *The Having of Wonderful Ideas*, in which Duckworth argues for a classroom culture in which teachers do whatever it takes to facilitate students' direct engagement with the world. The professor for this course, a believer in what Philip called "full bore" inquiry, modeled an inquiry classroom in her courses and professed to Philip and the other students that such a classroom could be established in any context.

Philip struggled to meet this ideal in his own classroom. Although he was committed to his students designing and conducting their own inquiries, many of his students were still learning the prerequisite skills that more independent work required. The skills he mentioned included several of the inquiry skills noted by researchers (Blumenfeld, et al., 2006). In spite of these skill-based challenges, Philip remained committed to the inquiry ideal represented by his mentor, who had taught his science education methods courses. He considered her a personal friend and continued to participate in a professional learning network she had organized. This professor came to visit his class regularly. In addition to her continued encouragement, Philip had experienced a visit to a suburban school where he observed inquiry in action. This visit, which included discussions with teachers, suggested to him that an inquiry classroom was possible in low poverty schools that were better-resourced.

> *They have a great inquiry model. So, those are the students you can um, and they're not as poor as our students. There's some [poor students], but by-and-large they, they have enough money to get by, and they're not poverty-level students or below poverty-level students like we have at a rate of, you know, 80% or so here. And so, they can [do inquiry] because they've started them, and they have specific constructs, and skills, and benchmarks…the kids are going to know how to do, set up this level of experiment and they, with this many kind of pieces to it or parts to it or this much time, or this hard of a*

concept, you know, a very easy concept early on. And so, they start them like in seventh grade.

In describing his visit to the suburban school, Philip also noted how inquiry had been integrated into the curriculum so that "specific constructs, and skills, and benchmarks" were taught at each grade level. Philip believed that Central needed to work out a similar plan for inquiry education. In describing this plan, Here Philip uses data analysis as an example of the work that was still ahead for him and his colleagues.

> *Those skills are transferable, and so as you grow those over time, you need to know where the students are, and have it layered so that you're adding capacity each time and intensity maybe isn't the right word, but I was going to, I was going to, you know, lay it out so that you had an example. But again, like seventh grade, if they were doing data analysis with pen and paper, you know, so we're talking, it's like the old lab with the three data points and you graph it. You know, like maybe take a slope off of it or something, and then, you know, not the next year but the next lab or whatever. Because it may not take just one lab where all your students are good with it that and, you know, because you have to teach axis and independent variables dependent variables and the whole bit, right? As well as they have to be able to get, you know, Y-intercept from their math teacher, and you have to be able to, because you know, things in math are like so abstract, so you have to be able to actually bring that into your science classroom and make it actually connect, which is a skill unto itself.*

At times, Philip felt overwhelmed by all that was required of him as a science teacher who was committed to doing inquiry in an inclusive setting. He described the wide range of skills and abilities of the students in his classroom and their struggle to learn the practices of science. He also described how his feelings of discouragement led him to question the inquiry ideal embedded in science education reforms and the practices of his inquiry mentor. In spite of this, Philip continued to provide opportunities for his students to experience inquiry and he negotiated the personal and professional risks that this entailed.

One way that Philip understood inquiry was through the 5E learning cycle model (Engagement, Exploration, Explanation, Elaboration, Evaluation), a model popular among science educators, including science teachers at Central (Bybee, et al., 2006). The tension that Philip experienced between an inquiry ideal and his own experience was most clearly expressed in a story he shared about his mentor, who had suggested that he have his students acting like bears in class as an engagement activity.

> *It will not work. What you're describing to me will not work. This is like my, actual even though I'm a young teacher, my actual experience is you're dead wrong. Right? I'll tell her this. And she'll be like no, I've had it where they're dancing and acting like bears in class and I'm like bullshit. You know? But so, I know that if it's something that wasn't full-go like I'm just going to make this happen, that she, in her head she's going no, this can work. Right? And I'm like no, there's no freaking way. Like I'll, I'll structure it, I'll scaffold it. I'll get it as close as I can where it doesn't fall apart on me, but I'm not going full, acting like bears in class. Like I'm not doing it. And, and um there's a time and a place to act like a bear, but not just like dive in the deep end, act like a bear, and I don't even know what they were simulating, ecosystems or something. And I'm like my kids would not go for that. Maybe seventh graders would, or a special group, or a certain class that you just had that culture built in that class. But I'm like, she's like just make that the assignment. And I'm like there's no chance. It's not going to work. It's going to be*

chaos and again, we're talking teaching generation that I'm in now, right? It's a tough time to be a teacher. You know, they got their eyeballs on you.

Philip's reasons for resisting his mentor's suggestion are multiple and overlapping. Clearly, having his students acting like bears is a risk that Philip does not believe he can afford to take. But why? At a personal level, Philip seems to be referring to the emotional risk of having things "fall apart" and the "chaos" that could potentially ensue. Second, he seems to be referring to the risk of doing something well beyond the norms of his classroom or the school, a cultural risk. Third, he is clearly referring to political risks and to the administrative others who "got their eyeballs on you." Each of these categories of risk—emotional, cultural, political—is noted in the science education literature as a significant obstacle to sustaining inquiry classrooms (Blumenfeld, et al., 2000; Dreon & McDonald, 2012; Fishman & Krajcik, 2003; Zembylas, 2002).

Several other teachers described a gap between an inquiry ideal and their classroom experience. Teaching for more than twenty years, David had participated in several waves of district-based reforms to science instruction. He described how the district had moved away from "hands-on experiences" and towards project-based learning, which he also called "relevance learning." Having had success with these innovations at a number of urban schools, David had developed a good sense for how they worked at different grade levels, and like Philip, he had resourced many of these efforts himself. Although David believed that these approaches made the curriculum more relevant to students, his experience suggested that this type of teaching needed to be carefully structured for students to be successful. He noted his student teacher, who was still working to establish an approach to inquiry teaching that worked for ninth grade students.

> *As a mentoring teacher, I have to constantly remind her of the importance of day-to-day, minute-to-minute, what is your structure? Like today's lab, looking at plant, animal cells. I mean, she had, she had it down what she had to do. But in terms of the framework that it was going to be presented in, the structure, the expectations. The expectation for um, you know, where are you going to be in 10 minutes, where are you going to be in 15 minutes, where are you going to be in 20 minutes. A lot of the way that she is presenting the information is, I mean, she's influenced by the inquiry model which is not bad. But, I mean, it's, it's a great model. The issue is are the kids able to be successful in a pure inquiry environment?*

Researchers who have collaborated with teachers on project-based and inquiry-based lessons have reached the same conclusion—that success requires a structured approach (Blumenfeld, et al., 2000; Fishman & Krajcik, 2003) Like Philip, David had never observed a classroom quite like his that worked as a "pure inquiry environment." When I asked him if he thought there were any ninth graders around the country doing pure inquiry, David said, "Oh, probably somewhere, but I've never seen it." In the absence of such models and exemplars, David had developed an approach that worked for the students he was responsible for teaching.

As a engineering teacher for juniors and seniors, Lucas was responsible for supervising students' senior capstone projects, the most independent inquiries at Central. Although Lucas taught two years above David, his practice reflected a similar tension between a project or inquiry ideal and his classroom experience. As a CTE teacher of juniors and seniors, Lucas did not feel as tied to the state's content standards as did his colleagues in the ninth grade, who were responsible for teaching content that was assessed by the state's graduation test. Lucas described what core teachers would need to do to be successful with project-based learning.

> *Project-based learning can still be done in a content or core class. A teacher has to be committed to it. They have to really know what they are doing and they have to really make sure that while they're doing the project-based content that they are also hitting their standards and that their kids are moving along, meeting the pacing guide that's assigned by their district. Otherwise, they'll spend eight weeks dong a project and they just won't get to all of what they're supposed to get to.*

Lucas had structured project-based learning in ways that reflected his background and interests and what he perceived to be the needs of his students. Each of his seniors was responsible for designing and completing their own year-long capstone project. In order to support their efforts, Lucas incorporated frequent checkpoints and deadlines into the syllabus, met frequently with students one-on-one during class time, and provided students with a list of internet sources after reviewing them himself. Lucas said that he hoped to involve more external partners in his engineering courses, persons who could serve as student mentors as well as providing an authentic audience for student presentations. Whether engineering professionals or university students studying design, Lucas saw these persons as offering his students additional support and experience as well as helping him manage the small groups required by his interpretation of project-based learning. To do project-based learning well, Lucas explained, "you need to have some really good help."

Although Lucas was committed to project-based learning and looked forward to refining his project curriculum, he expressed one interesting concern, that the practices of project-based learning were out-of-joint with the realities of higher education, where students were asked to endure long lectures and other didactic traditions, particularly during introductory courses. This same perception was shared by a teacher at Capital STEM Academy, the second school in this study, who said that the lack of project experiences at most colleges and universities limited the number of projects he felt comfortable doing in his high school classroom.

The benefits to 'collaborating alone.'

During the course of this study, teachers at Central continued to value project-based learning—which maintained the project-based culture established by the school's curriculum design team—while modifying the instructional aspects of project-based learning in response to the constraints they experienced and their students' needs. In doing so, they way these teachers understood the projects, and how their teaching looked in the classroom, varied considerably from a number of ideals, including the ideal of STEM education policymakers, the school's curriculum design team, and instructional theorists working in higher education (Krajcik & Blumenfeld, 2006).

For teachers to be successful at project-based learning, they need time to collaborate with one another and time to reflect on their practice (Blumenfeld, et al., 1994) Several teachers noted how difficult it was for them to find this time in the context of Central's schedule, which was largely determined by the state's requirements for general education and career and technical education. Time pressures appeared to affect how the teachers felt about project-based learning, about themselves, and about their colleagues. This situation made Central's intersession program increasingly attractive. In addition to providing time for teachers to pursue "place-based" and "community-based" projects, intersession released them from the stress of having to collaborate with one another (Smith & Sobel, 2010). Here, Althea describes why she preferred her week-long intersession project, which involved a corporate partner and was organized to address global water sustainability.

It [intersession] makes it easier because you don't really have to collaborate with anybody but yourself. So, if there's a math piece, you're teaching the math piece, not the math teacher. You don't have to tell the math teacher what to do, you don't have to talk about it, you don't have to decide about it, you don't have to do anything but teach what they need to know that's math-based for the project. That's in intersession, because you're the teacher of record. You're the only one that they get to see. But during the regular school year, like for the energy project, there were actually pieces that should be facilitated in technology class, pieces that should be facilitated in language arts class, that should be facilitated in the math class, which means that you have to coordinate and collaborate with those teachers who may or may not have the same vested interest in the project that you do.

Even in the context of intersession, Althea experienced challenges. Some of these challenges related to project purposes, and although Althea and her teaching partner had envisioned an intersession focused on the moral and political aspects of global water sustainability, it became clear that their corporate partner was more focused on product design.

When describing the loss of this intersession project, Althea commented on the loss of a particular relationship, one she had established with a female employee from the partner company. For Althea, who referred to her classroom as her "house" or "home," this relationship involved opening herself and her practice to someone who might not understand the realities of her life as a classroom teacher. For Althea, one of these realities was that she did not have time to meet with partners during the day, something that many professionals take for granted. Expressing a similar vulnerability, Philip described how he preferred to work with partners that he could trust to stay engaged even when he let them down, which he believed was inevitable considering all that was required of him as a STEM teacher.

Conclusion

In this chapter, I have presented findings from Central STEM High School—a state-designated STEM school designed by teachers to serve low income students of color. The findings indicate how the school's curriculum design team used project-based learning as a culture-building strategy and how the school's environmental projects represented an effort to implement the instructional and environmental aspects of STEM education discourse and policy. Each of the project teachers described childhood nature experiences, and several connected these experiences to their adult interests in science and environmental issues. These experiences motivated the teachers to infuse moral and political content into the classroom discourse and curriculum of the projects. At a general level, the environmental projects at Central reflected the opportunities afforded by a "green New Deal," although the economic and vocational goals of the projects were balanced by teachers' respect for their students' developing personal, vocational, and cultural identities.

In the course of this study, the participants experienced many of the challenges evident in the literature on project-based learning and inquiry-based learning. Time was the most significant constraint. The participants also described the emotional, cultural, and political risks of adopting an inquiry approach. Amidst these constraints, each of the project teachers created spaces for innovation. It was clear that these spaces were more difficult to create in the context of the school's core courses, which were tightly coupled to district standards and the state standardized tests. There was more space for innovation within the context of the school's career and technical education courses (CTE), which were uncoupled from standardized assessments.

From a policy perspective, the primary factor determining the innovativeness of the projects appears to be whether or not they occurred within a course that was coupled to one of the state's standardized tests.

There is a stereotype of urban public school teachers—that they "teach to the test" and have little desire to be creative. This was not the case at Central STEM High School. What I observed were courageous and committed teachers who were trying to sustain a project-based culture long enough for the state's policymakers to figure out whether or not they valued the same.

Chapter Six

Findings from Capital STEM Academy

Introduction

Capital STEM Academy is a suburban public high school serving approximately 500 students. The school's new LEED-certified building, which it shares with three other academies, sits on reclaimed farmland. Although the setting is just a few miles from a large metropolitan city, the view from the school is of cornfields broken by lines of trees. Capital identifies itself as an environmental STEM school and this identity is inscribed in its curriculum, instruction, building, and grounds. In addition to geothermal heating and daylighting, the school features an ecology lab, campus wetlands, and state-of-the-art greenhouse. Capital's formal classrooms, many of which have a removable glass wall facing a central hallway, add an agile and flexible feel. Although Capital STEM Academy does not require an entrance examination, and can be considered an inclusive school in that regard, students must be very strong in mathematics to survive their ninth grade year. Those who do are among the strongest students in the district. As evidence of this, two members of Capital's first senior class were accepted into MIT. Although not all of Capital's students will pursue advanced degrees and professions in the STEM fields, many are qualified to do so, and this adds a level of assuredness to the work of Capital's teachers and administrators. Capital STEM Academy is a model school in many respects—a "knowledge-society school" (Hargreaves, 2003). The experience of its teachers indicates the risks and rewards of teaching in the knowledge society.

