EXAMINING SMALL ‘C’ CREATIVITY IN THE SCIENCE CLASSROOM:
MULTIPLE CASE STUDIES OF FIVE HIGH SCHOOL TEACHERS

Dorothea Shawn Lasky

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Supervisor of Dissertation:

Susan A. Yoon, Associate Professor of Education

Dean, Graduate School of Education:

Andrew C. Porter, Dean and Professor

Dissertation Committee:

Susan A. Yoon, Associate Professor of Education
Stanton E.F. Wortham, Professor of Education
Al Filreis, Kelly Professor of English
R. Keith Sawyer, Associate Professor of Education, Washington University
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Dedication

I dedicate this dissertation to my father, Judge Herbert Lasky.
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ABSTRACT

EXAMINING SMALL ‘C’ CREATIVITY IN THE SCIENCE CLASSROOM:
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Dorothea Shawn Lasky
Susan A. Yoon

As the US continues to strive toward building capacity for a workforce in STEM fields (NSF, 2006), educational organizations and researchers have constructed frameworks that focus on increasing competencies in creativity in order to achieve this goal (ISTE, 2007; Karoly & Panis, 2004; Partnership for 21st Century Skills, 2007). Despite these recommendations, many teachers either do not believe in the relevance of nurturing creativity in their students (Kaufman & Sternberg, 2007) or accept the importance of it, but do not know how best to foster it in their classrooms (Kampylis et al., 2009). Researchers conclude that teachers need to revise their ideas about the kind of creativity they can expect from their students to reflect the idea of small ‘c’ versus large ‘C’ creativity. There is a dearth of literature that looks closely at teacher practice surrounding creativity in the US and gives teachers a set of practical suggestions they can follow easily. I examined five case studies of teachers as they participated in and implemented a large-scale, NSF-funded project premised on the idea that training teachers in 21st century pedagogies, (for example, problem-based learning), helps teachers create classrooms that increase science competencies in students. I investigated how teachers’ curricular choices affect the amount of student creativity produced in their classrooms. Analysis included determining CAT scores for student products and continua scores along the Small ‘c’
Creativity Framework. In the study, I present an understanding of how teachers’ beliefs influence practice and how creativity is fostered in students through various styles of teacher practice. The data showed a relationship between teachers’ CAT scores, framework scores, and school context. Thus, alongside CAT, the framework was determined to be a successful tool for understanding the degree to which teachers foster small ‘c’ creativity. Other themes emerged, which included teachers’ allotment of time and small group collaboration, how science teachers valued creativity, the importance of transdisciplinarity, teachers’ student knowledge, and school context. This study contributes to the growing body of literature surrounding teacher practice and creativity by revealing a clear and concrete set of practical recommendations based on the Small ‘c’ Creativity Framework.
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1. Introduction, Significance, and Research Goals

1.1 Chapter Overview

This chapter presents an introductory argument for studying creativity within science, technology, engineering and mathematics (STEM) classrooms through a small ‘c’ creativity framework. Research goals for this study are outlined.

1.2 Introduction

The US is facing an increasing crisis in preparing its students for science, technology, engineering and mathematics (STEM) careers. In 2003 alone, there were 1.3 million engineering and engineering technology jobs in the U.S. that lacked trained people to fill them (NSF, 2004). Furthermore, the federal government states that we will need 15 million engineers and technology workers by the year 2020 (Westermo, 2004). As the US continues to strive toward building capacity for a highly educated workforce in STEM fields (NSF, 2006), educational organizations have constructed frameworks that outline critical STEM literacies that need to be cultivated in K-12 education in order to achieve this goal. A common element amongst these frameworks is a focus on increasing competencies in creativity and innovation (ISTE, 2007; Partnership for 21st Century Skills, 2007). Researchers have also suggested that creativity has a place in school in order to help increase STEM careers (Karoly & Panis, 2004; Westermo, 2004).

For the past one hundred years, education theorists have tried to understand the processes by which students think creatively (Bergon, 1946; Buermeyer, 1954; Dewey, 1934). The importance of understanding creativity in the context of education has
become even more salient in recent years as several prominent organizations and theorists have explored the need to promote this skill in order to participate in 21st century society (Craft, 2005; Kaufman & Sternberg, 2006; Partnership for 21st Century Learning Skills, 2007; Sawyer, 2006). There are multiple reasons to focus on creativity in the science classroom. For example, as Sternberg (2007) argues, creative thinking in the field of science can lead to a better world, as fresh ideas lead to the construction of new and useful products that make our lives function more easily. Karoly and Panis (2004) found that in order to develop students with increased science skills and focused on STEM careers, science teachers should learn to construct classroom curricula that promotes creativity for all learners. In addition, because science is seen as a collaborative practice that produces new ideas in social contexts (Lemke, 2001), the essential collaborative practices by which many contemporary theorists suggest creativity is best fostered (Fleith, 2000; McWilliam & Dawson, 2008) has a natural fit in science classrooms.

1.3 Significance

Despite recommendations to incorporate creativity in schools, many teachers either do not believe in the relevance of nurturing creativity in their students (Kaufman & Sternberg, 2007) or accept the importance of it, but do not know how best to foster it in their classrooms (Kampylis et al., 2009). Researchers conclude that teachers need to revise their ideas about the kind of creativity they can expect from their students to reflect the idea of small ‘c’ versus large ‘C’ creativity. Small ‘c’ creativity values the kind of thinking that produces new ideas in the learner, but is not necessarily historically
important to the field or domain, like thinking that is large ‘C’ creative (McWilliam & Dawson, 2008).

 Researchers, like McWilliam and Dawson (2008) and Boden (cited in Craft, 2001), contend that small ‘c’ creativity is beneficial to teach in schools because it connects learners to knowledge that will solve real world problems. Boden (2001) discusses that teachers should allow their students to explore ideas that are new to them and free from the constraints of already accepted ideas in the field. She also maintains that teachers should allow students to explore ideas that cross the field-specific learning environments (i.e., by connecting ideas across disciplines, like bringing an idea from Chemistry class into a History class). This permission, Boden (2001) reasons, allows students to think of new ideas not are not only new to them, but that potentially no one else may have thought of before and can aid society’s problems. McWilliam and Dawson (2008) posit that small ‘c’ creativity is important to our world, which is increasingly affected by the digital economy and ‘creative capital.’ They cite scholars Florida and Goodnight (2005), who wrote in the Harvard Business Review, “a company’s most important asset is not raw materials, transportation systems, or political influence. It’s creative capital.” They define creative capital as a company’s ability to have a group of creative thinkers who can respond to the changing economic and digital landscape. Increasing students’ small ‘c’ creativity skills, they assert, prepares them to be productive members of our future society.

 There is a dearth of literature that looks closely at teacher practice surrounding creativity in the US and gives teachers a set of practical suggestions they can follow easily that helps them foster small ‘c’ creativity. Research in the field either looks at
teacher beliefs regarding practice without looking at their practice (Fleith, 2000; Newton & Newton, 2009) or provides theoretical constructs without looking at practice (McWilliam et al., 2008; McWilliam & Dawson, 2008). This study attempts to contribute to a growing body of literature surrounding teacher practice and creativity. Building on this research, I completed a set of case studies of five US high school science teachers over the course of 24 months. After an extensive literature review of research in creativity seen through the lenses of psychology, art, business, science, and complex systems theory, I have constructed an analytical framework. This framework explains that teachers who create a learning environment that fosters small ‘c’ creativity: 1) Support divergent thinking that is grounded in the lesson’s activities or concepts; 2) Accept learning artifacts that are novel and relevant to the lesson; 3) Nurture collaboration among small group members in which individual kinds of creativity within the group are supported; 4) Provide choices on what is an acceptable response (learning artifact or discussion point) to a lesson and; 5) Include lesson guidelines that enhance, rather than restrict, learning and self-confidence.

The main strategies of this study were to investigate how teachers do or do not cultivate the development of creativity in their students by studying teacher beliefs, curricular choices, instructional approaches, and student outcomes resulting from these pedagogical activities. The first goal was to use the small ‘c’ framework as a lens in both data collection and evaluation, so as to give practical cases in conjunction with the framework and thus, add to the body of literature from which it originates. In taking a close look at the practice of a range of educators, a second goal was to uncover how well teacher beliefs match up with their practice and reveal areas that support or constrain the
development of creativity. The overarching goal of the study is to provide educators with a set of practical recommendations that encourage creativity and in turn, potentially expand the group of high school students who intend to enter STEM careers.

1.4 Research Goals

In this study, I sought to address the following research questions:

1. To what extent does a small ‘c’ creativity framework reveal how teacher practice allows for creativity to occur in classrooms?

Specifically, I used the analytical framework I developed from my literature review as a lens to view what is occurring in the classrooms I observed.

2. How do science teachers’ beliefs about creativity and their practical strategies interact to support creativity in science classrooms?

Specifically, I explored teacher beliefs about the importance of promoting creativity in their students, how they conceptualize the importance of 21st century learning in science, their understanding of creativity as a characteristic that can be cultivated in all learners, whether they see themselves as creative, and whether an understanding of creativity was part of their teacher training. I also investigated ways in which they create and nurture creative learning environments, how important creativity is to their practice (especially in terms of what activities and theories they employ in their classrooms), and how important creativity is to the science concepts they are
teaching. This also added to my understanding of gaps in teacher beliefs and how these beliefs might be improved to support practice.

3. If students are judged to be more or less creative within the teachers’ classrooms, what are some possible relationships between their exhibited creativity and teacher practices and beliefs?

Specifically, I looked at the differences between the teachers’ classrooms and how teachers’ beliefs are related both to their practice and the amount of creativity students exhibit in their classrooms. This investigation intended to also lend support for identifying where gaps in teaching for creativity exist and in turn how these might be improved.

1.5 Summary

Many researchers and policymakers have long realized the importance of fostering creativity in the science classroom. This study attempted to consider teacher practice and creativity in the context of science, so as to help add to the growing body of literature that gives practical recommendations for teachers. It uses a small ‘c’ creativity framework to better understand real world practice. The next chapter will provide a review of the related literature and will lay the foundation for the study’s analytical framework.
2. Literature Review

2.1 Chapter Overview

The intent of this chapter is to review the literature surrounding creativity and education. It delves into a series of disciplinary lenses that have been a context for considering creativity in the classroom. The chapter includes the following sections that discuss creativity and education through a psychological lens, the argument between domain specificity and domain generality in creativity scholarship, creativity and education through an arts lens, creativity and education through a business lens, teacher beliefs and practice about creativity in the 21st century science classroom, creativity and education through a complex systems lens. The literature review concludes with a discussion of creativity and complex systems theory in the science classroom. The chapter ends with the study’s Small ‘c’ Creativity analytical framework and describes how theories were synthesized in the literature to construct it.

2.2 Introduction

Before undertaking this research, it was important to look at the ways in which teacher practice and creativity has already been discussed in the literature in other domains—psychology, art, and business. Through the literature review, I will consider both the benefits and the limitations of such discussions. I will show that while there are practical recommendations gleaned from studies in these three domains, they are not appropriate for the high school science classroom and do not give detailed recommendations that are necessary for the time constraints of today’s teachers. The
section immediately following will focus on a review of the education literature that views issues surrounding creativity through a psychological lens.

2.3 Creativity and Education: A Psychological Lens

For a large part of the 19th century, creativity research was premised on the assumption that creativity was a skill situated in traits of individual learners and likewise, tied closely to learners’ psychology and cognitive processes. Just as an IQ test is used by educators to assess an individual’s innate intelligence, a Creativity Metric was developed to assess the amount of creative potential an individual possesses. E.P. Torrance (1974) is a well-known scholar of creative assessment and his tests have been widely used as metrics for measuring creativity in learners (Arieti, 1976). His development of The Torrance Test of Creative Thinking has helped teachers determine how creative their learners are and was intended to better equip teachers to aid creative learning in their classrooms. The test measures, among other characteristics, the amount of fluency, originality, elaboration, and openness in learners. Similar to Torrance, other researchers, like Guilford (1957), developed creative intelligence metrics. Guilford’s metric measures the amount of divergent thinking in learners, among other traits. His test has also been widely used in classrooms.

Researchers, using a psychological lens in their study of creativity, looked closely at anecdotal accounts of the learning processes of individual creative geniuses (Guilford & Hoepfner, 1971) to understand creative traits and processes. Inspired by work like Guilford and Hoepfner (1971), Torrance (1974) created a test that measured the personality traits of learners, like the trait of intrinsic motivation. Intrinsic motivation, in
his definition, was the ability for learners to follow a creative project to its completion by an internal drive, in spite of the world around him or her. Byrd (1986, as cited in Cropley, 2001) developed a creativity matrix that was undoubtedly influenced by earlier work on creative intelligence by Guilford and Hoepfner (1971), called The Creatrix Inventory, which integrated a measurement of both cognitive processes and noncognitive processes or traits, like motivation. All of this research was done with the aim of trying to determine a finite set of traits that all creative individuals share—however multidimensional. There seems to be no true consensus among this work for a set of universal personality traits (Arieti, 1976). Researchers’ exploration into personality traits, especially intrinsic motivation, suggests that they believe there is some a priori quality of personality in creative learners that makes them yearn to create that can be measured and understood using the tools of psychology and psychological testing (Arieti, 1976).

Creativity research in the 20th century used a psychological lens to understand creative learning in educational contexts. Some metrics researchers still continue their research using a psychological lens. Taking the lessons of Torrance’s (1974) and Guilford’s (1957) work, more contemporary creative metrics researchers have spent much of their careers determining ideal methods of assessing creativity in students (Epstein, Schmidt, & Warfel, 2008; Miller, 2001). Some have even spent careers determining the reliability of past methods, like Kim’s (2007) work on the reliability of Torrance tests (as cited in Tan, 2007). Even as all of these scholars have set upon finding metrics for measuring creativity (Carroll, 1941; Taylor, 1947; Thurstone, 1938; as cited in Guilford & Hoepfner, 1971) in order to develop tools for teachers to determine which of their students have the greatest amount of creative potential, some creativity
researchers have done work in delineating the creative process and naming these steps and stages.

During the first half of the 20th century, theorists like Wallas (1926), Rossman (1931), Osborn (1953), and Stein (1967), attempted to understand creativity as happening in a series stages within a creative learner (as cited in Arieti, 1976). For example, Wallas's (1926) stages included: preparation, incubation, illumination, and verification (as cited in Arieti, 1976, p. 15). Worded slightly differently forty years later, Stein's (1967, 1974) three stages were “the stage of hypothesis formation, the stage of hypothesis testing, and the stage of communication of results” (as cited in Arieti, 1976, p. 16). Looking at Wallas's (1926) and Stein's (1967) understanding of the creative process in the stages mentioned, both scholars thought that a creative learner was prompted by something externally, processed it internally, and attempted to communicate it back to the outside world. Other theorists tried to pin down the language of the stages of the creative process. Taylor (1959) thought of creativity as happening not only in stages (he agreed with Wallas's stages), but also in types. His types included “expressive creativity, productive creativity, inventive creativity, innovative creativity, emergent creativity” (as cited in Arieti, 1976, p. 16). His belief in the simultaneity between types and stages of creativity shows a theoretical instinct to apply intelligence metrics and psychological metrics on creative processes (Guilford, 1967; Torrance, 1974).

These sets of creative cognitive processes were seen through a psychological lens, in an attempt to make sense of creativity on the scale of the individual learner. Certain areas of the research that arose out of this lens are helpful to a contemporary application of creativity in the classroom. For example, at one point in the history of creativity
metrics and stages scholarship, researchers' delineation of the specific traits, qualities, and behaviors of creative individuals influenced research into creativity metrics and the two strains of research converged on the Guilford's Alternative Uses Task Test for Creativity. Guilford's (1957; 1967) belief that divergent thinking is a hallmark of creativity resulted in a development of the test in which teachers could measure creativity in their students by asking them to list as many possible uses as they could for a household item, like a brick or paperclip. The test measured divergent thinking and measured six traits of students' work: Creativity, Recognition of implications, Spontaneous flexibility, Adaptive flexibility, Originality, and Fluency (Guilford & Hoepfner, 1971). In creating such a test, Guilford helped to progress thinking towards practical implications for creative teaching. His metric has a free enough format so that it is a worthwhile tool for measuring creativity in the various kinds of learners a teacher might encounter in a classroom.

No matter how multi-layered or complex creativity metrics and stages research has gotten, the wide array of terminologies and sets of creative stages suggests that it has been difficult for every creative learner to fit completely into a universal schema of creative processes. Despite the benefits of Guilford's (1967) test, to this day, there is still not one universal creativity metric that educators can use as a tool to recognize creative learners in their classroom. An assumption underpinning the creativity studied within a psychological lens is that the cognitive processes of an individual learner determine how creative he or she is or can be. The work in this strand of the literature has been rigorous, but it has been, at least in part, misguided. Even as this strand of research has given helpful terminologies for creative cognitive process, it has done little to give practical
recommendations to teachers who want to foster creativity in their classrooms and in all of their students.