Before discussing the environmental projects at Capital STEM Academy, and the work of the project teachers, it is important to place the school in a larger policy context. The state policy context was addressed in the previous chapter. Like Central STEM High School, Capital STEM

Academy is a state-designated STEM school and resulted from a seed grant from the state, although Capital's planning team was guided by a different interpretation of their work. The district context is described in the next two sections.

The District Context: A Suburban Innovator

Capital's district has a reputation for innovation. In addition to receiving national attention for instruction and leadership, many of the district's senior educators have experience with previous school improvement efforts, including the Small Schools Initiative and the Coalition of Essential Schools (Benitez, Davidson, & Flaxman, 2009). With such a tradition behind them, doing things *differently* is expected of the district and its teachers, and the local community has become quite tolerant of disruptive innovation. This community has experienced major economic setbacks in the last ten years, however, including the loss of a major telecommunications employer. In addition, a string of failed school levies has led to cutbacks, including major revisions to educational proposals, and many families have left the district. One teacher explained that this was a community in transition, with an older White population giving way to a younger and more diverse population, families who have moved to the suburbs in search of affordable housing and good schools. This diversity is reflected in Capital's student body, which is about 60% White, 30% African American, and 10% Hispanic and multiracial. According to this same teacher, who was active in local politics, STEM education represented for this community the hope that its youngest members might secure the economic livelihood of all.

Given its reputation for educational innovation, it is not surprising that Capital's district was awarded a grant by the state to start a new 9-12 STEM high school. In submitting their proposal, the district responded to the same call for proposals that elicited Central STEM High

School's successful proposal. These two proposals are unified in reflecting the STEM school attributes mandated through state legislation. Capital's proposal promised an "integrated" and "project-based curriculum" that incorporates "scientific inquiry" and "technological design" and draws explicit connections between STEM, regional innovation, and economic progress. The proposal suggested how a number of partners would help with the implementation of this model, including how a local engineering company would help teachers incorporate sustainable design into their environmental teaching.

Several teachers credited the district's assistant superintendent for his innovative leadership during the planning for Capital STEM Academy. Prior to the STEM school award, the assistant superintendent has lobbied to break the city's comprehensive high school into several smaller academies. After the STEM school award, the assistant superintendent worked to include multiple stakeholders into the school design process. His efforts included facilitating a design competition—or *charette*—to determine what to do with the school's wetlands, an activity which involved a variety of partners and led to the school's ecology lab. Laura, a teacher and administrator who headed Capital STEM's design team, described the assistant superintendent's leadership during the planning process.

> *He did a really great job, and if there's one thing I learned from him, it's this. He created the atmosphere and then just got out of the way. So he really kind of brought the dream, created this atmosphere. Be creative. Don't be afraid. Go out there and dream. Take a risk. And then he just got out of the way.*

In addition to this, the district and its assistant superintendent had introduced a deep structure that was equally important but harder to see. By contracting with a local educational change organization to facilitate the school design process, the district had ensured that the design team would benefit from the lessons learned by previous reformers. By the time teachers were integrated into the process, the district had already decided to move from a comprehensive high school to a series of smaller academies, contracted with a local organization with experience designing small schools, and rejected several popular models for restructuring schools, including career and technical education (CTE), which they believed would constrain their efforts at a complete and total redesign of the high school experience.

Building a Design-Based Culture and Curriculum

The summary above provides a background for the process of planning Capital STEM Academy's curriculum and culture. This work was accomplished by a team of teachers and facilitated by an educational change organization that provided a methodology and methods for designing small schools. Although this organization helped facilitate the process, the design team consisted of *teachers*—two math teachers, two science teachers, two social studies teachers, one English teacher, and one art teacher. This team of teachers was led by Laura—a former science teacher, middle school administrator, and city council member who had been involved in writing the district's STEM school proposal. When I spoke with Laura about her experience leading the design team, she described the benefits of working with an organization that had a vision and experience.

> *For me to know we were taking on something so huge, it was nice to be working with somebody whose already thought five years out and they kind of do the backward plan. So at the end of five years, this is where we want to be. What do we need to get there? So they have a great, they have a great structure in place. And then they have these protocols that help you get there.*

When I spoke with a representative from this organization, she identified the “backward plan” that Laura mentioned as *Understanding by Design* (Wiggins & McTighe, 1995), a popular curriculum development framework. One of the protocols the school’s design team used involved creating a portrait of an ideal graduate. In the language of “backwards design,” this portrait served as a “big idea” that the team could work backwards from in order to determine the culture and curriculum that would produce this ideal person (Wiggins & McTighe, 1995). The design team’s vision of a STEM educated student was also influenced by a monograph from the Teaching Institute for Excellence in STEM, which Laura shared with the design team at one of their first meetings (Morrison, 2006). This monograph describes the STEM educated student as an innovator, inventor, and problem-solver—a self-reliant and logical thinker who is familiar with the “STEM lexicon” (pp. 2-3). For Laura, this monograph offered a clear summary of STEM education and aligned well with what she had observed at exemplary STEM schools in other states.

Trey, the social studies teacher on the design team, joined the team after hearing an announcement over the intercom at the city’s comprehensive high school, where he and several other members of the design team were then working. Trey described himself as “one of those fools that listens to all of those announcements and goes to all of those meetings.” Trey had learned from his previous efforts at educational change that “the only way it really works is from the inside.” Although his past experience with reform efforts made him hesitant to become involved, Trey eventually committed and began reviewing innovative practices and programs on the internet. Trey was particularly interested in how different schools enculturated students through various rituals and activities. As an example, Trey noted an activity from a school that one of his colleagues on the design team had visited.

They have a big meeting every morning. The whole school gets together, and if a kid is tardy, they apologize. You know what I mean? And it seemed very effective, because the school had built a culture around the program, and the kids had all bought into it, and it made the program stronger. So, from day one, we wanted to build a program centered around student culture.

For Trey, building student culture was the most important aspect of school design. Likewise, maintaining school culture was the important aspect of his teaching. In the case of Capital STEM Academy, where students experienced an academic program being built around them—and sometimes just days ahead of them—Trey's focus on what he called "maintaining the kids' culture" was one of few stabilizing forces.

The engineering design process was integral to the team's vision for culture and curriculum (Morrison, 2006). How to achieve a design-based school became clearer as members of the team visited model STEM programs and schools in other states. For example, during her visit to a K-12 STEM program in a Texas district, Laura observed the a flow diagram posted throughout secondary and elementary schools—a "design wheel" that represented the steps and stages of the engineering design process. Based on this visit, Laura's team created their own design wheel and used it in their work. In addition to being visual artifact that could be posted in every classroom, and tailored for different age groups, the design wheel represented a process that teachers of science, engineering, art, and writing could all relate to. In addition to the design wheel, the team borrowed the idea of "design challenges" (Sadler, Coyle, & Schwartz, 2000) from post-secondary engineering education, and the process of designing concrete solutions to local problems became a ritualized part of the school's curriculum and culture. Laura recalled recruiting students for the new school by facilitating design challenges with all the eighth and ninth graders in the district.

In this way, design became a central aspect of the community's interpretation of STEM education, and the skills and dispositions of successful designers (e.g. creativity, persistence, reflection) became highly valued. Laura offered the examples of a student who had not done well on a homework assignment and a teacher who had taught a poor lesson. In both cases, rather than throw it all away, a good designer would identify the pieces that had not worked, redesign them, and try again. In my time at Capital, I often heard teachers referred to as "designers"—both by themselves and by school administrators.

In addition to design, the team indentified inquiry as their primary approach to instruction. Laura offered the idea of a spectrum, with project-based learning on the right, problem-based learning in the middle, and inquiry-based learning on the far left. In her framework, project-based learning represented the most structured approach and inquiry the least structured approach. Laura explained that she and the design team envisioned teachers' instruction falling somewhere along this spectrum but with the goal of having students conduct their own inquiries as much as possible. Laura explained that the design team wanted students to "identify solutions themselves, more than one solution" and not to get "stuck on…steps one, two, three, and four" and that they saw inquiry and design approaches as the best way to achieve these skills, which they believed were valued by employers, who were looking for persistent and creative problem-solvers.

The design team used templates provide by the educational change organization to plan integrated units for each quarter, incorporating a design challenge into each unit. In attempting to integrate the STEM disciplines, the team was inspired by Project 2061's *Atlas of Scientific*

Literacy (American Association for the Advancement of Science, 2001), which provided visual connections between STEM concepts. Laura explained that "science was the driver" during the curriculum development phase and that this was "hard in the beginning for language arts and social studies teachers." Trey, the social studies teachers on the design team, experienced this hardship. Trey started the curriculum development phase with the goal of "breaking all the sacred cows of English and social studies," which he saw as flexible and adaptable subjects. Faced with the realities of a science-driven school, however, Trey was forced to abandon the stand-alone humanities curriculum that he and the English teacher on the design team had developed and the humanities were shaped to fit the STEM subjects.

Other teachers provided examples for how they revised their curriculum for a STEM-focused school. Glenn, the art teacher on the design team, made his course an industrial design course by adding constraints to the creative process. Although Glenn admitted that it was hard at first to put his students "in a box" in this way, he was pleasantly surprised that his students' creativity improved when they added constraints.

A Change in Leadership, Curriculum, and Instruction

Laura, leader of the design team, served as the first principal of Capital STEM Academy. After the first year, Laura accepted a position at another school district and Denise joined Capital STEM Academy as the new principal. At her previous school, Denise had been involved in starting STEM across the state. She had also served on the committee charged by the governor to manage the state's first STEM grants. As such, Denise came to Capital STEM Academy with a refined interpretation of STEM education. I spoke with Denise about this transition. Denise described her work as introducing "formalizing structures" to the school, maintaining the culture and community that the design team had built but looking more closely at the "instructional performance" of its teachers. Among other things, Design introduced a framework and performance expectations for teachers' design challenges and classroom projects. Denise encouraged teachers to use authentic problems, including local environmental problems, as a context for their instruction. She believed that "context" was the most important aspect of STEM instruction.

> *I don't care what they call it. I just want it to be context rich. I want it to be an inquiry, the characteristics of inquiry, where it's context-rich, there's a problem that has to get solved with a prototype, so they have to do some kind of planning…and it has the capacity for students to work both individually and in teams and the ability to make a difference, in whatever it is that people are working on. If it doesn't have those characteristics, I don't know that it's very STEM.*

Denise's interpretation of STEM instruction was also influenced by administrators at other STEM schools in the state, who had moved away from project-based learning as an instructional identity and towards problem-based and inquiry-based approaches (Savery, 2006)

Denise also formalized the environmental teaching at Capital STEM Academy. At her previous school, students' interest in renewable energy had led to the development of a course on energy and the environment. She brought this course to Capital, where a social science teacher convinced her to add an economics component. Denise described how the projects in the new Energy, Economics, and Environment (EEE) capstone enacted her ideas about context-rich instruction. She provided an example of a project in which students worked in the school's wetlands, trying to determine why plants were dying and how they could design a solution, perhaps by diverting a nearby creek to bring more water. To Denise, this was a strong project because its activities were place-based, grounded in a particular problem, and relevant to the school community.

The Environmental Projects at Capital STEM Academy

Through the process of planning the school, the district and its teachers implemented the state's STEM education policy, established a design-based culture and curriculum, and incorporated environmental features into the building and grounds. The remainder of this chapter presents findings related to the work of four teachers who were involved in two of the school's capstone projects, the most advanced experiences available to the school's students. Each of these capstones featured an integrated curriculum that addressed problems related to energy and the environment, and each featured an internship component that placed students with professional partners in the local community. Here is a brief introduction to the teachers and capstones.

Robert, Dick, and George collaborated on the school's Energy, Economics, and Environment (EEE) capstone. Robert had taught government and economics courses in the district for 17 years. Dick had taught science in the district for 23 years. George had taught social studies for 5 years, but in another district. This capstone was as exceptional initiative in many ways, and I have interpreted it as a demonstration project—a demonstration of what can happen under exceptional circumstances. In addition to integrating an AP Microeconomics course (taught by Robert) and an Environmental Analysis course (taught by Dick), this capstone featured a college-level course in Government and Policy (taught by Robert) and an environmental science lab (taught by Dick). To facilitate the capstone, a three-hour block was carved out of the school's morning schedule. This arrangement also gave the technical writing teacher—who was responsible for all four of the school's capstone projects—room to experiment with his instruction. Within the EEE capstone, Dick was responsible for supervising students' internships.

In order to help manage the capstone, Denise had arranged for George, a social studies teacher who worked at Denise's previous school, to come to Capital three mornings a week. In addition to understanding Denise's instructional philosophy, George had internalized the problem-solving and project management methodologies of a local research and development firm that was involved in STEM education. From George's perspective, STEM education was an effort to build the professional skills required by this organization and others like it, and one of George's primary roles in the capstone was assessing the development of students' professional skills. In regards to student outcomes, George was very clear that he wanted students to develop "efficient, effective, and sustainable public policy," qualities which an audience of policymakers would help him assess during a "youth policy summit" scheduled for the end of the year.

Allie was also a participant at Capital STEM Academy. Allie had been teaching math in the district for 20 years. She saw teaching at the STEM academy as an opportunity to work with kids who "love the math and the science." Allie taught AP Calculus and Principles of Engineering courses within the school's Engineering and Design capstone, where she collaborated with the technical writing teacher and a social studies teacher, who was responsible for teaching the ethics of engineering and design. Every morning, Allie taught calculus and engineering to the same group of 40 students for three straight hours. Although Allie's calculus instruction was traditional, her classroom was filled with tools and materials for engineering, and her classes were a mix of didactic methods and free-flowing projects. Many of these tools and materials in her classroom were provided by Project Lead the Way, who had trained Allie to deliver the Principles of Engineering curriculum she taught as part of the capstone. During the classes that I observed, Allie's students were exploring the applications of renewable energy sources by building and testing hydrogen fuel-cell cars.

How the Projects Reflected Teachers' Environmental Experiences and Values

As was the case at Central, the findings from Capital indicate a strong connection between the participants' life histories and their adult interests in STEM and environmental issues. Dick and Robert, the two content teachers for the EEE capstone, were particularly strong cases of this. Both described nature experiences during childhood and adolescence, and in the context of a life history interview, each connected these experiences to their environmental values and beliefs (Wells & Lekies, 2006). A natural affiliation was also evident in their classroom teaching (Chawla, 2006).

Contexts for science instruction.

During a life history interview, Dick reflected on his childhood and adolescent nature experiences. Although Dick had never connected these experiences to his adult interests in science and environmental issues, time for reflection allowed him to do so. Here is a story that Dick shared about fishing with his high school friends.

> *We'd go fishing a lot, and it wasn't anything really to do with science, you know. We'd go there to drink beer and fish. But, in retrospect, that's probably where my love of the outdoors, and learning, and seeing on my own, and that maybe set the framework, or the groundwork for, OK, now you've seen things, so now you're going to have an interest in learning about how it works. You know? How does the natural world then really work? Now I teach zoology and I love to learn and teach my kids about these people that go out and research this particular animal, or they go out in the field and they watch this animal migrate. And you know, that's good science, solid science work. And, and I think maybe*

my appreciation for that started you know, with that, without ever really knowing it, and without ever really having an understanding that that really was science.

What Dick described is a developmental sequence in which outdoor experiences lead to an affinity for nature, an affinity which provides the “groundwork” for an inquiry into how nature works, an inquiry which leads to an appreciation for science and scientific methods. This developmental sequence is quite thematic and was mentioned by teachers at both sites. It is a significant finding.

Traces of Dick’s outdoor experiences were evident in the contexts he chose for his science instruction and in the language he used to describe these contexts. It is significant that Dick had gone directly from his undergraduate studies to work in a toxicology lab. As such, he had been formally trained as a laboratory scientist, and he was very familiar with formal scientific procedures. He respected the laboratory and what he called “bench science” and described to me how he liked to take his students on field trips “to see what it’s like in real life labs.” Dick was an interesting case because he also appreciated field science, which he considered to be “solid science work.”

As a result, Dick’s science instruction combined laboratory and field science methods and took place in both indoor and outdoor settings. In preparation for a design challenge related to the production and distribution of food, Dick guided his students through their own experiments in the controlled environment of the school’s greenhouse. In preparation for a design challenge related to ecosystems management, students’ conducted their experiments outdoors in the wetlands, with field observations providing the data. Despite the difference in setting, Dick used the same scientific criteria for assessing the quality of his students’ work.

Going out in the wetlands…we went out there and, you know, kids want to set up an experiment, and it's pretty easy for me to look at their experiment and see if they controlled variables and if it was a valid experiment. You know, they might think it was really cool that they charted 23 birds, I think it was, that flew south, then it was easy for me to say yes, but, you know, did you set up your experiment this way such that, you know, I just, I've always been able to pick up on that and I think a lot of that has come through, just reading and, and the experiences.

Through these experiences Dick introduced his students to a particular view of science. In this view, science can involve observations of many different phenomena—from instruments to animals—and can take place in a variety of settings. Most significant of all, by using the school's ecology lab and wetlands as a context for his science instruction, Dick embedded science learning in the context of students' direct experience of the natural world.

The mystery and politics of food

As a science teacher, Dick's teaching within the EEE capstone was purposed towards students conducting their own scientific experiments. In addition to this primary focus, however, Dick's teaching addressed the moral and political aspects of sustainability. For Dick, who had never taught about the environment before, the capstone was an opportunity for him to explore his environmental values, beliefs, and politics. These aspects of his experience shaped the capstone's curriculum and pedagogy.

In order to prepare for teaching about food production, Dick collaborated with Robert, several other teachers, and two university professors to write a curriculum that integrated environmental science, economics, and public policy. In addition to providing guidelines for student experiments, this curriculum provided a strong critique of big agriculture's use of chemicals and genetically-modified organisms (GMOs), ideas which were reinforced by the movie *King Corn*, which Dick showed to his class. Although Dick was pleased that students were experimenting with growing food in the school's greenhouse, which he had required they share with a local "stakeholder," his primary goal was that his students would break free from a food system which he believed was "out of whack." When asked what he wanted his student to learn as a result of the food production unit, Dick replied:

> *That they are the masters of their own domain. They control their own nutrition. That they don't have to be a part of the system. The system is, you know, corn fed beef. That there are options. You can buy grass fed beef, or if you don't like how our chickens are fed certain things, you can go buy free range chickens, there is labeling now. And, you know, that they can teach their children about vegetables and fruits and that kind of stuff. So, that's my big picture for food systems.*

Clearly, Dick's purposes for the food production unit extended well beyond environmental science. He hoped that his students' experience with the curriculum would change their thinking and behavior. This involved moral, social, political, economic, and cultural perspectives on food, all of which the capstone addressed. When I suggested to Dick's partner Robert that their food production unit was designed to "demystify" food, Robert was clear that their goal was just the opposite. The teachers wanted to "mystify" food for their students by having them experience the mystery of growing it themselves. This is another example of how the capstone curriculum led students to directly experience the natural world, an experience which both teachers' life histories had inclined them to value.

Using STEM to make sense of an insane world.

Like Dick, Robert drew connections between the environmental experiences he had as a child, his adult environmental values, and the narratives he provided his students within the context of the EEE capstone. His case offers a very clear example for how childhood experiences can drive a STEM teacher's environmental pedagogy.

Robert described growing up in a small town filled with chemical companies, who freely polluted the area's streams, rivers, and lake. For him, the tension between pure and polluted was deeply inscribed into the landscape of his childhood. He recalled his mother saying to him once, "Don't play in the river *there*, but you can play in the river over *there*." Robert told me that his school bus drove by two 'Superfund' sites on the way to school and he remembers several times having to quickly close doors and windows in the house to avoid a cloud of approaching chemicals. On top of the environmental concern that this engendered, Robert also learned as a child that his town was considered a likely target for nuclear attack. This led him to a number of basic questions.

> *It became a very profound idea. What are we doing? Yeah, we're polluting all this, and my bus goes by two Superfund sites, and then somebody wants to come drop a nuclear weapon on you. And so, growing up these things became a matter of why, why, why. It didn't make sense from a sociological standpoint, but it also didn't make sense from an environmental standpoint.*

Robert suggested that these experiences engaged him to "make rational sense of an insane world," an inquiry that would involve sociological and environment aspects. Robert offered the following description of this inquiry, which drove his high school and college studies. His description incorporates his adult interpretation of STEM as the "application of reason" to the social world.

> *This, this was insanity, why do we want to do this to ourselves? There has to be a reason, a reason. So the STEM application of reason, I can understand that the world has a rational purpose. It follows certain rules. It follows certain principles. It's testable. You can understand it, articulate it, and if necessary, experiment to find a different solution. That idea mattered to me, and I'm not saying I ever sat down at the age of 18, or even the age of 22, and thought about it that way, but looking back, that's what I was trying to do. I was trying to make rational sense of an insane world, and I found that the tools of political science, the tools of historical and regressive analysis, those things helped.*

As part of this work, Robert also studied language and culture and became heavily involved in Model United Nations during high school. In the context of the EEE capstone, Robert offered his students these same tools, which he hoped they would use to make sense of their own world. In the AP microeconomics classes I observed, Robert used examples from his students' experience to demonstrate how a concept such as resource scarcity could be used to make rational decisions. Robert's classes were multi-toned and complex as he jumped back and forth between real-world examples and the content he was teaching, content which was context-free until he grounded it in the lifeworld of his students.

The economic perspective that Robert offered his students framed their approach to environmental issues. For example, when teaching the concept of externalized costs, Robert offered the example of a car that burned donuts for fuel. "You get to move cheaply, we get to breathe the crap." Through such comments, Robert demonstrated the need to balance self-interest against the social and environmental consequences of one's actions. After this classroom moment, Robert discussed how technology was important for the efficient use of natural resources, but he quickly countered whatever optimism this might engender in his students, suggesting that one of the "tragedies of the American economy" was that "we can only do well when we use as much as we can. Good for the economy. Bad for the environment."

Through his use of environmental examples to engage students with economics content, Robert infused moral and political content into what could have been a value-free course. Although Robert added this content partly to suit the environmental purposes of the course, the examples that he chose, and they way in which he presented them to his students, revealed that Robert had a particular view of environmental problems and solutions that he wanted his students to consider. The maturity and depth of Robert's environmental politics seemed a product of an exceptional childhood, which had predisposed both he and his wife to become involved in environmental advocacy, environmental policy, and environmental justice concerns—areas which provided a rich context for his classroom teaching. This is Robert's interpretation:

> *As you grow up in this environment, and you see this kind of stuff, it left an impression on my wife, too. That's why she got involved with the National Wildlife Federation and does environmental lobbying. She could do other things and make more money, but she's chosen environmental lobbying. It left an impression on us all. Where I grew up, 20,000 people there, so small area. For about 20 years, it had its own cancer hospital. That's some powerful visual cues. We're a small town, yet we've got our own cancer center? That left an impression on me. That's why I'm sitting over here with a National Wildlife Federation poster and, you know, stickers, because when you grow up in that environment, it left an impression on my wife. It left an impression on me. As we talk*

> *about it, we've, we've explored how that common background really took us to where we're at today.*

One of Robert's major challenges was to persuade his students—who did not have such "powerful visual cues"—that the environment *mattered.* In the absence of the "common background" that he shared with his wife, Robert used a narrative approach to make his case. Several times, I observed him offering classroom vignettes designed to introduce his students to alternative visions of society. These vignettes supported Robert's main thesis, that climate change and resource scarcity would require that his students live "dense by design." For them, this involved abandoning the suburbs for the urban core and adjusting to a lower standard of living. The most remarkable aspect of Robert's teaching was how he persuaded his students that this way of living was in their best interest. In the following interview excerpt, Robert describes his process and rationale.

> *You've got to change where people are at. But you've got to give them a reason to change. And those incentives are going to be fiscal or financial and make it so that living in one space is easier to afford than others. We simply make it attractive. Create a narrative. When I tell these kids is look, do you really use all the space in your house? The kids say no, we have unused rooms. Does that seem wasteful? Yeah. Is waste to be desired? No. Not in our world. We can't have waste in our world. They want to know, now what's the tradeoff, what's the incentive? You're living closer to your friends. You can see them quite often. You can hang out in these environments where it's hip. You know the restaurants. You can walk to the restaurants. You don't need to drive. You don't have to worry about parking or insurance costs on your car.*

Robert explained that he had settled on this type of approach after trying different presentations and failing with what he called "doom and gloom." At the end of one class I observed, Robert admitted to his students that he "didn't know the future" but that he was providing his students with "tools" so that they could understand "what futures are possible." In spite of this, Robert *did* have a sense for what lay ahead of them, and he was frustrated by their lack of engagement with anything beyond their present experience.

> *What I just said about being coddled, being protected, being nurtured and they're used to everything provided for you instantaneously, cheaply, individualized, now, now, now, and as much of it as you possibly want, and let's have it right here in front of me, and I don't need to worry about anything else because I've got everything I need. Yeah, that's, that's an obstacle for me with this generation because I don't think they realize that that's going to shift sooner rather than later, that this idea of the economy collapsing around them or the economy changing, it's not collapsing, it's just changing, uh, they're not used to that idea. The idea of having a long-term career is not going to happen for this generation. And it's not going to happen ever again. This will be the first generation that deals more with contract by contract, pay as you go.*

One of the main challenges that Robert faces as a teacher is how to engage his students with his vision for a sustainable society, a society which would require them to sacrifice their individual interests for the greater good. Robert was not the only teacher in this study to face this challenge, nor was he the only teacher troubled by his students' lack of engagement with their future. Robert was unique, however—uniquely confident in his social vision and uniquely descriptive of possible worlds.

What Collaboration Looked Like: The Political Rhetoric Debate

Dick and Robert were the two primary content teachers for the EEE capstones. As described above, they way they understood their teaching, and how their teaching looked in the classroom, expressed their environmental experiences. At times, there were conflicts in their environmental positions. For example, although Dick was wary of genetically-modified organisms (GMOs), Robert saw them as a necessary adaptation to climate change and required for global food security. The environmental aspects of the capstone were made more complex by the addition of George, who, although he did not teach content for the capstone, was responsible for managing it. George provided an instructional vision. His goals for the capstone were very clear and reflected his belief that content needed to be "presented with relevance…with real world application." This was achieved through the design challenges that anchored each quarter's curriculum.

Although design challenges typically involve building a machine or other technical artifact within certain constraints, the design challenges that George created asked students to design policy papers that they could share with STEM professionals. Each of these papers involved responding to an "essential question" that integrated the environmental science, economics, and political science content taught by Dick and Robert in their respective courses. These questions invited students to consider how natural systems and social systems interacted in the context of particular problems. The following question drove the second design challenge:

> *How do market forces such as price, quantity, and efficiency affect individual choices in economic systems the same way that nature, influenced by human society, affects the nature and quantity of wild species and bio-diversity?*

The policy recommendation papers that students designed in response to this question would be sent to the state's department of natural resources, where several students were interning. In order to reinforce the political and rhetoric aspects of answering this question, the three teachers organized a debate, moderated by Dick, where George and Robert would offer different perspectives on the issue. For the debate, George assumed a liberal position and Robert a conservative position. Students were advised during the debate to note the key beliefs of the liberal and conservative positions, which they would need to understand in order to "sell" their policy to legislators. In other words, the primary audience for the papers was state representatives. The main constraint of the design challenge was to create a policy recommendation that appealed to members from both parties, a skill which real-world policymaking required.