2.4 Domain Specificity versus Domain Generality

Arising from the discussion of creativity and education within the field of psychology, there is a longstanding conversation regarding domain generality versus domain specificity in creativity. For example, researchers have questioned if creative thought processes behave the same way in all individuals (domain general), or if they are distinct depending on what disciplinary the creator is working within (domain specific). Much of this discussion emerges out of the field of psychology’s interest in determining similar mental steps or stages within creative learners (Guilford, 1967; Taylor 1959). To date, there is no consensus among scholars as to whether a purely domain general or domain specific framework should be used to understand student creativity. Some current researchers (Hee, 2011) believe that a domain general framework is still relevant for 21st century educators in understanding their students’ creative thought processes, while other scholars like Baer (2011) contend that the whole argument between the two theories serves as a kind of distortion. In Baer’s view, strictly domain-specific theories can be misleading, since creativity is nurtured when teachers use a domain-by-domain scale understanding of the creative potential in their students within domain-specific classes (i.e., by guiding their teaching practice towards fostering their students’ small ‘c’ creativity within specific subjects). Plucker and Beghetto (2004) explain that creativity has both specific and general components. They assert that creativity changes with the
social context that develops as one goes from childhood to adulthood (i.e., becomes more
domain specific as the individual interacts more with the social world as an adult).

In their chapter “Creative Problem-solving in Physics, Philosophy, and Painting:
Three Case Studies,” Crosby & Williams (1987) explain that creative processes among
artists do not diverge too much from creative processes among scientists (as cited in
Amsler, 1987). Moreover, they attempt to make standards for what is considered creative
in both. To them, it is not enough for a creative act to be novel or innovative, it must also
be germane to the field or discipline it is part of and be determined to be influential to
that field by a community of experts within that discipline. According to them, individual
thought processes may be similar whether a person is creating a new product in Calculus
or painting, but because a group of experts in the field judges its value within a particular
field, creativity is always also domain specific.

Cropley (2001) argues for this type of domain specificity. Because products and
ideas are created within creative fields that require specialized knowledge, there is always
domain specificity as a community of experts judge products’ value within the field.
Likewise, since fields have their own communication systems or languages (Cropley,
2001; Csikszentmihalyi, 1996), there is always an element of domain specificity to what
is being created. Not only do creative products and ideas have to be validated by experts
with knowledge of the field, but creative individuals must also possess an ease of
expression in the particular field they are creating within in order to communicate their
new ideas effectively.

Other researchers reason that the processes of learners are complicated
interactions between an individual and the field. Ludwig’s (1998) four-dimensional
framework demonstrates that domain specificity comes into play as it interacts with complex processes within individuals. As he explains, there are four dimensions for describing fields: impersonal versus emotive; objective versus subjective; precise versus imprecise; formal versus informal. According to him, STEM fields tend to be more impersonal, objective, precise, and formal; whereas fields within the arts (painting, design, writing, etc.) are more emotive, subjective, imprecise, and informal. Similarly, Hong and Milgram’s (2010) three studies of the relationship between domain generality and domain specificity creativity show that although both contribute to the development of creative thinking, schooling and culture affects domain-specific thinking more than domain-general thinking. They connect their findings to Simonton’s (2002) idea that some domain generality exists in creative thinking in all learners, but that societal factors come to play in creative output within specific fields.

Although there is no true consensus and the discussion within the literature is likely to continue, it seems that many scholars do agree that creativity is not purely domain general or domain specific. These scholars contend that the creative process is an interaction of both the creative individual and the field to which they are creating within. This intersection connects well to an application of complex systems theory to the field of creativity, which will be discussed in a later section in this chapter. In the following section, I review how creativity in education has been understood through an arts lens.

2.5 Creativity and Education: An Arts Lens

Creativity is often thought of in the context of art, so much so that even contemporary scholars often use the terms “creativity” and “art” synonymously (Perkins,
1994). Historically, arts education theorists have defined creative processes in vague, mystical terms commonly connected to describing art making. Buermeyer (1954), a student of John Dewey, described the creative process in terms of, "in mystical states of mind...we are conscious of an expansion of our personality thought union with something not ourselves, but this union is felt and not seen" (p. 76). Dewey (1934) offers equally mystical and vague advice to arts educators as he investigates the creative process in *Art and Experience*, in which he explains that the spirit of both the artwork and artist commingle in the process of art making. Sartre (1940) also couches creativity in a mystical context, as he writes that creativity involves a learner having "visions" (p. 37). Not only does Sartre explain the process of creativity vaguely and spiritually, he gives no explanation where these visions are coming from. Such creative thoughts seem to originate from nowhere within the real world and cannot be enhanced or predicted by a learning environment. While there is charming mystery in such explanations of creativity, they give no practical recommendation for teachers to help their students engage creatively in their classrooms.

More recent arts education literature sees creativity similarly to earlier arts education scholars, as a set of processes that are fostered by a vague set of circumstances and predilections in special learners. In *Creativity: Psychoanalysis, Surrealism, and Creative Writing*, Brophy (1998) uses the lenses of psychoanalysis and surrealism to explain how the creativity in artists (creative writers specifically) is connected to muddled unconscious processes. Using the work of the French Surrealists, such as Andre Breton’s famous work *Nadja* as an example, Brophy explains how the work of great artists relies on their ability to tap into the uncontrollable part of their minds—their
unconscious. The crux of Brophy’s argument is taken from Freudian ideas of creative processes, which rely on the instability of the unconsciousness of creative individuals. Likewise, in his case study of six creative geniuses, Gardner (1993) attempts to distinguish their creative processes in order to find one universal set of processes among them, but simply concludes that their creative processes are complex confluences of random life experiences and personality traits. None of the occurrences of creative genius could be replicated in a social learning system, like a school. In both Brophy’s (1998) and Gardner’s (1993) studies, the ability to be creative relies in the potential of vague and complex processes in individuals. This view of creativity gives no practical recommendations for teachers to teach creativity. Thus, it is not helpful for promoting curricula to enhance creativity in 21st century classrooms, because it does not consider that creativity can be fostered in all students.

Arts educators, often in a defensive stance of their maligned place within schools, simply make the case that the arts foster creativity without taking the time to explain how all students might learn to be creative versus just a special few. This is due to the fact that many arts educators are forced to defend a correlation for the arts and many attractive deliverables (like increased creative thinking skills, as well as test and SAT scores) in order to maintain their place in the public school curriculum (Winner & Hetland, 2007). However, their argument often stops at the proof that students who are exposed to the arts produce more creative products and ideas (i.e., are more creative than other students) without explaining what the arts do to tap into learners’ creativity. For example, Deasy et al. (2002), through research with the Arts Education Partnership, showed how arts programs produced creativity in students, but measured only the effect and not the causal
relationship of the programming. Similarly, Eisner (1987) describes how visual arts curricula leads to increased creativity in students, but makes no attempt to define what about the curriculum leads to creativity other than it is in the arts. Champions of Change, edited by Fiske (1999), gives accounts of the work of some of our country’s best arts educators. The argument in the text is that the arts engender the deepest kind of learning, because they promote creativity. However, the process by which they do is unclear and there is no practical advice for educators, except only to always offer arts curricula to students. The policy-driven, defensive stance of recent arts education literature surrounding creativity is understandable, but not helpful. Without clear guidelines, it may not be easy for today’s busy teachers to implement arts-based curriculum that promotes creativity when they are not sure exactly what to do.

There is one thread of the literature involving the relationship between creativity and learners’ imaginations that does give some practical recommendations for teachers. Greene (1995) explains how arts learning can free up imaginative thinking in students, which leads to creativity. She asserts that the open-endedness of arts activities can tap into learner’s individual imaginations, which gives them agency in their learning and allows them to think of new ideas. Allam (2008) studied the use of filmmaking as a creative learning tool. She found that an arts curriculum, focused around making films, allowed students to tap into their imaginations and subsequently, their creativity. The filmmaking curricula she studied did so naturally by allowing for blocks of independent time. In a study of American and Chinese college-age art students, Niu and Sternberg (2001) found that open-ended tasks were best for fostering artistic creativity, because they gave students time and space within a class to access their imaginations. Arts
educators often support freethinking in their classrooms and this leads to creativity in students. In practical terms, this can be helpful in giving advice for 21st century educators, as one concrete thing they can do is give their students time blocks within the classroom to explore their own ideas. Unfortunately, however, there is little direction about what to do during this time. In the next section, I will consider some of the affordances and constraints of viewing creative learning through a business lens, another common disciplinary lens used in the study of creativity and education.

2.6 Creativity and Education: A Business Lens

Corporate trainers, learning specialists, and business leaders often tout the benefits of creativity for burgeoning businesses (de Bono, 1970; Penaluna & Penaluna, 2009). Daniel Pink’s (2006) *A Whole New Mind: Why Right-Brainers Will Rule The Future* has been a widely popular book in the business community for its emphasis on cultivating creativity in corporate organizations. Pink’s argument in the book is that the future of business lies in the ideas of creative individuals and that all people have the power to become creative individuals. He outlines six kinds of thinking that learners can engage in to stimulate their creativity: design, story, symphony, empathy, play, and meaning. He presents a whole host of games and exercises to strengthen these types of thinking, many of which could work well in a classroom. For example, Pink favors computer simulations, in which learners maneuver treacherous digital conditions in order to progress to new levels, as perfect ways to build creative thinking skills. Other suggestions he gives are to tell jokes in learning environments and then to parse out what makes them humorous and to engage in role-playing games in whatever domain is
appropriate to the learning environment. Sir Ken Robinson is another key figure in creativity education within a business context. In “How Creativity, Education, and the Arts Shape a Modern Economy,” Robinson (2005) asserts that a viable American workforce needs an educational system that favors creativity, because a mercurial global economic market, fueled by the intellectual demands of using technology daily, necessitates developing adaptive thinking in workers. Robinson argues that this is due to the fact that never before in history has the global economy been in such a persistent state of change. According to him, 21st century workers need to be trained to thrive in times of change, so as to maneuver in such a fluctuating economy. For Robinson, teaching students to be respond creatively to changeable situations and to be comfortable with risk strengthens the economy.