During the debate, Robert took a "promethean" position (Dryzek, 2005), expressing his confidence that technology and innovation would allow for continued economic growth. He supported this view by noting nature's ability to adapt to human influences. Robert also adopted an instrumental view towards the natural world, suggesting that nature existed to serve human purposes. Reflecting the sentiments of many outdoorsmen, Robert suggested that public lands were necessary to educate the younger generation in good stewardship. George, on the other hand, suggested that when it came to environmental issues, the rights of the individual, which Robert has been emphasizing, must be balanced against the rights of others. Although I anticipated George to extend this right to animal species, or to suggest the "intrinsic" value of nature itself, he stopped short of doing so. As the debate unfolded, it became clear that the primary difference between their positions was the extent to which each believed that individuals acting in their own best interest would benefit everyone. Contrary to Robert, George adopted the position made famous by Garrett Hardin's "tragedy of the commons" (1968) paper in which Hardin demonstrated how the self-interested behavior of individual shepherds would inevitably destroy a village's common lands. Hardin used this scenario to argue for reducing the human population. Although neither teacher suggested population reduction as a solution to environmental problems, George's echoed Hardin by suggesting that individuals acting in their own self-interest was an unlikely basis for sound environmental policy.

The political rhetoric debate provides a good example of the capstone's discourse on environmental problems and policies. Although taught within a STEM high school, the capstone's design challenges were public policy papers rather than engineering or technological design projects. Writing these policy papers required students to know social science perspectives on environmental issues in addition to concepts from ecological and environmental science. The political rhetoric debate was designed to provide students with the additional content they would need in order to persuade policymakers to accept their proposals. To this end, the debate repositioned scientific evidence as a rhetorical and narrative tool, and in this way, the debate reflected the capstone as a whole. Perhaps symbolic of this, the capstone's science teacher, Dick, moderated the debate rather than participating. The environmental discourses represented in the debate constructed environmental problem-solving as something that rational individuals did to protect their self-interest after considering—more or less—the interests of others. What I did not observe were radical perspectives on environmental policy and cultural perspectives on environmental problem-solving (Bowers, 2000; Dryzek, 2005). These alternative perspectives are important for students in democratic society to learn and could be incorporated into future debates (Stevenson, 2007).

How and Why Allie Taught Environmental Content

Allie was one of several content teachers for the Design and Engineering Capstone. Her primary collaborator was the school's technical writing teacher, who appeared suddenly during her class to teach APA style or some other content. Unlike Dick and Robert, Allie did not attach much significance to her early outdoor experiences—which included summer trips out West—and she drew no clear connections between these experiences and her teaching. Allie spoke more strongly about the mechanical projects she and her father completed when she was younger, which included repairing box fans and lawn mowers others had discarded. Allie's father was a mechanical engineer for a large research and development firm. She recalled how fascinated she was with his work, which as she grew older became more classified—and more mysterious.

Allie had been asked at Capital STEM Academy to teach a Principles of Engineering course within the Design and Engineering capstone. Although a math teacher by training, Allie interpreted engineering as being similar to math because both involved clear problems and verification processes. So, although she had never taught engineering before, her background and experience made her a good candidate. Allie's Principles of Engineering course was designed by Project Lead the Way (Handley, et al., 2012) and included content related to energy, mechanics, and materials. In addition to introducing the concepts students might see in a postsecondary engineering program, this course incorporated projects and activities designed to develop students' problem-solving and collaborative skills. In this framework, projects were where concepts were applied and how professional skills were learned. Like all Project Lead the Way teachers, Allie enrolled in an intensive summer training where she became familiar with the curriculum and supporting materials. In the span of two weeks, she and the other teachers in the training went through every Power Point presentation and project activity. In the evenings, they completed many of the homework assignments included in the curriculum.

The Principles of Engineering course that Allie was trained to deliver included several units on energy. Here, it is important to note how engineering courses differ from science courses in regards to energy. Studying energy in a high school setting does not necessarily mean that a teacher will address environmental concerns. For example, in most high school physics courses, students will study the characteristics of energy in order to understand how energy behaves. Engineering education courses are different, however, because in addition to this, students will also study the applications of energy, which in the real world can carry environmental consequences. This does not mean, however, that all engineering courses address environmental issues. In other words, engineering education is *not* the same as environmental education. But when the environmental consequences of energy use are a driving concern, and when students use environmental criteria to evaluate different energy sources, and particularly when these things lead students take action, engineering education can be considered a type of environmental education (Huckle, 1983; Kim, 2003). These distinctions are helpful for interpreting the environmental aspects of Allie's teaching about energy.

Early in the year, Allie had taught a lesson on energy sources. This lesson was designed to introduce students to different energy sources, which they would learn to identify and categorize. The curricula recommended that each student create a presentation about the pros and cons of one energy source—either renewable or nonrenewable. Allie chose to add a "call to action" piece to this assignment. She describes how this idea came about:

> *It was their first day of presenting their Power Points [on energy sources] when I kind of thought of this. The Power Points were very factual, which is what they were supposed to*

be, you know. Um, they investigated wind farms, and this is what they found out, you know. Wind farms are great because of this and wind farms are bad because they're killing birds and bats. It was very factual, which is exactly what it's supposed to be. And then I thought, I just, I wanted them to start to form an opinion.

In this way, Allie moved the assignment away from what the curricula was "supposed to be" by requiring that her students form an opinion based upon the facts they had learned. As we continued our conversation, Allie noted that the idea came from hearing a colleague share during an in-service.

Actually, the project did come out a little bit of, we had a group working on LDC [Literacy Design Collaborative] modules a couple weeks ago and they were reporting about what they were doing, and one of the teachers, his LDC module was about oil fracking and stuff, and his was a lot more specific on a specific energy topic, but I thought, I should do that.

This is one example of how collaboration among teachers leads to innovations in practice. In this case, it seems that Allie was inspired by her colleague's willingness to incorporate a politically-charged issue such as "fracking" into their energy curriculum. Allie decided to add a paper to the Power Point assignment, which also enabled her to involve the technical writing teacher, who prepared the students to write a persuasive essay that incorporated scientific data. Allie shared with me one of her students' papers, which addressed a fictional "Energy Commission." In it, the student proposed that the Commission increase its commitment to renewable sources such as wind and solar after considering the data on coal pollution that her paper provided.

The lesson on energy sources was followed immediately by a lesson on energy applications during which students built and tested cars that were powered by photovoltaic cells and hydrogen fuel cells. The curriculum for this lesson positioned this activity as a context for deepening students' understanding of key energy concepts. As Allie described it, this activity also challenged students' basic conceptions about renewable energy sources, which would have gone untested had they not experienced the activity. She described, for example, how this experience had challenged some of their assumptions.

> *They were out there, and then someone would walk by, and their shadow would cross the [solar] panel and their car would stop. And so, you know, they're seeing a lot of the issues when we're working on it. Yesterday it was cloudy when we first started. So they were having trouble getting much to run out there. So it really makes them understand, wow, solar's great, but as soon as a cloud comes, and you need a huge area, they're really starting to understand that. I mean, they have 9 volt batteries in their kit, too, so they already know how to run the motors off a 9 volt battery. Well, that 9 volt battery runs that motor a whole lot faster than the two solar panels.*

For students, including the student who proposed an increase in solar power to the local energy commission, this experience created the type of disequilibrium that preceded conceptual change. Interestingly, this process led students to question what was politically and culturally expedient.

> *They're really getting to experience how that is. I think now, you hear all the politicians, you know, renewable energy and clean energy and all this stuff, but I think they really need that real understanding of the good and the bad, the two sides. And they've done plenty, plenty showed up in the Power Points about you know, the problems of the oil and gas and the environment…and I don't think there's much disagreement that the coal and the oil and the gas are bad. I think that's pretty much ingrained in their heads. I think they've heard that enough. And then they've also heard about, you know, we need to use*

renewable sources and clean energy and they've heard that. But now they're starting to really understand some of the problems with it.

For Allie, these were important lessons. She explained that her students had also learned that combining a hydrogen fuel cell with a solar panel helped alleviate some of the problems they experienced with solar alone. As a result, she believed that her students were "starting to get the idea that combining methods might be effective." Allie hoped that some of her students would "solve some of those problems…in a few years. I mean, they'll be out there."

It is significant that Allie can imagine her students solving these type of problems in the real world of STEM professionals. The fact that Allie can imagine her students working in this world also speaks to the type of students she teaches, the majority of whom would go directly from Capital STEM Academy to postsecondary education and the professional world. Considering this, Allie could be comforted that what her students had experienced in her engineering course—which included a certain disequilibrium in regards to renewable energy—could contribute to their future success.

The Risks and Rewards of Teaching in the Knowledge Society

Capital STEM Academy is a model school in many respects—a "knowledge-society school" (Hargreaves, 2003). For this reason, teaching at Capital STEM Academy was a demanding job, and the participants experienced many of the pressures noted by Hargreaves (2003) as endemic to teaching in innovative schools. Several teachers said that their work was negatively impacted by the rapid cycles of technological and instructional innovation within the district. One teacher said that her students "felt like guinea pigs" due to these changes. The teachers also experienced the stress of having to do more with less time. The success of the school, aided by the rising interest in STEM generally, had led to an increase in students but no increase in teacher numbers, which resulted in larger class sizes. Additionally, many of the school's initiatives were funded by external grants and donations that required ongoing attention from teachers. Finally, the school's stellar performance on the state's standardized tests and report card has created a culture of very high expectations and made it difficult for teachers to meet the state's "value-added" criteria for teacher performance. As one teacher explained, it's hard to add value when your students are already testing so high. Sustaining the capstone projects required the project teachers to negotiate these challenges.

The challenge of coordinating capstone internships.

I observed two main challenges to the capstone projects at Capital STEM Academy, observations which were supported by the interview data. The first challenge involved coordinating students' capstone internships. The second challenge involved collaborating with teachers from other content areas. Each of these challenges had strong relational aspects and involved teachers' pedagogical beliefs.

Each of the two capstones included an internship component where students worked on a research project with an external partner. The school's administrators had created a schedule that allowed students to travel outside of school building to meet with project partners during regular school hours, but the responsibility of managing these internships day-to-day fell primarily on teachers, and proved to be a significant challenge.

Dick was particularly interested in making these internships work. He explained to me that he had come to Capital STEM Academy because he saw it as an opportunity to return to a type of instruction he had experienced during the early 1990s, when the district was smaller and teachers were organized into teams. At that time, Dick was able to draw on his laboratory experience to connect students with professional partners, an idea which he referred to as "grassroots STEM."

> *Years and years ago, I found that the most success I had with my kids scientifically and like at the district science fair and even at the state science fair that we qualified for many years, are when kids partnered with actual professionals. That was years before STEM…and I was a single science teacher, doing my own thing, trying to call these people, you know, based on my lab experience, these people I knew and trying to get kids hooked up.*

This had become Dick's ideal context for science instruction and he appeared satisfied with the instructional aspects of the EEE capstone to the extent that the capstone incorporated partner-supported research projects.

In order to coordinate the internships piece, Dick had been released from his teaching duties for the last hour of each school day, time set aside for him to visit students' internship sites. Although this schedule appeared warranted, Dick felt uncomfortable with the arrangement because it applied only to capstone teachers. This tension added to Dick's conclusion that the internship piece was unsustainable, regardless of how strongly he believed in the idea from an instructional standpoint.

> *The STEM internship…it's too much for a teacher to encompass. To manage the internship piece with the teaching responsibilities, you know, they gave us, well, it's already been bent a little bit just for this year for me. My teaching responsibilities were to end at 2:30 and from 2:30 [to 3:30], that extra hour, five hours a week, I'm not in a classroom like other teachers. But that was for me to manage my 15 kids, if that meant I have to go visit, I have built time in my schedule. What do you think that did to the*

freshmen teachers who, or like the chemistry teacher right there who from the time his day starts at 7:45 [knocking three times on the table for emphasis] or when kids get here at five to 9:00, he has kids straight though the day, other than his lunch hour, and he still has kids in there at lunch. And he teaches kids straight through.

In response, Dick had agreed to taking on a freshman class two days a week even though he had not taught freshman for 15 years and had no clear idea what to do with them. Dick made this decision based upon the workload that other teachers in the building had to bear, which he believed was directly related to the STEM academy taking on more students than it had been designed to serve.

So the beginning of this year I had five hours a week, Monday through Friday, between 2:30 and 3:30. Well, because every other teacher is pushed to the brink here and our numbers are huge now as far as kids and stuff, I've said, what can I do to help out?

Dick is driven here by his notion of distributive justice—how students and work should be distributed within the school. In Dick's case, the personal rewards he might have experienced from his own release time were overcome by his sense of fairness. By taking on more students, Dick re-aligned himself with a school culture in which being "pushed to the brink" is the norm.

Dick was not the only capstone teacher who struggled to manage students' internships. Trey was a member of the school's design team and the social studies teacher assigned to the Design and Engineering capstone. Trey explained that his capstone had "internship coordinators" who had worked during the summer to connect each senior with a partner and that his role was to "shepherd them through" these internships during the school years. Trey had agreed to play shepherd for two of the school's capstones and explained that this took up a "huge amount of time." I was interested in how Trey was incorporating ethics into the Design and Engineering capstone, which he was responsible for doing as the social studies teacher on that team. Trey explained that he had done some lectures on it early in the year, and had posted some readings for students to review, but that he had become so "bound up" in the internship piece that he had yet to get back to teaching ethics. In Trey's case, the cost of doing capstone internships included less time for teaching content although he planned to return to the ethics of design and engineering in the spring.

The challenge of collaborating with other teachers.

The capstone projects at Capital STEM Academy were designed to encourage collaboration among teachers. One key feature was the school's schedule, which gave capstone teachers a three-hour block each morning. Collaboration was also built into individual teachers' roles, such as the technical writing teacher, who was assigned to all four of the school's capstones. This teacher, who had no classroom of his own, could only meet the requirements of his position by moving around the building, bouncing from room-to-room to determine how the teaching of writing fit with the activities of each capstone. His movements helped integrate the curriculum and provided opportunities for improvisation and innovation to occur. Allie described how the two of them negotiated the call to action paper that was added to the energy curriculum.

> *I told the English teacher, he goes oh, that would be a great argumentative piece. He goes, let's do an argumentative model so he um went and did some, some research. OK, if they were going to do an argumentative piece, this is what they would need to have. He came in and talked to them. This is the pieces you need to have. We need to start with factual information, what's the problem, give some data to back up the problem that you want to say, you know, what your action is. We want to make sure we address people that would be in opposition. So he went through all the pieces.*

Sustaining this relationship meant that Allie had to accept a level of uncertainty that many teachers would have found untenable, including teachers with no interest in integrated projects. For Allie, uncertainty looked like not always knowing when—or whether or not—the technical writing teacher was going to appear in her classroom.

Allie, however, had worked across content lines before and had experienced how her students benefitted from teacher collaboration. She described a connection she had made a few years before STEM with a science teacher who happened to teach nearby, when both of them worked in the district's comprehensive high school. Allie remembered a time when he students were working on math problems related to the half-life of elements.

> *Somehow that year, it seemed like my kids had this one particular chemistry teacher who happened to be a couple doors down, so he wasn't hard to find. Because in a big building, there's people you never, I mean there's people here I haven't seen for a month. It's like are they here, are they not here? But it's just that year it happened to be that we shared all these kids. He was very conveniently located. He was very excited that I was, kept coming in, asking about this stuff. Like he was excited I was doing it. So I kept talking to him more and it kind of continued, and so I think that was the point that I really first started to integrate more science into what I was doing.*

Allie's language suggests how unpredictable such partnerships can be and the importance of proximity and personality. The benefit of these conversations was that Allie could share what she had learned about science with her students, which provided a context for their mathematical calculations.

I started to work a little bit with that science teacher and try to make, you know, try to really understand. We were doing all the math, but it was like OK, what is this? What am I doing? What are we doing? We're calculating. What are we really calculating?

The primary barrier that Allie experienced was her lack of content knowledge, particularly in science, a content-heavy discipline. So, although Allie valued the instructional context that science concepts provided, her lack of a science background made talking to science teachers difficult and placed her in a vulnerable position.

I don't have a science background. I mean, I had to take a physics class, and a chemistry class, but I don't have that content knowledge. So trying to make those connections, I don't always see where they are and then even when I see them, sometimes I know enough science to, you know, talk intelligently about it and other times I don't. Since I've been in STEM, there's been a number of times that I'm going to the science teachers, asking them questions. This year, particularly with some of the engineering stuff, part of it's content questions, part of it to go and talk to them about OK, what do the kids know? Did you teach, so I have all these juniors and seniors, did they learn this in chemistry class last year? I don't know, like I don't know what they, because I don't know what they're doing in chemistry class. So, starting to build some of those relationships and, and making those links for the kids.

This excerpt demonstrates the deeply relational nature of the capstone projects at Capital STEM Academy. In Allie's case, STEM integration required her to leave the comfort of her own classroom to ask questions of her colleagues that revealed how little she knew about science—a risky undertaking. Allie took these risks because she wanted her students to see the connections between the STEM disciplines. It is significant that Allie used the words “relationships” and “connections” to describe her efforts to integrate the curriculum.

Conclusion

In this chapter I have presented findings from Capital STEM Academy—a state-designated STEM school with an environmental focus. Capital is a model STEM school in many respects, a demonstration of what can be achieved when state policy, district support, innovative leadership, and excellent teaching are aligned. The experience of Capital’s teachers provides a glimpse into what life is like for those who teach on the leading edge of STEM education.

Based upon visits to STEM schools in other states, Capital’s planning team used the engineering design process as a culture-building strategy and adopted inquiry as an instructional ideal. Their work was aided by a local educational change organization experienced in the design of small schools and supported district leaders. During Capital STEM Academy’s second year of operations, a new principal formalized the school’s instructional approach and introduced an innovative Energy, Environment, and Economics capstone. When considered alongside the school’s Design and Engineering capstone, the capstone projects at Capital STEM Academy prepared students—who were among the state’s strongest students—with the knowledge and skills required of environmental policymakers and professional problem-solvers. In support of this, Capital’s campus and curriculum offered a range of high-quality STEM experiences, including AP coursework, professional internships, and an ecology lab.

As was the case at Central STEM High School, the participants at Capital described environmental experiences during childhood and adolescence, and these experiences were evident in the curriculum they designed and in their classroom teaching. In the context of the two capstone projects, the participants felt free to address the moral and political aspects of sustainability and to incorporate their personal values and beliefs into classroom discourse. As a result, students experienced many moments of cognitive disequilibrium and change in regards to energy problems and policies and environmental problems and policies. They were also provided with the high-status knowledge and skills required for professional involvement in these areas.

The participants at Capital STEM Academy also described being “pushed to the brink” by demands placed upon them by policymakers, administrators, parents, students, and themselves. In addition to larger-than-expected class sizes, the project teachers experienced rapid cycles of technological and instructional innovation and a culture of very high expectations. Several teachers questioned the sustainability of the capstone projects, which required them to collaborate frequently and to tolerate a high-degree of pedagogical uncertainty. The teachers at Capital STEM Academy were still in the process of sorting through the innovations they had developed and experienced to determine which were sustainable and empowering and which were not.

Chapter Seven

A Comparative Analysis of the Findings and Recommendations

Introduction

This chapter offers a comparative analysis of the findings related to teachers' understanding and enactment of environmental projects at Central STEM High School and Capital STEM Academy. Although Central STEM High School and Capital STEM Academy are very different schools, the participants shared similar experiences when trying to meet the formal and informal mandates of STEM education discourse and policy. First, I examine the participants' perceptions of STEM education. Second, I examine the participants' perceptions of project-based learning in the context of existing models for practice. Finally, I consider the environmental projects as representing environmental discourses and environmental education traditions. The chapter ends with recommendations based upon the comparative analysis of the findings.

A General Comparison of Central STEM High School and Capital STEM Academy

Central STEM High School is an urban public high school serving low income students of color. The guiding hope among Central's teachers and administrators is that STEM will help change the outcome for the school's students. Prior to converting to STEM, the building housed five academic programs. The STEM grant awarded by the state offered the district an opportunity to convert Central into a large comprehensive high school. Although the five members of the school's curriculum planning team experienced significant freedom, their design process was complicated by the projected size of the school, nearly 1,000 students. In addition, the team's lack of a school administrator forced them to consider many non-curricular aspects of school design, including scheduling, which an administrator could have handled.

Capital STEM Academy is a suburban high school that attracts the strongest students in the district, the majority from middle class backgrounds. Although Capital was seeded through the same process as Central, the two districts were moving in opposite directions when the grants were awarded. At Central, the STEM grant funded a move from separate academies to a comprehensive high school. At Capital, the STEM grant funded a move from a comprehensive high school to separate academies, including a STEM academy. With the decision to use grant funds to contract with a local educational change organization, Capital's planning team experienced supports that Central's team did not. These supports extended to the district, whose assistant superintendent was an ongoing presence, and to a local community accustomed to educational innovation.

At Central, the planning team interpreted STEM as curriculum integration. To this end, the team drew upon their previous experiences with project-based learning, co-teaching, thematic units, and community partnerships. When Central STEM High School opened after a year of planning, project-based learning was integrated into an effort among administrators and teachers to build school culture and was revalued as a culture-building strategy. Based upon the work of a public Montessori school in the district, the school's master schedule included a week-long intersession each spring, a time for teachers and students to connect with STEM professionals and community partners on place- and community-based projects (Smith & Sobel, 2010).

The curriculum of Capital STEM Academy was based on the principles and practices of the engineering design process, represented visually by a "design wheel" displayed throughout the school. Classroom projects were interpreted as "design challenges" and the skills and dispositions of successful designers became core values. As was the case at Central, Capital's planning team used an instructional approach as a culture-building strategy. Capital's second principal, Denise, introduced "formalizing structures" in regards to instruction and encouraged teachers to focus on the context of their instruction. Teachers such as Trey retained their commitment to building culture and community. Robert described the transition from one principal to another as a "change in style."

The environmental projects at Central STEM High School reflected the promise of the "green New Deal" and were attuned to jobs and careers in the green economy. A process of building students' "climate resilience" was expressed most clearly by Deborah, who encouraged her students to approach environmental crises as economic opportunities. Several teachers described how they balanced the vocational goals of Central STEM High School with respect for students' personal autonomy and developing identities. An annual climate change assembly reinforced the school's dominant discourse on climate and energy by highlighting vocational opportunities and the need for students to change their environmental behavior.

The environmental teaching at Capital STEM Academy was integrated into two capstone projects—the Energy, Environment, and Economics capstone and the Design and Engineering capstone. Through design challenges that combined environmental and social science perspectives with professional internships, the EEE capstone prepared students to be "knowledge workers"—adept at politics, science, and rhetoric. Within the field of global environmental politics, such persons might serve as mediators between climate scientists and environmental policy elites (Litfin, 1994). Allie's ability to imagine her students working "out there" in the world of STEM professionals, where they would solve real-world energy problems, reflects the comparative privilege of Capital's student population. At Central, teachers experienced far less assurance that their students would end up in these places.

There were tensions at Central STEM High School related to culture and instruction. Although the school's first principal and teachers had worked to establish a culture of trust and community, several teachers expressed their frustration with colleagues they perceived as disinvested in project work. Several teachers suggested that the school had spent too much money on computers and not enough on the "hands-on" materials that science and engineering projects required. One teacher's opinion that computers were not "hands-on" opens a number of important questions regarding the materials needed for project-based learning in STEM education settings.

Despite its outward appearance as an ideal STEM school, Capital's teachers and students struggled to find stability. Part of this was due to the district's desire to be a leader among innovators. When Allie said that her students felt like "guinea pigs" she could have been speaking of herself, or her colleagues, all of whom were adapting to rapidly changing conditions. For Allie, innovation involved a revolving door of "learning platforms" as older technologies were replaced by new ones. Although, as Allie explained, the experience of learning in such an environment produced flexible and adaptive graduates, the experience of teaching in it could be costly. So, although the teachers at Capital STEM Academy had met many of the demands of STEM education policy, it was uncertain how much longer they could do so. Their experience is shared by others who have taught in knowledge-society schools (Hargreaves, 2003).

Teachers' Perceptions of STEM Education

The instructional and environmental implications of the findings must be considered in the context of the participants' perceptions of STEM education. Teachers at both sites identified STEM as a set tools and methodologies used by professionals to solve problems and conduct inquiries. Teachers perceived STEM education as preparing students for careers in these professional fields. There was considerable agreement among the teachers that STEM education involved developing students professional skills as well as teaching STEM content. Several teachers noted that this STEM “skill set” included professional skill such as collaboration. Teachers referred to 21st Century Skills framework quite often (Bell, 2010).

In general, teachers did not discuss the political aspects of STEM education or mention feeling pressured to reform their classroom practice. Rather, veteran teachers at both sites noted the regressive aspects of the movement. For them, STEM education offered new opportunities to teach in familiar ways, whether that was doing “hands-on” science, connecting students with external partners for research projects, or integrating science and mathematics content. One teacher at each school noted the involvement of politicians and business leaders in STEM education but neither questioned the economic and vocational goals of the movement or its political groundwork. The teachers’ lack of critical attention to the politics of STEM education is significant because many of their difficulties were related to policy effects, and some teachers appeared to blame themselves for not meeting instructional ideals that were politically-motivated.

The teachers perceptions of STEM education were summarized by a teacher at Capital, who noted that STEM education was a “model” with no clear “identity.” From a teachers’ perspective, this is quite true, and accounts for the wide variety of meanings attached to STEM education by teachers. Politically, however, STEM education is a model with a *very* clear identity. What remains missing are practical ways for teachers to implement this model in K-12 schools and classrooms (National Research Council, 2011b). In the absence of established practices, the participants drew upon their previous experiences, what they have observed teachers doing at other STEM schools, and the STEM education literature available to them. The risk involved was that their interpretation of STEM education would be different from what policymakers and non-participant observers had envisioned a STEM school to look and feel like.

Teachers' Perceptions Project-Based Learning

Teachers' perceptions of project-based learning were as varied as their perceptions of STEM education. Teachers at both sites understood project-based learning in the context of their previous experiences with instructional innovations. Less than half of the teachers had been introduced to project-based learning during their teacher training although some had experienced professional development sessions, including Project Lead the Way trainings. The two youngest teachers in this study were exceptions to this. Both had been introduced to project-based and inquiry-based approaches during their teacher education programs, which were only a few years behind them. Philip, for example, had developed a detailed understanding of the differences between project-based, problem-based, and inquiry-based learning and could discuss the relationship between project design and inquiry cycles. At Capital STEM Academy, it was clear that concepts such as "project" and "inquiry" had been incorporated into the school's lexicon of "design." Although teachers at Central also suggested project-based learning as "design process," they were referring to the design of the projects themselves rather than the design of project artifacts. At Central, designing projects was a skill that many students were still learning.

Teachers at both sites understood project-based learning as a method for developing students' personal, professional, and technical skills. This understanding was related to teachers' perceptions of STEM education as a skill-building enterprise. Teachers discussed how project work provided a balance to classroom lectures, which provided students with content but little opportunity to develop skills. At both sites, teachers referred to the 21^{st} Century Skills (critical thinking, communication, collaboration, creativity) as those skills that projects were believed to develop. For teachers at both sites, the instructional challenge was how to balance skills with content and projects with didactic approaches.

The skill set required of STEM professionals provided a strong rationale for project-based learning. In this way, project-based learning was oriented more towards the economic and vocational goals of STEM education than the educational goals of instructional designers, educational psychologists, and learning theorists (Blumenfeld, et al., 1991; Katz & Chard, 2000; Krajcik & Blumenfeld, 2006). There were other ways in which the professional workplace intersected with teachers' understandings of project-based learning. For example, George's (Capital) framework for project-based learning incorporated the mission, values, and methods of a global research and development firm that partnered with the school. For George, a "project" was what people did when they had a "problem" to solve or a "challenge" to meet, and the primary difference between problem-solving students and problem-solving professionals was the extent to which the problems were "real-world."