Other researchers contend that teaching students to be creative is important because it ensures their own survival in a temperamental global market. Hargreaves (2008) writes about how it is the ethical duty of university educators to create classrooms that promote creativity in students to prepare them to be independent thinkers in the workforce. A crucial component of Hargreaves’ argument is similar to Robinson’s in that teaching students how to take risks in their thinking promotes creative thinking, which encourages their minds to thrive during times of change. In their study of university engineering students, Silva et al. (2008) investigate how entrepreneurship is inherently creative, despite the fact that there is no agreed upon method of understanding or teaching creativity. A recommendation they give for educators is to promote creative thinking as students create products for the global economy, while developing an interdisciplinary understanding of the market to which their products will be sold in.
They also explain other benefits of a creative curriculum for students, which include: learning to be comfortable creating for complex environments, using real products in real-world environments, and utilizing the freedom to build and test new products on their own. By giving students agency to be creative independently, Silva et al. argue, they will be confident to be creative in real-world corporate environments.

While Pink (2006), Robinson (2005), Hargreaves (2008), and Silva et al. (2008) discuss the benefits of helping all students learn to think more creatively so as to increase the amount of world citizens who are able to maneuver the global market, other researchers, like Clark (2009) and Zampetakis (2008) have focused on creativity specifically in a business learning context. Clark (2009) illustrates the ways in which creativity can be taught to business students, despite the fact that there is no agreed upon set of methods or definition of creativity. He explains that the best thing for educators to do is to foster enterprising behavior in students, which includes a learned ease of developing products for a changeable economy. To him, enterprising behavior includes the ability to think and react adaptively, which is much like creative behavior.

Zampetakis (2008) studied 199 Greek business students and found that creativity was related to proactivity (the ability to take charge of a situation) in young entrepreneurs and that creativity was a key component of the entrepreneurial process. According to him, these findings suggest that creativity should be fostered in business learning environments, because it teaches leadership (a hallmark trait of entrepreneurs).

Business educators recommend creativity as a trait to foster in business people and business students, due to its relevance to a changeable contemporary economy that demands intellectual adaptability. Their recommendations and practical suggestions can
be helpful for K-12 educators looking to foster creativity in 21st century learners, because they are geared towards the real-world workplace that most students will enter. However, because many of the recommendations are written for business learning environments and not other educational ones, there is the possibility that teachers might find them hard to translate into K-12 classrooms.

2.7 Creativity and Education: Summary of Psychological, Arts, and Business Lenses

Three domains—psychology, art, and business—through which creativity has been applied have been reviewed thus far, in order to reveal plausible methods for understanding how creativity can be applied in learning contexts. However, none of these lenses establishes a set of practical curricula for supporting creative learning in classrooms in order to combat our current science education crisis. A psychological lens gives teachers metrics, but metrics only go so far in giving teachers lesson plans for nurturing creativity daily in their classrooms. An arts lens emphasizes imaginative thinking and supports the arts in schools, but it does not directly allow students to think creatively in a science context. An arts lens also ultimately defines creativity in vague terms, which does not aid science teachers. In addition, scholars tend to now think of creativity as happening across all disciplines taught in schools, not just in the context of art which was the traditional lens of 20th century creativity studies (Kaufman & Baer, 2005). Understanding creativity through a business lens promotes adaptive thinking for the sake of a mercurial world economic market, but it does not address how adaptive thinking is relevant to the sciences. Simply put, teachers need to view creativity in the
context of science in order to understand how they might create science lessons that encourage creativity as none of the other disciplinary lenses provide sound practical advice for them. Researchers recommend science teachers see creativity as something that can be fostered in every learner (McWilliam & Dawson, 2008; Newton & Newton, 2009) and teachers need practical suggestions that they can use everyday in the classroom. Below I explore the current body of literature in science education that is related to creative learning.

2.8 Teacher Beliefs and Practice: Creativity in the 21st Century Science Classroom

Studies of creativity in a K-12 context have revealed challenges in developing creativity in the classroom, most notably related to teachers’ lack of skill and understanding. Kaufman and Sternberg (2007) report that many contemporary educators believe that creativity is “irrelevant to educational practice” (p. 55). In recent years, several studies have delved into the deeper aspect of teacher beliefs regarding creativity. Kampylis et al. (2009) surveyed 132 in-service and prospective teachers regarding their views about creativity. Most responded that they believed it was the teacher’s role to cultivate creativity in students, but that they themselves did not know how to cultivate creative thinking skills and practices. Newton and Newton (2009) analyzed UK science teachers’ conceptions of creativity and found misconceptions in teachers’ understanding of creativity and how to foster it. For example, many of the teachers they looked at did not understand how imaginative thinking is involved in the scientific process, whereas many scientists agree that it is. Also, some of the teachers were only able to conceive of
creativity as occurring in an arts context and not in a science classroom. To address teacher misconceptions, the researchers argued that 21st century science teachers should start to see creativity in the sciences more in the realm of “productive thought,” i.e., a combination of creative and critical thinking, versus irrelevant thinking. For example, if students are conducting science experiments in class, if a student has a new and divergent hypothesis for a natural phenomenon, this is both productive thought and creative. In this situation, according to Newton and Newton’s ideas about 21st century creativity, a teacher should allow his student to test out this new hypothesis in order to further his creative thought.

One study has attempted to connect teacher beliefs and practice. Fleith (2000) looked at teacher and student beliefs regarding ways in which curricular choices contribute to creative learning. She interviewed seven elementary school teachers and thirty-one students in the third and fourth grades in Connecticut about their perceptions regarding creativity and learning. Themes that emerged from the interviews indicated that teachers and students agreed that a classroom that helps to support creativity: gives students choices, embraces divergent ideas, stimulates self-confidence, and tends to give assignments that are tailored to students' strengths and interests. They also concurred that in an environment that stifles creativity: student ideas are disregarded, teachers try to manage the environment too much, and class time is excessively structured.

There are a few recent studies that have looked exclusively at teacher practice and creativity. McWilliam and Dawson (2008) culled together this recent literature and created a framework for what constitutes teaching for creative learning. According to them, creative teaching occurs when the teacher acts in a facilitator’s role, group
members work collaboratively and are self-organized, and there are curricular constraints that promote new ideas rather than inhibit them. They also delineate between small ‘c’ and large ‘C’ creativity, explaining that large ‘C’ type of creativity is rare and found only in certain individuals who become influential in their fields. These individuals are more in line with how creative genius has been thought of historically. In the case of students who exhibit large ‘C’ creativity, constructing a specific learning environment just for them is not important, as the process by which their creative leaps happen is not very well understood. It also tends to be mystically explained, in a similar way that past arts education theorists, like Dewey (1934) and Buermeyer (1954), described creative individuals. Small ‘c’ creativity, on the other hand, is a type of creativity that every learner is capable of engaging in. It refers to a kind of creativity in which the ideas of the learner may be new to them, but are not necessarily of historical importance to their fields. An example to differentiate between the two types of creativity is the difference between a teacher having a scientific creative genius in her classroom, like a young Einstein, and a classroom full of students with creative potential. The young Einstein is large ‘C’ creative and all of the students in the class have the potential to be small ‘c’ creative. The young Einstein will come up with new theories that advance science, but teachers should not view only his new ideas as creative. All students can be small ‘c’ creative, because all students can have new ideas that advance their own thought about a particular topic or idea. As McWilliam and Dawson (2008) contend, small ‘c’ creativity can and should be encouraged in every student through social, collaborative learning.

The work of a few researchers emphasizes how advanced knowledge of scientific principles is important for fostering creativity. A recent dissertation study (Franske,
2009) looked at problem-solving pedagogy in high school science classes and found that it increases creativity in students because students can ground their new ideas in real-world concepts. Franske (2009) studied students in three Minnesota high schools and found that creativity in engineering classes was directly connected to how many advanced science classes students had already completed. He also found that problem finding scenarios (where students pinpoint the engineering problem and try to find ways to solve it) had a great effect in increasing student creativity. From Franske's work, 21st century teachers might consider increasing problem finding scenarios in their engineering and science classes. Ramadas (2009) surveyed some of the current ideas in science education literature that visual and spatial models help students relate to real-world scientific research and foster creativity. According to Ramadas (2009), building mental models of the research real scientists engage in is key to both science and creative learning. Taking these recommendations into consideration, science educators might use problem-solving pedagogy and visual and spatial models (aided by 21st century technology) grounded in real-world concepts to help build creative science learning in their classrooms.

Lee and Erdogan (2007) studied twenty science teachers in Korea, who were part of a professional development program that promoted creative learning. The pedagogy the teachers learned in the program encouraged student inquiry and collaborative learning. For example, students were told to ask their own questions during lessons and teachers' roles were to facilitate discussion and debate among students. They also trained seven science teachers to revise their teaching of science concepts through a context of the human experience. The approach was called Science-Technology-Society teaching.
This type of teaching translated into curriculum with an emphasis on open-ended inquiry and problem-driven activities. After asking these teachers to employ such an approach, they found that the 591 students studied not only had more positive attitudes towards their science classes, but were also more creative, i.e., thought of new ideas that were grounded in the science concepts being taught. Clearly, the two kinds of learning—science and creativity—worked well together in the context of problem-based, open-ended curriculum. As the researchers conclude, the creativity the students exhibited in the science classrooms was relevant to the ideas being taught. Thus, the combination of the two—science and creativity—positively influenced each other.

In an article by McWilliam et al. (2008), the researchers contend that incorporating creativity in science classrooms has the ability to keep students pursuing careers in the science fields. They give five hypotheses for why this is the case, which include the idea that creativity in science classrooms promotes active tasks versus a passive consumption of core concepts, that it is not the rigor of scientific concepts that disengages students from the subject, but boredom (something that is combated by creative learning), that creativity is integral to scientific learning, not the antithesis of it, and that a new understanding of creative pedagogies that make thinking visible through the use of new technologies which build academic, digital and social in concert is of great import to the science educator. An argument such as McWilliam et al.'s (2008) suggests that more should be done to prove how some of these hypotheses can be practically applied to curriculum.

Another strand of recent literature studies how real world problem solving and creativity curriculum can be beneficial to science learning and building creativity skills.
These methods include seeing the creative process as a learning process that is promoted by the act of making and creating new ideas through objects. Barry and Kanematsu (2008) suggest ways that teachers can create learning environments that support original thinking through multisensory and interdisciplinary approaches. Burke-Adams (2007) writes that creativity is not an “intangible component” (p. 58) of the science classroom, but a process that requires teachers to use physical tools to foster it. Resnick et al. (2000) argue that, in creative disciplines, creativity is more than just a mental act, but one heavily steeped in the act of construction through tangible ideas and objects for the sake of innovation. Piggott (2007) contends that it is through the act of doing in the classroom that allows learners to naturally think creatively. Practically speaking, the work of these researchers provides ideal recommendations for the benefits of seeing creativity through a science lens, as science learning naturally is ground in real world and object-based learning.

A related conversation in the literature stresses the importance of the context of the learning environment in promoting creativity in science, particularly when such contexts engage students in interdisciplinary learning. Educators like Benedis-Grab (2011), Angle and Foster (2011), Merten (2011), and Maurer, Tokarsky, and Zalewsky (2011) suggest that science educators using arts-based curriculum to convey science content. Benedis-Grab (2011) discusses how he taught his 7th grade science students about the cell’s components and how to use microscopes effectively by connecting the fields of art and science. He collaborated with an art teacher at his school to meet both of their curricular goals. Together they joined their classes and watched a video by contemporary artist, Shannon Kennedy, called Building Project. In the video, Kennedy outlines all of the
microscopic life that can be found in a series of buildings. The students then re-enacted Kennedy’s process of inquiry and learned about science concepts and skills through a visual arts focus. In small groups, they collected biological samples, mounted them on slides, photographed the slides using their microscopes, selected photographs for a class exhibit at the school, and wrote artist statements.

Angle and Foster (2011) explain how science-learning environments should be inquiry-based, collaborative, and interdisciplinary spaces. They describe a lesson in which they asked their middle school students to create sailboats, collect data on its motion, and report their findings. Water-themed music and videos were also used in the lesson to help students consider alternate interpretations of the ocean, such as Claude Debussy’s “La Mer (The Sea).” They argue that these types of activities teach science students more about force and motion than a textbook, lecture, or worksheet. Merten (2011) advocates using arts learning and assessment in the science classroom, because it helps students to value small group collaboration and observation of nature. In her article, she gives an example of how she asked her 8th grade students to not only create traditional lab reports for an assignment, but also to create an alternative product to demonstrate their learning, such as a Powerpoint presentation, a poster, or a drawing.

Maurer, Tokarsky, and Zalewsky (2011) describe their smART camp for 7th-9th grade students, which utilizes activities in the arts to help students engage with science concepts. For example, their students made cell models using edible materials, like Jell-o and cookies, made DNA sculptures using pipe cleaners and beads, and made their own boats and then tested their boats’ buoyancy.
This survey of the literature shows that, despite some helpful recommendations, there are multiple gaps in understanding how creativity can best be practiced in the US high school science classroom. Much of the research that combines creativity and teacher practice has been done internationally, either in the UK (McWilliam & Dawson, 2008; Newton & Newton, 2009) or Korea (Lee & Erdogan, 2007). Other studies look at students who are not at the high school level (Benedis-Grab, 2011; Angle & Foster, 2011; Merten, 2011; Maurer, Tokarsky, & Zalewsky, 2011). Barry and Kanematsu’s (2008) study is based in Japan and is a study of college-age students. Resnick et al.’s (2000) work is a set of cases based on elementary and middle-school aged children in informal learning environments and is not easily translatable to high school science classrooms. Other studies of teacher beliefs surrounding creativity uncover elementary school teachers’ assumptions and misconceptions, but they do not look at practice directly, study the interaction between beliefs and practice, nor provide teachers with a set of practical recommendations for fostering creativity (Fleith, 2000; Newton & Newton, 2009). Kaufman and Sternberg (2007) explain that today’s educators often feel that creativity is irrelevant to their practice, but they do not sufficiently explore why these teachers have this belief, nor the ways that this belief might translate to their actual practice.

Studies like Burke-Adams’s (2007), McWilliam et al.’s (2008), Piggot (2007), and Ramadas’s (2009) are based on a set of theoretical constructs and do not provide teachers with practical advice that is grounded in a study of teacher practice. Similarly, McWilliam and Dawson (2008) give teachers a list of practical suggestions, but their guidelines are based in theory and are difficult to follow. The broad categories they give are not detailed, clear, or concrete enough for busy 21st century US teachers who face the
time constraints of the No Child Left Behind (NCLB) Act (Ambrosio, 2004). There are few studies that look at creativity at the high school level. Franske (2009) investigated how science curricula can promote creativity in high school students and looked at teacher practice directly, but his study is rare in the current literature. While researchers have looked at teacher beliefs and practice in other contexts, there needs to be a study that looks both at teacher beliefs and practices and how the two interact in the high school science classroom. If we are to promote creativity in students in order to help address the STEM career crisis, we need to better understand teacher practice. By studying teacher practice closely, it will be clearer what elements of teacher practice in the science classroom are working and what needs to be changed. This study will attempt to fill this need. Before I explain my proposed methodology, I will discuss another strand of research that explores practical ways teachers can enhance creativity in their classrooms. This research investigates how creativity is something that emerges out of collaborative learning environments by viewing a study of creativity through a complex systems lens. This body of literature will connect well to McWilliam and Dawson’s (2008) helpful theoretical suggestions that teachers should begin to foster small ‘c’ creativity in their students.

2.9 Creativity and Education: A Complex Systems Lens

A complex systems lens can be a useful theory to see creativity through in the 21st century. Theorists, like Sawyer (1999; 2006), explain that a classroom is a complex social learning environment and the creativity that emerges within it can be understood under the theory of complex systems. Complex systems theory, when in the context of a
learning environment, asserts that the sum of all of the learners in the environment act in concert in a way that is greater than any of the learners' potentials calculated individually. As Sawyer (1999) explicates in his essay, "The emergence of creativity," new ideas arise in emergent learning systems that are greater than a mere sum of their parts or are predictable from considering individual learners or ideas in the environment. His notions in the essay are grounded in Czikszentmihalyi's (1988) ideas of complex learning systems and creativity, which claim that creative ideas arise out of an interaction between creative individuals, fields, and domains. According to Sawyer (1999) creativity can be fostered in classrooms, if teachers consider the ways their students can react together and respond to lessons unpredictably. An example he gives of how this might occur is an improvisational theater dialogue. In such a dialogue, players take longer pauses between their speeches and make space to listen to each other's responses. This gives each member a chance to ground their responses in others' ideas and a chance to make the whole dialogue cohesive. A model like this could be translated obviously into an improvisational theater classroom, where a teacher might create lessons that insist that students make the time between responses to listen to each other. Looking at creative thinking as a result of social, collaborative learning could also translate into any classroom that uses discussion or group work to foster new ideas (e.g., an engineering class where students are creating a model for a new city bridge and are brainstorming ideas in a discussion). By viewing creativity as part of a social, collaborative process, students can be taught how to think creatively in any context or discipline.