The hope that project-based learning might bring the world of "school" closer to the world of "life" is not unique to the teachers at Central STEM High School or Capital STEM Academy. This hope is embedded in the history of the project method in education (Alberty, 1927; Kliebard, 2004). For example, Stevenson's (1921) idea that educational projects involved solving problems in their "natural setting" is very similar to George's desire to provide a "real-world" context for students' problem-solving activities. And has been true throughout the history of vocational education (Kliebard, 2004), the challenge for George and the other participants was to provide students with "real-world" experiences in the absence of an apprenticeship system, which would have educated students *on the job.*

The Obstacles and Challenges that the Project Teachers Experienced

The teachers at both sites discussed the challenges of sustaining project-based learning in the context of a public school. In order to provide a comparative examination of these challenges, I have used a framework for interpreting the sustainability of project-based science in urban public schools (Blumenfeld, et al., 2000; Fishman & Krajcik, 2003). This framework organizes the challenges of sustaining project-based learning into three main categories: challenges related to organization culture; challenges related to teacher capability; and challenges related to management and policy.

Cultural challenges.

The culture of both schools was designed to support constructivist pedagogies, and the majority of the participants appeared to value project-based learning and believe in its potential to develop students' personal, professional, and technical skills. During the planning phase at both schools, instruction had been used as a culture-building strategy. For this reason, ongoing professional development in instruction was needed to maintain school culture.

The need for professional development was more pressing at Central, which due to its size and rapid expansion had many teachers that were still being enculturated. Several teachers at Central expressed their frustration with colleagues whom they perceived as less committed than they were to project-based learning. Several of the participants at Central said that they needed more time to plan projects, to reflect on projects, to improve projects, and to learn about project-based learning. Lucas, for example, described how he made the same mistake on one project two years in a row because he did not have time to reflect and revise.

Although the teachers at Capital discussed many instructional challenges, the majority of these were not related to school culture. At both the district and school level, innovation appeared to be valued and supported. This culture of innovation had side-effects, however. As several participants noted, being “pushed to the brink” was the norm. At Capital, the capstone project teachers experienced an exceptional level of autonomy in regards to their curriculum and instruction. This was offset by the exceptional level of work that the projects required of the teachers. Unlike the teachers at Central, Capital’s teachers were rarely without students in their classroom, even during lunch.

Comparing the organizational culture of the two schools is difficult because of the striking difference in context. At Central STEM High School—a large, inclusive, urban public high school serving low income students of color—building and maintaining a project-based culture was a complex process. From the district’s perspective, school culture was instrumental to improving students’ behavior and reducing discipline referrals. Although the district had adopted the rhetoric of project-based learning in advance of the Common Core State Standards, its interpretation of positive school culture penalized schools for the sorts of disruptive expressions that project-based learning involved. In this context, teachers who valued project-based learning placed themselves at-odds with the dominant culture of the district. This explains, I believe, why the projects at Central were more carefully-structured than at Capital. Several teachers at Central discussed the value of “checklists” and “spreadsheets” as project management tools. The work of avoiding classroom disruptions involved the more procedural aspects of project-based learning, which are the primary content of PBL “toolkits” addressed to practicing teachers (Boss, 2013; Larmer, Ross, & Mergendoller, 2009).

This is an important finding. Like other innovative school’s in poor communities, Central’s teachers were at risk of “performance training” (Hargreaves, 2003) whenever the school’s test scores and report card stirred public perceptions of failure. These interventions, both real and imagined, discouraged Central's teachers from sustaining constructivist classrooms—the types of classrooms that researchers have argued are required for knowledge society skills (Bereiter, 2002; Blumenfeld, et al., 2006; Hargreaves, 2003; Sawyer, 2006a). Due to high test scores, Capital and its teachers were free from outside intervention and could depend on that freedom. As a result, their students experienced more opportunities to build knowledge society capital and leverage their class-based advantages (Lareau, 2003).

Capability challenges.

Both schools were significantly larger than planned, and in both cases, the district was unable to provide additional teachers. At Central, large classes combined with architectural features to make co-teaching difficult. At Capital, teachers had adapted to more students by considering alternative approaches to instruction such as blended learning and "flipped" classrooms. The extent to which teachers' projects were affected by depended upon how they understood their work. For example, Allie seemed relatively comfortable managing forty students in her project-based Principles of Engineering course, but this number was nearly twice what George believed was the upper limit for project-based learning.

A primary concern among Central's teachers was a lack of "hands-on" materials for science instruction, which some teachers purchased on their own. Materials were a concern at Capital, too. During an engineering project I observed, Allie explained that she would need "twenty screwdrivers" to run the project smoothly. She also noted that the school had purchased portable technologies that few teachers had been trained to use. Teachers at Capital also mentioned the school's dependence on grants and donations for STEM resources.

A significant challenge shared by the participants was how to sustain the partnership aspect of the projects. Although the teachers at Capital experienced supports for this work, several believed that the internship piece of the capstones could not be sustained. At Central, partnering required many of the school's teachers to reach across lines of race and class and to bridge the divide between an urban school culture and the corporate world. Several teachers at Central mentioned partners' lack of understanding about how schools and teachers actually work. Althea described a partner's assumption that she could meet on a school day in the early afternoon. Because the majority of the participants at both sites had worked at professions other than teaching (e.g., banking, public policy, engineering, science) they were more aware than many partners of the differences in culture.

Among STEM education policymakers (National Academy of Sciences, et al., 2007; President's Council of Advisors on Science and Technology, 2010), the instructional ideal is that STEM professionals will support the work of teachers—serving as classroom guests, curriculum advisors, technical assistants, and content experts as well as providing off-school sites for internships, field trips, and design competitions. These things happened at both Central STEM High School and Capital STEM Academy, but not as often or as neatly as some would have liked. Deborah, who taught CTE at Central, described *her* ideal, which was to have a local engineering firm that she could call, one that was familiar with her Project Lead the Way curriculum. There would be "no barriers" for her to make these calls and she would have a key contact person, maybe even a list of engineers in the region, or a list of graduate students who were familiar with her curriculum and were willing to come in and teach. Deborah suggested that this meeting her ideal, which was not far from the ideal of policymakers, would require a "liaison," someone employed as a mediator between teachers and the school's partners. Teachers at both sites also described obstacles to collaboration and project integration that were content-related. Althea noted that science was a content-intensive subject. She told the story of a conversation with a project colleague that had gone well until the two of them discussed science content, at which point she "lost him." Allie, at Capital, was on the other side of the fence. Although she was very interested in making "connections" between math and science, her lack of science content knowledge made communicating with science teachers difficult. Allied said that she "wished she knew more science" or could review the science courses she took during college. Because the planning teams at both schools had interpreted STEM education as involving an integrated curriculum, and science-driven projects, these examples of content-related challenges are particularly significant.

Policy and management effects.

The third category of project challenges related to policy and management effects, and there were a number of ways in which policy measures and management structures made project-based learning difficult at both schools. One was the state's standardized assessments—a series of achievement tests given in the third through eighth grades and a graduation test given in the tenth and eleventh grades. Although state legislation had waived certain restrictions for its STEM schools, state testing was not one of them. As a 7-12 high school, Central's state report card included the results of the seventh grade achievement tests in mathematics and reading and the eighth grade achievement tests in mathematics, reading, and science. Capital's students scored poorly on all five of these tests and earned the school no "credits" towards their state report card. The same held true for the tenth grade graduation test. By comparison, Capital's students scored very highly on both graduation tests, earning full credit from the state. As a 9-12 high school, Capital did not participate in the state's seventh and eighth grade achievement tests. All of the above assessments were tied to the state's academic content standards.

As tests of content knowledge, the state assessments were not designed to measure students' personal, professional, or technical skills, which would have required a performance-based assessment, portfolio-based assessment, or some other qualitative measure. As such, the teachers primary rationale for project-based learning—skill development—was not measured by the state's "high-stakes" tests. For Capital, whose students scored very highly on these tests, this did not appear to be a problem. Although George at one point suggested that Capital's high standardized test scores proved that projects could be good "test prep," the success of Capital's students on the state tests was likely class-based. As a school that was highly-rated by the state, Capital and its teachers experienced a reprieve from the oversight that befalls schools such as Central, where low test scores had led to the re-allocation of resources towards test preparation.

The academic content standards of each of the districts were closely aligned with the state's standards, and each district assessed students at the end of each quarter or semester in core content areas—science, mathematics, social studies, and English/language arts (ELA). Teachers at Central mentioned a district "pacing guide" linked to the district standards and semester tests. Because the results of the district tests were not shared with the state, they did not appear to affect the teachers' instruction at either site. The district's calendar, however, did. For example, the teachers of the EEE capstone at Capital had organized their year into four nine-week units in order to remain aligned with the district's quarter schedule. Several teachers at Capital said that one of the challenges of the project-based learning was that it was difficult to know in advance how much time each project would require. For this reason, Capital's teachers were challenged with how to assess students whose projects were incomplete at the close of a quarter. How they negotiated this challenge depended upon their understanding of the freedoms they had been given by administrators.

At both sites, these management and policy effects were differentially distributed among subjects and grade levels. It was evident that the instruction of the core teachers at each school was constrained by the state tests. I was also clear that eleventh and twelfth grade teaches, including core teachers, were less constrained than ninth and tenth grade teachers, whose students had yet to take the state's graduation test. For example, Dick at Capital was surprised to hear that Central's ninth and tenth grade teachers were trying to do project-based learning in core classes. He could not imagine core teachers anywhere in the state doing what he was doing with his juniors and seniors. Lucas, who taught at Central, disagreed. Prior to becoming a CTE teacher for eleventh and twelfth graders, at prior to Central' conversion to STEM, Lucas had taught tenth grade chemistry. He believed that his course could be taught by a project-based approach but that a teacher would need to "make sure" that they "got across" the district's content standards. Reflecting on his own experience at that grade level, he explained that he could not have taught an "extended three week project" because of the "pacing, sequence, and timing of the year." In order to stay on pace, Lucas explained, the projects would have to be shorter and carefully-organized.

Lucas (Central) had a very different experience in his CTE courses, which he described as being "all project-based." At the time of this study, CTE courses were an anomaly. Although there *were* state standards for the school's engineering pathway, there were no state or district assessments. For this reason, Lucas experienced an exceptional level of freedom. Deborah, who also taught CTE at Central, had a different situation. Her courses required curriculum and materials from Project Lead the Way, which the district paid for using funds allotted by the state for its CTE programs. When we spoke, Deborah did not know yet whether she would be teaching a robotics curriculum or a sustainable design curriculum. The robotics curriculum was considerably more expensive, and it was up to the district to decide which to purchase. At Capital, Allie's Project Lead the Way course (Handley, et al., 2012) was purchased by the *school* rather than the district because Capital was not a state-designated CTE school and was disqualified from receiving CTE funds.

At a school-level, teachers at both sites mentioned the relationship between the school's master schedule and their ability to teach integrated projects. School schedules determined, for example, which of their project colleagues the participants would see, when they would see them, and for how long. At Central, the challenge for administrators was how to design a master schedule that provided common planning time for teachers. Central's teachers believed strongly that integrated projects required common planning time. When a non-core position disappeared, as it did one year due to district finances, common planning time disappeared as well because, as David explained, there was no "out bell" that could take the team's students. At Capital, the scheduling problem had to do with mathematics. As Allie explained, the school had hoped to create grade-level teams, each of which would include the grade's four core teachers. This could not happen, however, because the mathematics courses at the school included students from *across* the different grade levels—not within. For this reason, mathematics teachers were not included on grade-level teams, which made it hard to incorporate mathematics content into the projects designed by each team.

Interpreting the Projects as Environmental Discourse and Environmental Education

To this point, this chapter has compared the projects at the two schools from an instructional perspective. In the next two sections, I will compare the projects from an environmental perspective. As was discussed in Chapter Two, federal policymakers have interpreted STEM as a means of solving complex problems related to energy and the environment. As a consequence, these problems have become instrumental to the economic and vocational goals of K-12 STEM education and helps explain why STEM schools have strong environmental programs. As such, the environmental projects at these two STEM schools were the result of political as well as educational forces, and for this reason I will interpret these projects as both environmental politics and environmental education.

Interpreting the projects as environmental discourse.

In regards to environmental politics, I will use Dryzek's (1995) work on environmental discourses as an analytic framework. According to Dryzek (1995), environmental politics exists because there are conflicting ways to interpret environmental problems and solutions—competing discourses. Dryzek (1995) suggests that each environmental discourse is tied up with a particular "kind of politics" (p. 20) and has direct effects on institutions and policies and indirect effects on people's values and behaviors. Although Dryzek does not directly address educational effects, the field of environmental education offers a range of pedagogical traditions inspired by environmental discourses (Sauve, 2005).

The participants at Central—science teachers and engineering/CTE teachers—were involved in environmental projects related to global climate change, renewable energy, and global water sustainability. Participants also developed "hands-on" projects related to sustainable design and wind energy. At Capital, the participants included environmental science, mathematics, engineering, and social science teachers from two of the school's capstones. These capstones integrated STEM and non-STEM disciplines.

The findings indicate that stories about the future were an important part of the curriculum and instruction of projects at both schools. The content and purpose of these stories varied depending on the classroom. At Central, Deborah shared stories with her students about a future in which climate change and resource scarcity led to environmental and social decay. She shared these stories, which she reinforced with dystopian film clips, in the hopes that her students would change their environmental behavior. These moments were the effect of survivalism—an environmental discourse of looming tragedy, global collapse, doom, and redemption (Dryzek, 1995). Several of the projects showed traces of survivalism and told stories of a troubling future. Within several projects, such as David's "mini-project" on the Adélie penguin, these stories included survivalist interpretations of scientific data. At Capital, the effects of survivalism were most evident in Robert's AP Microeconomics classroom. In this context, Robert shared stories that made living in a "collapsed" economy appear attractive. Like David at Central, Robert grounded his stories in scientific data.