Kaufman and Sternberg (2007) also assert that creativity can be taught in classrooms, especially when teachers consider ways of measuring student work that
connect to their definition that all creative ideas, acts, or objects consider the domain and field from which they arise. As they contend, a creative idea, act, or object must be innovative or different than anything created before it, be of excellent quality (i.e., shows itself to be of high standards and conveys the work put into it to make it well-crafted), and relevant to the task or problem from which it was created. This is similar to Sawyer’s (1999) theory of the creative learning environments as emergent systems, as both he and Kaufman and Sternberg (2007) argue that creative acts are part of a social system when one defines them as relevant to their domain and field from which they were created. Sternberg (2005) also suggests that creativity can be seen as a process that is mediated by the environment in which it is created. To him, there is no singular kind of creativity that only certain students can esteem to be, there are multiple ways that all students can engage in creative work in the classroom but must be nurtured in the classrooms they belong to. Culling down literature by Gardner (1993; 1994), Sternberg explains that creativity can look differently among learners, who might all be working together on a group project. Creating a new theory (for example, a new hypothesis in a science experiment), creating a “frozen work” or new object (for example, designing a new city bridge in an engineering class), or creating a ritualized social performance (for example, presenting an original science project to the rest of the class) are all examples of creativity in students, but they might not all occur simultaneously in the same student. Sternberg contends that creativity is something that can be cultivated in every student, as long as teachers begin to accept all of these types of learning artifacts as creative. Once they do so, they can create curriculum that harnesses the creative potential of each learner by constructing group work in which students can collaborate together. This acceptance
of different outputs of creative thinking takes into account the difference between creativity that is important to a field of study (for example, an accomplishment that changes a field, like a scientific discovery) versus a type of creativity that can be supported in every learner. It is a way to foster small ‘c’ creativity in every learner, as McWilliam and Dawson (2008) suggest.

Boden (2004) also sees creativity in the classroom as a result of emergent learning systems in order to acknowledge the difference between the two types. She describes creativity as functioning on both the individual (P-creativity) and field/domain (H-creativity) scales. H-creativity is of historical importance to a discipline or the world while P-creativity is a kind of creativity that is a creative leap for an individual learner. She uses the letter H to refer back to the word ‘historically’ and the letter P to refer to creativity that is meaningful on a ‘personal’ level. According to her, P-creativity is ‘real’ creativity in that it is the kind of creativity that real people engage in daily throughout normal life tasks. This P-creativity is a kind of creativity that can be supported in schools, as it relies on nurturing new ideas within every learner, without the burdens that each creative individual need be conscious of how his new thought is helpful to the history of a discipline. As she writes throughout the book, it is society and history (i.e., the judgments of a discipline) that define if an act is a great creative breakthrough or accomplishment and is thus, H-creative. This is the case because every idea is part of the social system of that discipline and thus, its worth to the discipline is vetted by the people within the discipline. Disciplines are able to determine if ideas are H-creative, as these ideas are borne out of a whole group of thinkers, not just one singular genius. Ideas that are P-creative are lower stakes and do not depend on the approval of the entire discipline’s
social system. In order to support the creative thinking of multiple learners in a classroom, educators can begin to redefine their notions of creativity from seeking to uncover singular genius in their learners (H-creative) and help learners to be P-creative. Just as Sternberg (2005) explains how teachers can begin to accept various individual outputs of creative thinking, Boden asserts that teachers can help their individual learners produce ideas, acts, and object that are creative in their own thinking and thus, teach them how to be creative.

McWilliam and Dawson (2008) examine creativity equivalently to Boden (2004). As they argue, it is important for 21st century educators to value the creativity in their students, which is small ‘c’ creativity, or according to Boden, P-creativity. If teachers learn to develop small ‘c’ creativity in their learners, McWilliam and Dawson (2008) claim, teachers can begin to teach creativity through the construction of ‘creativity-enhancing’ learning environments. These learning environments might include: a tolerance to diversity of thought among the members, where the rules of self-management are internalized and so not necessary to be enforced by a facilitator, collective responsibility among all members in the learning environment, and an inclusion of curricular constraints that enhance, rather than inhibit learning.

Given the fact that there is a dearth of literature surrounding creativity and education that supplies detailed practical recommendation for 21st century educators, a revision as to what various creative outputs are to be accepted is necessary. To construct these practical recommendations, it is important to make the case that creativity can be nurtured in all learners in environments, like classrooms. Including the work of these researchers who see creativity through a complex systems lens allows 21st century
teachers to value the result of collaborative and purposeful curricular activities they can foster in their classrooms (McWilliam & Dawson, 2008). By learning to acknowledge the small ‘c’ creativity that can be nurtured in each of their learners and being accepting of the various ways that this can look, teachers can construct learning environments that cultivate creativity in all students. As researchers like Boden (2004) argue, such an approach can be useful for student learning because students learn how to appreciate their own new ideas. Foremost, contemporary creativity theorists’ (Sawyer, 1999; Sternberg, 2001; 2005) understanding of creativity as emergent in social learning systems allows teachers to understand the complex relationship between creative learners, the field and domain of the subject, and the work itself. This understanding of how creativity functions in classrooms prepares them to foster learning environments that promote creativity.

2.10 Small ‘c’ Creativity Analytical Framework

In reviewing the literature, several key studies of creativity in the science classroom, social, collaborative learning, complex systems theory, teacher beliefs, theoretical constructs of ideal practice, and definitions of creative products have emerged as providing a collective understanding among scholars of teacher practice (Fleith, 2000; Kaufman & Sternberg, 2007; McWilliam & Dawson, 2008; Newton & Newton, 2009; Sawyer, 1999; Sternberg, 2005.) These theorists contribute to the contemporary understanding of how teachers can nurture creativity in their classrooms. Sternberg (2005) argues that teachers should accept divergent thinking and modes. Fleith (2000) explains that teachers ought to provide choices for completing assignments. Newton and Newton (2009) argue that teachers foster creativity in their students when they foster
“productive thought.” Sawyer (1999) asserts that creativity is enhanced when teachers utilize small groups, where power is distributed equally, for social, collaborative learning. Lastly, McWilliam and Dawson (2008) maintain that teachers should begin to value small ‘c’ creativity in all of their students. Taken together, these theories represent a current set of recommendations in the field for teachers to help their students be more creative and produce learning artifacts that are new, good, and relevant to the subject they are studying (Kaufman & Sternberg, 2007).

This literature gives recommendations to teachers; however, these recommendations are not concrete enough, as they do not integrate the creative products students produce as a result of following these recommendations. Moreover, Kaufman and Sternberg’s (2007) definition of creative learning artifacts is not appropriate for a classroom that cultivates small ‘c’ creativity, as their definition necessitates the products be new, good, and relevant to the field or domain (i.e., in the case of this study, science) and thus, is dependent on viewing only large ‘C’ products as creative. The Small ‘c’ Creativity framework (see Figure 1) combines the recommendations of these authors with Kaufman and Sternberg’s (2007) definition, synthesizes a small ‘c’ definition of creativity from McWilliam & Dawon’s (2008) theoretical constructs, and incorporates the student products created in classrooms. Before I go into my methodology in the next chapter, I will present a visual representation of the Small ‘c’ Creativity framework, along with a description, so as to show how the components work together in a learning environment that supports creativity.
Teachers who foster Small 'c' Creativity in their classrooms

4) Provide choices on what is an acceptable solution to the lesson.
3) Nurture collaboration among small group members in which individual kinds of creativity within the group are supported.
2) Accept learning artifacts that are novel and relevant to the lesson.
5) Include lesson guidelines that enhance, rather than restrict, learning and self-confidence.
1) Support divergent thinking that is connected in their minds.

Figure 1. Analytical framework for fostering small 'c' creativity in the classroom.

Figure 1 shows how in the Small 'c' Creativity Framework the learning environment fosters small 'c' creativity in students because teachers’ practice includes this definition. As teachers only seek to nurture creativity on the scale of the student, not the field or domain in science they are teaching within, there is more opportunity for students in engage in their lessons creatively and produce novel products that can be evaluated on a small 'c' scale.
I developed the Small ‘c’ Creativity Framework through a synthesis of the creativity literature discussed above. In the table below, you can see where each part of the small ‘c’ creativity framework originates.