Several teachers adopted a more promethean approach (Dryzek, 1995) and were confident that STEM could be used to solve environmental problems while humans learned to adapt. At Central, Philip understood sustainability as "leveraging science and technology to make us not have to adjust so much." As was the case with all of the participants, Philip recognized sustainability as involving a process of adjustments. He differed, however, in his confidence that science-based technologies could intervene in this process. Philip also believed that nuclear power would play a major role in this process. At Central, a similar position was taken by Robert during the political rhetoric debate. In this context, Robert expressed his confidence that "technology" and "innovation" would solve environmental problems if the government would stay out of the way. This is similar to the position of the economic rationalists, who propose that environmental problems can be solved by "market mechanisms" Dryzek, 1995, p. 121). In the context of the capstone, students were advised to consider Robert's position when writing their environmental policy proposals.

Also at Capital, Allie believed that solar power offered a “real solution” to the energy crisis, and although she and her students had experienced the limits of current solar technologies, she believed there *had* to be ways to make them more “effective,” a challenge she hoped her students would take up as professionals. Allie’s confidence in technical solutions is embedded in the PLTW curriculum she used for the Design and Engineering capstone at Capital (Handley, et al., 2012) and the PLTW curriculum Deborah used for her CTE courses at Central (Rogers, et al., 2013). Although Deborah and Allie extended this curriculum into moral and political territory, the curriculum as written is strongly promethean and expresses a “boundless faith” in human ingenuity (Dryzek, 1995, p. 61) and the idea that technological advances are a sign of social progress (Marx, 1993).

Deborah and Allie’s curriculum revisions are important because they extended the projects’ discursive reach. For example, when Deborah worked with the schools’ technical writing teacher to add a “call to action” assignment to her unit on energy sources, she had also acknowledged her students’ right to comment publically on energy issues. By recognizing her students in this way, Allie had adopted the position of the democratic pragmatists (Drykek, 1995), who extend environmental agency to ordinary people.

Projects at both school contained elements of green radicalism (Dryzek, 1995). Dryzek (1995) organizes this discourse into efforts to change people (green consciousness) and efforts to change society (green politics). In regards to changing people’s consciousness, none of the projects promoted deep affinities with the natural world, although several included outdoor activities. These were *not* romantic projects. However, projects at both sites introduced students to a “green lifestyle” (Dryzek, 1995) by encouraging them to recycle, compost, give up their cars (Capital), and make healthier food choices. Some were green politically, such as Althea’s global water sustainability intersession, which mixed perspectives from the environmental and global justice movements. In addition, David at Capital used Greenpeace materials for his climate change unit, an organization he described to students as “politically involved in policy.” For the most part, however, the projects took the liberal capitalist political economy for granted and were more reformist than radical.

Interpreting the projects as environmental education.

A common typology for environmental education distinguishes between education *about* the environment, education *in* the environment, and education *for* the environment (Huckle, 1983). Education *about* the environment is subject-centered, quite common in secondary schools, and strongly scientific. Education *in* the environment is topic-centered, often community-based, and involves “safe” action projects such as recycling initiatives (p. 105). Education *for* the environment is issue-centered and designed to prepare students to “participate in environmental politics” (p. 105). Stevenson (2007) argues that to participate in a democratic society, students must be introduced to a wide range of environmental positions, which is difficult to do in public school settings.

The environmental projects at Central STEM High School and Capital STEM Academy involved all three of Huckle’s (1983) types. Those projects that were conducted by individual science teachers, not surprisingly, were strongly scientific. At Central, climate and energy projects included content from the district’s biological and physical science standards. At Capital, the EEE capstone included science content related to ecosystems, climate change, energy, and food production. Other projects were topic-based and involved community partners. Central’s week-long intersession was designed to facilitate this type of environmental education and both Althea and David had taught water-based intersessions—one with a corporate partner and one with a community non-profit.

If a hypothetical student had experienced all of the projects included in this study, they would have been introduced to a range of environmental positions and been given the knowledge and skills to participate in environmental politics. In this sense, the aggregate data suggest that education *for* the environment was occurring at these two schools, but inconsistently. Often this occurred when a teacher with a particular background, who happened to have a particular set of values and beliefs, lead their class into political terrain. One example is when Robert explained to his AP Microeconomics class how the American economy could not grow without hurting the environment. By saying this, Robert challenged the world's leading environmental discourse—sustainable development—which imagines that this dialectic does not exist (Dryzek, 1995). For students to recognize this, however, they would need a deep understanding of how different environmental discourses understand the relationship between economic systems and natural systems and how all of this is bound up with political power.

Although Robert's economics and political science courses—and the EEE capstone as a whole—presented a range of environmental ideologies, including during the political rhetoric debate, some positions received more attention than others, and it was unclear if students understood that there were "substantively different perspectives" on environmental problems and solutions (Stevenson, 2007, p. 143). As Stevenson (2007) noted:

> to be consistent with democratic principles students should be exposed to the plurality of environmental ideologies, and that through a process of inquiry, critique and reflection they can be assisted to develop and defend their own set of environmental beliefs and values (p. 143).

Achieving this runs counter to the central purpose of public schooling: "the transmission of cultural knowledge, skills and values" (p. 145), including dominant notions of environmental decision-making. In this regard, the work of the EEE capstone teachers is particularly significant. Their experience suggests the range of environmental positions currently available to teachers and students and the exceptional conditions required to support a socially critical approach.

As Huckle's (1983) typology suggests, environmental education projects can be interpreted by looking at the actions students are required to take, both during and at the end of the project. In the EEE capstone, students were asked to write four environmental policy papers. These papers were their "design challenges." By comparison, Deborah's PLTW curriculum (Rogers, et al., 2013) represented the dominant interpretation of the environmental actions available to students. The storyline of this curriculum is that the future can be secured—but only if we improve our energy technologies and energy behavior. As such, the curriculum is both technical and normative. So, in addition to designing and testing wind turbines (technical) students learn to conduct "energy audits" of their own energy use with the goal of reducing their "carbon footprint" (normative). At Central, changing students energy behavior was a key outcome for the environmental projects. Within the renewable energy project, students learned to conduct energy audits and were encouraged to build community awareness around energy conservation. Within the global climate change project, reducing one's carbon footprint, and educating others to do the same, was the primary avenue for student action.

The difference between having students write policy papers and having students conduct energy audits represents the contrast between the environmental projects at these two schools. The teachers at Central STEM High School and the teachers at Capital STEM Academy were preparing their students for very different worlds. Central's teachers hoped that their students would find jobs and careers in the green economy and become active in environmental affairs, including voting on local ballot issues. Considering the projected growth for the green energy sector, skills such as conducting an energy audit could prove valuable. The risk is that Central's students will equate environmental advocacy with monitoring one's own behavior and participating on election day. This leaves the root causes of social and environmental injustice—the political economy—unchecked. By comparison, Capital's teachers hoped that their students would become scientists, engineers, and mathematicians—or environmental policymakers. Some likely will. The risk is that Capital's students will build a more sustainable world without considering justice and equity as their primary design constraints.

Recommendations

The remainder of this chapter provides recommendations based upon the findings. The first and second sections provide recommendations related to STEM education policy. The three sections after that include recommendations for a greener and more democratic STEM education

STEM Education policy recommendations.

As was described in Chapter Two, policymakers, business leaders, and educational theorists have reached a consensus—that K-12 STEM education in the United States must be restructured to meet the demands of the knowledge economy. In the process, experiential and constructivist approaches to instruction have become politically-expedient and required for implementing STEM education policy. For this reason, policymakers should focus on creating the conditions necessary for constructivist pedagogies to work in public schools.

The findings of this study indicate that state policies related to testing and curriculum are the most significant obstacle. The teachers in this study experienced far more freedom to innovate in courses that were uncoupled from the state's standardized tests—the CTE courses at Central and the capstone projects at Capital. These courses occurred in the upper grades, *after* students had completed the state's core requirements. Considering this, I recommend that state policymakers fund experimental STEM schools that are released from *all* policies related to testing and curriculum, including requirements that limit school designers to project-based approaches to curriculum integration. This would allow STEM schools and their partners to experiment freely with curriculum, instruction, and assessment and to determine what is possible, what is not, and what policies are needed to support student and teacher learning.

At the same time, I recommend that policymakers support the research and design of integrated STEM projects, projects that have a high-degree of usability and include high-quality assessments related to content mastery and skill development. Under current policies in STEM education, teachers are responsible for designing these projects themselves, either alone or in collaboration with school partners. Although this appears to be empowering for teachers, this expectation is unrealistic and burdensome. As evidence of this, the participants in this study were unable to design a project-based and integrated STEM curriculum *while teaching full-time*. In spite of this, the majority remained positive about project-based learning and were anxious to see exemplars of integrated STEM projects that were specific, carefully-developed, and teacher-friendly. Their experience suggests that projects designed by other—including university personnel—will be well-received by teachers, particularly if the projects help them meet policy mandates and are accompanied by high-quality professional development (Blumenfeld, et al., 1994; Krajcik, Blumenfeld, Marx, & Soloway, 1994).

In regards to implementing projects, I recommend that STEM teachers and their partners in higher education come together and revisit project-based learning as an approach to instruction (Krajcik, et al., 1994). The concept of a “design study” or “design experiment” provides a methodology for this professional learning process, which will require teachers and university personnel to work closely together through several cycles of project enactment and reflection (Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Confrey, 2006).

This is not to suggest that teachers are unable to design high-quality projects on their own. The findings of this study indicate that teachers can and will design innovative, effective, and integrated projects in they have the time and resources. For this reason, I recommend policy measures that provide teachers with these things. These policy measures could include seed grants and summer funding for individual teachers and teaching teams who want to design their own projects and project-based curriculum. These funds could also be used for professional learning experiences, including coursework, related to instructional design and curriculum development. There needs to be concrete incentives for teachers to undertake this challenging work (Elmore, 1996). The results of these initiatives could be shared through professional development and training networks, where additional incentives would be available for teacher-trainers. In many innovative schools, including STEM schools, these networks are already part of the organizational culture.

My next recommendation, that policymakers create policy measures that support strong professional learning communities in STEM schools, is based upon Hargreaves (2003) conclusion that professional learning communities are the most effective way to combine the “cultures of excellence and understanding” that exist in innovative schools with the contractual obligations of teaching professionals. Many of the measures recommended by Hargreaves (2003) are already included in STEM education policy, including those related to educational partnerships, the regionalization of professional development and training activities, and school accreditation processes. Others, such as providing teachers with seed money to establish their own professional networks, should be considered. The guiding purpose of these policies should be the professionalization of STEM teaching from within. This will require STEM teachers to advocate strongly on their own behalf—much more strongly than they currently do. With this in mind, I echo Hargreaves (2003) and strongly recommend that STEM teachers organize themselves into a self-regulating professional community and create their own norms and standards of professionalism.

Professional learning communities are no panacea, however. In order to work in the context of STEM schools, these learning communities must be supported by strong leadership and effective administration tailored to each situation. The fact is that schools are in different stages of development and improvement. In schools that are struggling academically—including STEM schools—performance training may be necessary in the short-term for tested subjects such as literacy and math, but these initiatives must be complemented by the creative work of a professional learning community in other areas of the curriculum (Hargreaves, 2003, p. 199). This "complementary growth" model (Hargreaves, 2003) assumes that, over time, performance training will give way to increased teacher autonomy and professional learning. This is a pragmatic approach. Managing this process will require STEM school administrators and teachers to grow the school's professional culture while negotiating standardizing forces from without. The principals who participated in this study indicate that STEM schools are attracting exceptional leaders who are more than capable of managing this internal and external process.

In order to support the work of STEM teachers, I also recommend policy measures that provide STEM schools with professional personnel to serve as liaisons. These liaisons would work closely with teachers and school partners to provide students with research internships on capstone projects and other independent inquiries. The findings of this study indicate that STEM teachers need support for this. A liaison would help. Providing every student with a high-quality research internship during their junior and senior years would be the liaison's primary purpose. Partners would be determined based upon students' research interests and career goals and would involve individuals from higher education institutions, business and industry firms, community organizations, and non-profits. It would take some time for the liaison to establish relationships with individuals and organizations in the local community and in the region. Once they were established, the liaison would leverage these relationships to provide similar experiences to students in other grade levels.

A greener K-12 STEM education.

A central proposition of this study was that environmental projects in STEM schools would reflect a more technocentric view of environmental problems and solutions. This was not the case, and I observed many moments in which the participants addressed the social, moral, and political aspects of environmental issues. These moments were unpredictable, however, and often reflected a teachers' personal values and beliefs rather than any objective criteria. In response, I recommend that STEM teachers and curriculum designers 'green' STEM by incorporating environmental politics into classroom discourse and project activities. Green STEM projects should introduce students to different environmental ideologies—which Stevenson (2007) argues is necessary if teachers are to prepare students to participate in a democratic society—and should provide opportunities for students (and teachers) to identify their personal positions on environmental issues (Dryzek, 2005; Stevenson, 2007). Teachers should consider including corporate and community partners as authentic representatives of alternative positions. Preparing teachers who can effectively manage this will require that teacher educators incorporate environmental politics into the leadership education of pre-service teachers (Neumann, Jones, & Webb, 2012). The findings of this study indicate that these types of projects and activities would be well-received by teachers and students.

The findings of this study also indicated the importance of outdoor experiences related to STEM education. Several of the participants connected their adult interests in science and environmental issues to their childhood experiences outdoors. This suggests that outdoor experiences should be mandatory in early childhood and elementary school programs. In addition to meeting policymakers' goals for engaging students in STEM (President's Council of Advisors on Science and Technology, 2010) these experiences would provide a natural affiliation to balance the rational and managerial approach of the STEM disciplines (Chawla, 2006). The result would be an increasing population of adult environmentalists who are also STEM-literate.

To put this another way, there is a big difference between using the environment as a context for STEM education and using environmental problems as a context for STEM education (Fensham, 2009). Although problems such as global climate change may provide a context for developing STEM knowledge and skills, this type of education much be balanced with experiential approaches if students are to connect what they are learning in school to environmental issues in their local community (Smith & Sobel, 2010). From a ethical and developmental perspective, it is inappropriate to ask students to solve global environmental problems without providing them with opportunities to experience nature directly and in person (Sobel, 1996).

Providing opportunities for students to connect with nature is a pedagogical tradition within science education and environmental education, particularly at the elementary level

(Gruenewald, 2003a; Kohlstedt, 2010; Sauve, 2005; Stebbins, 2012). As such, there are many existing approaches to draw from, but I would offer several recommendations. Research evidence suggests that children develop a relationship with the natural world in stages—from early childhood through middle childhood and into early adolescence (Raymund, 1995; Sobel, 1993, 1996). With this in mind, it is critical that outdoor experiences be incorporated into elementary STEM education programs, including the 800 new elementary STEM schools recommended by the President's advisors (President's Council of Advisors on Science and Technology, 2010). In other words, the high school years are too late to begin for reasons addressed above.

The most important constraints, however, have to do with class and culture. The ecology movement was born to serve middle class interests and has helped reproduce a pastoral approach to nature that is culture-bound and inaccessible to many minority groups (Buell, 2005; Enzensberger, 1974). Recent types of environmental education, which have drawn upon critical theory and ethnography, offer alternative perspectives on what it means to connect students with 'nature' in different contexts, including urban areas (Bowers, 2001; Gruenewald, 2003b; Kahn, 2010; Martusewicz, Edmundson, & Lupinacci, 2011). These types of environmental education add social and cultural analysis to the naturalist project and have the potential to make a green STEM education more relevant to students from non-dominant cultures. A critical analysis of discourses on children and nature suggests that we still know very little about *how* nature matters to students of different races, classes, and cultures (Buell, 2005). Additional research in this area is needed in order to crack the "demographic homogeneity" of the naturalist tradition in science education and environmental education (p. 115). These studies will aid in making green STEM education relevant to students from minority cultural traditions.

A more democratic and equitable STEM education.

Green political theory supports a participative democracy—what Arias-Maldonado (2000) called the “democratization of democracy.” For greens, building a sustainable society should be an open, inclusive, and decentralized process (Dobson, 2007). Based on the findings in this study, I recommend that the STEM education community consider a similar approach to the political process.

This recommendation addresses several levels of STEM education. At the level of federal and state policy, it is crucial that STEM teachers be included in policy discussions. When one looks at the contributors and advisors for official STEM education policy documents (e.g. *Rising Above the Gathering Storm*, *Prepare and Inspire*) it is clear that classroom teachers are not represented by policy discourses on STEM education. While this is not surprising given the elitist and technocratic tradition in educational policy, this lack of inclusion runs counter not only to democratic ideals but to basic theories of the knowledge society, which suggest decentralized networks as the infrastructure of innovation (Castells, 1996; Cooke, 2004). Although policy discourse remains generally rooted in the rational and positivist tradition (Torgerson, 2003), STEM educators have adopted a networked approach to governance in several states. These networks offer a platform for new experiments and innovations in policymaking. To succeed, however, these experiments must include the voices of elementary and secondary teachers and build upon their experience and expertise. This study provides empirical evidence of a deep interdependence among STEM education's stakeholders and the need for a collaborative approach to solving STEM education’s problems (Hajer & Wagenaar, 2003).

Teaching in the knowledge society is an exceedingly complex professional activity (Hargreaves, 2003). Today’s innovative schools and innovative teachers, including those that participated in this study, are often asked by policymakers and administrators to do the impossible and to do so in less time and with fewer resources. As the findings of this study demonstrate, however, this struggle looks very different when one compares schools and classrooms in suburban and urban areas. The findings of this study suggest that STEM teachers who teach in affluent schools experience a level of instructional freedom that STEM teachers who teach in disadvantaged schools in urban areas do not and that this is directly related to the difference in students' performance on state standardized tests. For this reason, creating an "innovation space" for STEM education at disadvantaged schools in urban areas must address the impact of standardized testing on instructional innovations, including those that connect students with STEM professionals and partners.

This is a complex problem. Looking at recent Race to the Top (RTTT) priorities and rewards, it would appear that disadvantaged schools in urban areas are the primary beneficiaries of federal grant monies for STEM and other 'turn around' models. As such, it would appear that lower class and minority students receive more than their share of STEM experiences. As the finding of this study indicate, what counts here is the quality and kind of experiences students are receiving. At Central STEM High School, the majority of STEM experiences were arranged through networks of kinship, community, and culture. These experiences represent the real world of Central's community, but they were far from the world of STEM professionals and high-status careers imagined by STEM education policymakers. This situation needs to be carefully examined, theoretically and empirically. A vibrant democracy depends upon students having equal opportunities to high-quality STEM experiences.

Hargreaves (2003) describes how schools and teachers in poor communities that have low test scores are "thrown into performance-training sects" (p. 191) in order to alleviate public perceptions of failure. Unlike schools in more affluent communities, these schools and teachers experience district intervention and serious restrictions related to culture and instruction. Although test scores may rise, temporarily, these gains are purchased at the expense of students' futures in the knowledge society. The types of inflexible learning environments that are created in the process prepare students that will *cater* to the knowledge society but not students that will *create* the knowledge society (p. 191). STEM schools and teachers are not immune to these actions and effects. The fact that the two schools in this study, Central STEM High School and Capital STEM Academy, prepared students for very different roles in the world economy indicates the justice and equity work that lies ahead.

Closing Remarks

Although this study has drawn upon many sources, Dryzek's (1992) work on political inquiry has very important to this analysis. Drykek (1992) argued that political science had two traditions—one involved in an imaginative and idealist project, to create visions of the "good society." The other tradition, an empirical tradition, focused on "structural necessities" and "real-world constraints." Dryzek (1992) urged his colleagues to combine these two traditions so that they could figure out what "spaces for innovation" remained once political ideals were tempered by empirical evidence.

This dissertation has performed the same, although not necessarily by design. In Chapter Two, I offered an analysis of STEM education policy, which I now understand as a political ideal, tied to economic and vocational goals, that carries instructional and environmental implications. The findings presented in Chapter Five and Chapter Six, from two STEM high schools, describe how teachers interpreted this policy ideal and the spaces for innovation they found within the constraints of a public school district. Some of these spaces were the effects of policy. Others were created by the teachers themselves, including those who had designed the schools. Based upon a comparative analysis of these findings, I provided recommendations. Some of these recommendations were designed to expand possibilities. Some were designed to remove constraints. Some were tied to my own imaginative and idealist project—my vision for a greener, more democratic, and more equitable STEM education.

I hope that the work of combining idealist and empirical traditions continues within the context of K-12 STEM education. Looking forward, I am excited to see policymakers, teachers, and researchers working together to determine what combination of policy measures, school cultures, and pedagogical practices are necessary in order to provide *every* student with a high-quality STEM education.

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Appendix A

Semi-Structured Interview Guide for Teachers

Interview One: Early Childhood and Teacher Training

1. How would you describe yourself to someone who doesn't know you?
2. How were you interested in STEM growing up?
3. How were you interested in nature and the outdoors growing up?
4. Can you tell me a story about a significant outdoor experience you had during childhood?
5. When you were in school, do you remember your teachers using a project-based approach?
6. Where, besides school, did your significant learning take place?
7. Who was with you during these experiences?
8. Why did you decide to become a teacher?
9. Can you describe how you learned to be a teacher?
10. How were you trained to use a project-based approach?
11. How were you trained to teach about sustainability or environmental issues?

Interview Two: Current Teaching Practice

1. If a parent asked you to describe project-based learning, what would you tell them?
2. Can you describe for me a typical class period when you are doing project-based learning?
3. How is project-based learning different from the other kinds of teaching that you do?
4. What supports would you need in order to do project-based learning more often?
5. What environmental problem are you working on during this project?
6. How do you present this environmental problem to your students?
7. How does this environmental problem organize project activities?
8. What do you want your students to learn from this project?
9. What do you want your students to be able to do as a result of this project?
10. Do you think of yourself as doing environmental education?\

Appendix B

Semi-Structured Interview Guide for School Planners

1. Can you tell me the story about how this school came to be?
2. What was the role of teachers in this process of becoming a STEM school?
3. How was the curriculum envisioned?
4. How was instruction envisioned?
5. What models for instruction did you draw from?
6. How closely does what you see today match this vision and these models?

Appendix C

Adult Consent Form for Research
University of Cincinnati
Department: College of Education, Criminal Justice, Human Services
Principal Investigator: Dr. Gulbahar Beckett

Title of Study: Evaluation of the ITEST NSF: CincySTEM Urban Initiative Project

Title of Sub-Study: Green Pedagogy: How STEM Teachers Make Sense of Project-Based Learning and Sustainability

Introduction:
You are being asked to participate in a dissertation study at your school. This study is as a sub-study within a larger research project called the ***CincySTEM Urban Initiative***. The CincySTEM Urban Initiative looks at the implementation of STEM projects and is currently funded by a National Science Foundation grant. This sub-study focuses on STEM projects that address an environmental problem (e.g., global warming, sustainable energy, water quality). Please contact the researcher to ask questions about anything you do not understand.

Who is doing this research study?
The person in charge of this research study is Simon Jorgenson, a doctoral candidate in Educational Studies at the University of Cincinnati. Simon's dissertation supervisor is Dr. Miriam Raider-Roth from the University of Cincinnati. Simon is a graduate research assistant for the main study.

What is the purpose of this research study?
This study collects qualitative data from suburban and urban STEM teachers who teach projects focused on environmental problems such as global warming, sustainable energy, and water quality. This data will be used to answer the following research questions:

1. How do STEM teachers understand and enact project-based learning?
2. How are environmental problems and solutions constructed in these classrooms?

Who will be in this research study?
This project will begin in the spring of 2012 and will end in the summer of 2013. Between 8 and 12 STEM teachers will take part at 2 different schools.

What will you be asked to do in this research study, and how long will it take?
You will be invited to participate in two interviews if you agree to be tape recorded. Each interview will last between 60 and 90 minutes. Interviews will take place in person, at your school, and will be audio taped, transcribed, and presented in aggregate without using personal identifiers. The researcher will also be observing your classroom, writing down what they see in field notes, and looking at classroom documents related to the project, some paper some electronic. Only teachers who have consented to be part of the study will be observed. Data from this study will be used for a dissertation study, publications, and presentations. Your real name will not be used.

Are there any risks to being in this research study?
No, the risk of your being hurt by this research study is probably no more than your would have in everyday life. The researcher does not think there is any risk from your involvement in this research study.

Are there any benefits from being in this research study?
No, you will probably not get any benefit from taking part in this study. But, being in this study may help other educators understand how to teach science, STEM foundations, and technology to other high school students.

Will you have to pay anything to be in this research study?
No, you will not have to pay anything to take part in this research study.

What will you get because of being in this research study?
You will not be paid or given anything to take part in this study.

Do you have choices about taking part in this research study?
Yes, you have a choice in whether or not you want to take part in this research study. If you do not want to take part in this study, you cannot sign this form. If you sign this consent form, you can still decide to not complete any activities during the project. Your participation, or not, will be kept confidential by the researcher but we cannot guarantee that other participants in the project will not talk with one another.

How will your research information be kept confidential?
Your participation, or not, will be kept confidential by the evaluation team because they will be the only ones who have access to the consent forms. Any data will not be identified to an individual and will be discussed in aggregate.

Information will be kept private by:

- using a study ID number instead of the participant's name on all forms and keeping the master list of names and study ID numbers in a separate location from the forms. Evaluation data will be kept at the University of Cincinnati Evaluation Services Center.
- limiting access to evaluation data to the evaluation team and keeping the data on a password-protected computer and forms in locked offices at the University of Cincinnati.
- not including the participant's names on the typed transcripts and erasing audiotapes as soon as they are transcribed.

Your consent information will be kept at University of Cincinnati Evaluation Services Center for three years after the end of the project. After that it will be destroyed, shredded. Survey data will be kept until this time also and these data files will not have identifying data in them. Reports will be kept but no individual data will be identified.

While every attempt will be made to keep data confidential, the researcher will ask for things said in the discussion group to be kept private but people in the group might talk about it anyway. The researcher cannot promise that things sent by internet or email will be private.
Agents of the University of Cincinnati may inspect study records for audit or quality assurance purposes.

What are your legal rights in this research study?
Nothing in this consent form waives any legal rights you may have. This consent form also does not release the investigator, the institution, the sponsor, or their agents from liability for negligence.

What if you have questions about this research study?
If you have any questions or concerns about this research study, you should contact Simon Jorgenson at 349-6540 or simon.jorgenson@uc.edu. The UC Institutional Review Board (IRB) reviews all research projects that involve human participants to be sure the rights and welfare of participants are protected.

If you have questions about your rights as a participant or complaints about the study, you may contact the Chairperson of the UC IRB at (513) 558-5259. Or, you may call the UC Research Compliance Hotline at (800) 889-1547, or write to the IRB, 300 University Hall, ML 0567, 51 Goodman Drive, Cincinnati, OH 45221-0567, or email the IRB office at irb@ucmail.uc.edu.

Do you HAVE to take part in this research study?
No, you do not have to be in this research study. Refusing to take part will NOT cause any penalty or loss of benefits that you would otherwise have. You may start and then change your mind and stop at any time. You may skip any interview questions that you do not want to answer.

You may give your permission and then change your mind and end participation in this study at any time. To leave the study, you should tell Simon Jorgenson at 349-6540 or simon.jorgenson@uc.edu.

Agreement:
I have read this information and have received answers to any questions I asked. I give my consent to participate in this research study. I will receive a copy of this signed and dated consent form to keep.

Participant Name (please print) ____

Participant Signature ____ Date _________

Signature of Person Obtaining Consent _____________________________ Date __________
If the consent form is not signed in the presence of the researcher, this line will be blank.