Table 1

*Theories Synthesized for Small ‘c’ Creativity Framework.*

| 1) Support divergent thinking that is grounded in the lesson’s activities or concepts. | • Support divergent thinking (Sternberg, 2005)  
• Should see creativity as “productive thought” (Newton & Newton, 2009) |
|---|---|
| 2) Accept learning artifacts that are novel and relevant to the lesson. | • Create learning artifacts that are new, good, relevant to the field or domain (Kaufman & Sternberg, 2007)  
• Nurture small ‘c’ creativity (McWilliam & Dawson, 2008) |
| 3) Nurture collaboration among small group members in which individual kinds of creativity within the group are supported. | • Allow creativity to emerge in social, collaborative student groups (Sawyer, 1999)  
• Value the range of ways students can exhibit their creativity (Sternberg, 2005) |
| 4) Provide choices on what is an acceptable response (learning artifact or discussion point) to a lesson. | • Give choices of what learning artifacts are acceptable (Fleith, 2000)  
• Value the range of ways students can exhibit their creativity (Sternberg, 2005) |
| 5) Include lesson guidelines that enhance, rather than restrict, learning and self-confidence. | • Give assignments that are tailored to students' strengths and interests and stimulate their self-confidence (Fleith, 2000)  
• Provide curricular constraints that enhance, rather than inhibit, learning (McWilliam & Dawson, 2005) |
2.11 Chapter Summary: Creativity and Complex Systems Theory in the Science Classroom

Creativity has been designated as an integral skill for 21st century learners (Partnership for 21st Century Learning Skills, 2007). If teachers are supposed to be helping their students to be more creative there needs to be a better consensus of what practical recommendations might benefit teachers the most. Previous studies of creativity have considered how creativity occurs through the psychological and cognitive tendencies of individual learners, in arts classrooms, and in business environments. These studies have been helpful in uncovering themes of creativity’s various roles in learning environments; however, none of these disciplinary lenses furnish quite enough of a complete set of practical recommendations for teachers.

There has been research already completed investigating how science teachers can cultivate creativity in their classrooms. This research forms the basis of the Small ‘c’ Creativity Framework. Nevertheless, more research needs to be conducted as to how creativity actually works in high school science classrooms, in order to create a set of clear and concrete practical recommendations for teachers. A complex systems lens can be a helpful addition to the study of creativity in a science classroom, as it takes into account how students learn in collaborative learning environments (Sawyer, 1999; 2006.) This connects well to ideas about science learning that states that science is a collaborative practice that produces new ideas in social contexts (Lemke, 2001). Some recent science education literature has focused on fostering creativity in the classroom, but not in terms of collaborative learning. Taking collaboration into account is important, as it encourages small ‘c’ creativity in all learners. This consideration will be included in
the study. The Small ‘c’ Creativity Framework is the lens I used to approach data collection and analysis in my study. In the following section, I present the methodology, which illustrates how the Small ‘c’ Creativity Framework was incorporated within each step.
3. Methodology

3.1 Chapter Overview

In this chapter, I outline the methodology used in this study, so as to present a reasoned argument as to why the results and conclusions from the study may be considered sound. Sections include information on the research site, case study methodology, study participants, data collection methods (including focused observations, interviews, and artifact collection), a logic model, data analyses methods, a summary of data sources, information about Consensual Assessment Technique (CAT), training of CAT raters, scoring of student products using CAT, and case study scoring along the 5-part Small 'c' Creativity Framework (including information about how teacher portfolios were used in this process, the Small 'c' Creativity categorization manual, and the training of raters).

3.2 Research site

The ITEST-Nano project is a NSF-funded professional development program for Philadelphia high school science teachers, in which teachers are taught cutting-edge science concepts, like nanotechnology (Yoon et al., 2010). The project looks at ways in which teachers create curriculum for their own classrooms, after being exposed to nanotechnology concepts and problem-based learning pedagogy in the professional development program. It is run by a team of researchers at the Graduate School of Education at the University of Pennsylvania. I was a member of the research team from the summer of 2009 until the spring of 2011. Teachers are organized into cohorts, which
correspond to the year they were in the program (e.g., the teachers who were in the first year of the program were the first cohort). I worked with the second cohort and third cohort of teachers. The program offers a three-week summer session, in which teachers are taught concepts and pedagogies and then have a chance to pilot their work. During the summer session, teachers align the concepts with core curriculum to construct their own school lessons. Teachers are trained in Information Technology tools, such as Google groups, podcasts (specifically, Garageband for Apple computers and Audacity for IBM computers), and videocasts, so that they might incorporate these tools into their lessons.

Teachers in the program are trained extensively in using problem-based learning pedagogy. Problem-based learning pedagogy involves a teacher giving his or her students a real-world scenario that contains a problem and that has several possible solutions (Savery, 2006). The students' task is to solve the problem. They must work with ideas presented in class, along with individual and group research, in order to create a learning product constructed with peers that represents their solution and rationale for this solution. An example of a problem-based learning scenario might describe the problem of skin cancer to the students and ask them to come up with a type of sunscreen that utilizes advances in nanotechnology research. The students, ideally in small groups, would then have to present their new sunscreen and their rationale. All teachers in the program were asked to use a problem-based learning scenario for their culminating ITEST-Nano assignment, although the scenario and form in which they ask their students to create their product (i.e., an audio podcast, a video, or a poster) is up to them.
After being trained in this pedagogy in the summer, teachers are put into groups of three to four teachers in order to construct units that they pilot to groups of Philadelphia high school students during the last week of the session. After the professional development session is over, teachers implement lessons during the regular school year. Their implementation is then observed by members of the research team. By the nature of their collaborative bent, these pedagogies are in line with the theoretical bent of my study, as they combine complex systems theory with creativity in a science context. Because teachers are trained to create curriculum in which students collaborate to create new ideas and products grounded in core concepts, the program provided a good context to see how the study's analytical framework might be operationalized into practice. By looking closely at teacher practice in this context, there were optimal conditions to construct a set of practical recommendations from.

3.3 Case Study Methodology

As the ITEST-Nano program trains teachers to develop their practice, the program becomes a perfect setting to consider teacher practice. Case study methodology was chosen for this study to focus on teachers within the program in their classrooms. Denzin and Lincoln (2000) define case study methodology as the study of a bounded and integrated system, complete with a working combination of physiological, psychological, and cultural factors. Studying the complex system of how teachers' classrooms nurture creativity logically necessitates such a holistic methodology. In my study, I constructed a set of cases, a collective case study as Denzin and Lincoln (2000) call it, in order to understand the similarities and dissimilarities between the teachers' classrooms I
observed. In doing so, I sought to uncover what is particular about each case and what is common among them.

The practical focus of the ITEST-Nano program also leads to case study research, as this method of qualitative research allows for the researcher to observe and record real-life phenomena soundly and as completely as possible (Yin, 2003). In addition, because a case study methodology relies on the researcher gathering as much data as possible from real life situations, like classrooms, such a methodology promotes seeing a complex learning activity like creativity as completely as one can. Case study methodology eliminates the problems of generalizability inherent in indeterminate research design in which conclusions should not be drawn from a single observation (Kin, Keohane, & Verba, 1994) and thus, allowed me to make inferences about creative learning. Due to my role in the program, I visited teachers’ classrooms multiple times. Multiple visits allowed themes to emerge from teachers’ curricular choices that can became generalizable and could be used to develop a detailed set of practical curricula more soundly.

3.4 Participants

In case study methodology, sampling logic of participants (in which certain amounts of participants are required) is not relevant. The concern is more about how to control for external factors, in order to be able to compare and contrast themes gleaned from the cases (Yin, 2003). Because all of my participants are high school teachers in the same city and have been exposed to the same professional development curricula, certain elements of training and experience have been controlled enough in the context of this study to allow for conclusions to be made while using case study methodology.
According to Yin (2003), anything over two cases allows for the researcher to make conclusions from the data collected and any number over five cases gives a high degree of certainty about these conclusions particularly when the cases have similarities (for example, the same training in the same city), but subtle differences (for example, different backgrounds or teaching in different school contexts). In order to have a high degree of certainty regarding my conclusions, I selected five participants to serve as cases, who have had the same training in the ITEST-Nano program, but who come to their classrooms with different backgrounds, both personally and professionally. In addition, during the observation period, the five cases taught in four different schools that present a variety of contexts to consider how small ‘c’ creativity is both restricted and fostered in various learning contexts. These five individuals provide a multifaceted portrait of how high school science teachers are nurturing creativity within the same city.

Three of the teachers are from Cohort 2 and two are from Cohort 3. The three Cohort 2 teachers are Bill, Ginny, and Kraig. Rob and Anna are Cohort 3 teachers. I observed each teacher’s classroom for one year. I observed Bill’s, Ginny’s, and Kraig’s classrooms during the 2009-2010 school year and Rob’s and Anna’s classrooms during the 2010-2011 school year. The table below elucidates biographical details of the five participants and their school contexts.

Table 2

<table>
<thead>
<tr>
<th>Participant Background Information</th>
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<tbody>
<tr>
<td>Bill is a Caucasian male. He is a Biology, Physical Science, and Environmental Science teacher with 15 years of teaching experience. He is a mid-career changer from a career in business. Aside from teaching, he recently finished a Masters</td>
</tr>
</tbody>
</table>
degree in psychology from a local university. During the observation period, he taught at the same arts-focused magnet high school as Rob (Participant D), which has a 99% on-track-to-graduation rate and has PSSA scores in both reading and math in the top 25% of schools in the city (School District of Philadelphia, 2010).

Ginny is an African-American female. She is a Physical Science and Chemistry teacher with 5 years of teaching experience. She holds a Masters in Education from a local state university. During the observational period, she taught at a public high school that has the reputation to be one of the best public high schools in Philadelphia, in terms of college preparation. The school has a 100% on-track-to-graduation rate and has PSSA scores in both reading and math in the top 25% of schools in the city (School District of Philadelphia, 2010).

Kraig is a male Chemistry and Math teacher with 35 years of teaching experience. Originally from India, he taught at the high school he was teaching at during the observational period for seven years. After the observational year, his high school was determined to be a Renaissance school by the Philadelphia School District. This district-wide practice mandated that if a school is designated a Renaissance school, they must fire or relocate at least one-half of their faculty before the next school year. The school has a 17.1% on-track-to-graduation rate and has PSSA scores in the bottom 25% of schools in the city (School District of Philadelphia, 2010).

Rob is an African-American male. He is a Chemistry teacher with 14 years of teaching experience. Prior to teaching, he had a career in the Air Force as an Engineer and also worked as a Medical Technician. During the observation period, he taught at the same arts-focused magnet high school as Bill (Participant A), which has a 99% on-track-to-graduation rate and has PSSA scores in both reading and math in the top 25% of schools in the city (School District of Philadelphia, 2010).

Anna is a Caucasian female. Prior to the observational period, she had one year of teaching experience. She had experience teaching both Physical Science and Chemistry. After the observational year, her high school was determined to be a Renaissance school by the Philadelphia School District. This district-wide practice mandated that if a school is designated a Renaissance school, they must fire or relocate at least one-half of their faculty before the next school year. Their on-track-to-graduation rate is at 54.8% and their reading and math PSSA scores are in the bottom 25% of schools in the city.
Teachers were selected in part to create a representative sample of both the ITEST-Nano group and a fair breakdown of gender, race, and length of teaching experience in accordance with methods of case study participant selection (Maxwell, 2005). Teachers are two females (Ginny and Anna) and three males (Bill, Kraig, and Rob) and come from a range of ethnic backgrounds. They come from four different schools. Two are high performing (Bill’s, Ginny’s, and Rob’s schools) and two are low performing high schools (Kraig’s and Anna’s schools). I selected two teachers from the same school (Rob and Bill), in order to control for this variable and to observe how greatly school context affected how much creativity was fostered in the two different teachers’ classrooms. All five of the participants have varying levels of teaching experience that will likely provide differences in their level of energy and approaches to teaching and make for a sound set of multiple case studies (King, Keohane, & Verba, 1994). Teachers were also selected to represent a fair sample of levels of personal creativity and approaches in providing creative curriculum to the pilot students. Before observations of teacher behavior and teaching in the summer session, I selected Fleith’s (2000) definition of creative teaching and McWilliam and Dawson’s (2008) definition of an ideal creative learning environment as lenses in which to measure the teachers’ approaches to creativity and thus, their selection for my study.

After observing all of the Cohort 2 and Cohort 3 teachers during two summer sessions as both recipients of the professional development program (learners) and constructors of curriculum (teachers), I selected the teachers based on the rationale that they represented...
a range of approaches to creative teaching and learning. I assessed that a set of cases about these participants would help provide cases that addressed my main research questions: 1) To what extent does a small 'c' creativity framework reveal how teacher practice allows for creativity to occur in classrooms?; 2) How do science teachers' beliefs about creativity and their practical strategies interact to support creativity in science classrooms?; 3) If students are judged to be more or less creative within the teachers' classrooms, what are some possible relationships between their exhibited creativity and teacher practices and beliefs?

To create a set of cases that might help me answer Research Question #1, I looked to the ways in which teachers taught their pilot students that fell more or less under the Small 'c' Creativity Framework's constructs (i.e., how much they valued small 'c' creativity in their students and how this translated into their practice). During selection, I also thought it would be important to choose teachers who seemed to both learn and teach creativity, as it would be pertinent to the study to see if teachers who understand what it is like to think creatively may try to promote it in their students (i.e., if teachers thought creativity was more or less relevant to their own learning, they might think similarly about how relevant creativity was to their curriculum construction, see Research Question #2). To select participants who might help me understand how student creativity is influenced by teacher practices and beliefs (i.e., in order to address Research Question #3), I looked for a range of teaching styles and how these styles promoted creativity.

In his pilot class, Bill appeared to have a high tolerance for promoting group work that allowed for a diversity of thought among members. During his problem-based learning pilot lesson, he asked students to debate the ethical dilemmas in nanotechnology.
research surrounding cancer and encouraged their new ideas. He exhibited creative
learning behaviors himself during the program sessions. He frequently exhibited
divergent thinking, often bringing up issues not obviously connected to large and small
group discussions during the session. At times, these provided relevant and helpful
additions to the knowledge advancement of the group, such as when he suggested a new
and useful topic on cancer research for his small group to teach the pilot students. Other
times, his connections to the topic on hand were tenuous, but seemingly relevant to his
own learning. As he often needed to go off by himself during small group work with
other teachers, I thought it would be interesting as well to see how he might construct
collaborative learning environments in his own classrooms during the school year. He
explicitly tried to nurture creative behaviors in his pilot students, often asking them to see
ideas “in a new way.” Many new student ideas came out of his urgings.

Ginny promoted group work in her pilot students that allowed for a diversity of
thought among group members. She also created curricular constraints that enhanced
learning and creative products. She engaged her students successfully by asking them to
make posters of concepts that required their creativity. She did not exhibit particularly
creative behaviors in her learning style. She was relatively quiet during group
discussions, but appeared to be on task. When she contributed suggestions to the large
and small groups, her ideas were on topic and relevant. Nevertheless, because she did
seek to promote creative thinking in her pilot students through collaborative learning and
hands-on activities, there were a lot of creative outputs that were made by students in
response to her lessons.
In his pilot class, Kraig was much less tolerant than Bill or Ginny in promoting group work that allowed for a diversity of thought among members, nor did he create curriculum that enhanced learning through creativity. Kraig was the least creative of the teachers observed in the summer workshop, both in the ways he approached his own learning and the ways he approached the lesson construction for the pilot students. In the learning sessions, he did not contribute to the discussions. It was hard to tell how on task he was during large and small group discussions. He always looked at the people speaking during discussions, but was never asked what he was thinking. Also, he did not seek out creative behaviors in his pilot students. For example, he lectured the students on core nanotechnology concepts and did not ask them to contribute new ideas to the discussions, nor did he create curriculum in which students might create novel products from his lessons. During the pilot classes, he was most interested with issues surrounding behavior control and having the students complete the assigned tasks quietly.

Rob is a Cohort 3 teacher. During the 2010-2011 school year, he served as a comparison teacher to Bill within the larger ITEST-Nano project. I informally observed 5 hours of his teaching during this period and witnessed him giving students time for group work in class and encouraging students to take initiative for their new ideas. During the spring of 2010, he showed me a website his students had constructed showcasing his class experiments that demonstrated their creativity. I recruited him to be a Cohort 3 teacher for these reasons and selected him as a case during the 2010 summer professional development session. I witnessed both his learning and more of his teaching during this period. As he gained knowledge on nanotechnology research and problem-based pedagogies, he showed an excitement for learning new ideas. This excitement was
exhibited as he brought in books he had checked out from the library after the session hours and called his public library card his "Intellectual Visa." In addition, he participated heavily in large group discussions and freely offered new ideas to the group how he might incorporate what he was learning into his school year curriculum. I also observed him fostering creativity in his pilot students. He taught a series of modules to the students with another case study teacher, Anna. In these classes, he encouraged students' small group work, telling them to "work together to come up with new ideas." He also frequently encouraged their self-confidence after successful group work and explained how "proud" he was of "his little scientists" for their new ideas and products.

Anna is also a Cohort 3 teacher and was selected during the same summer session as Rob. During the classes on nanotechnology and problem-based learning pedagogies, Anna did not contribute much to class discussions, but was seemingly on task. When learning how to make podcasts, Anna was engaged in the process and made a humorous podcast with another teacher. She, Rob, and another teacher collaborated in constructing curriculum in their learning modules for the pilot students. In the context of her teacher group, she invented a novel problem-based learning lesson, in which students would develop a new flavor for a local water ice franchise (Rita's Water Ice). She also devised a way for students to work in two sets of small student groups during her learning modules. In the first set, she broke up the students into Flavor Experts, Marketers, and Chemists. These students did research together to help think of novel flavors, ways to market their flavors, and ways to build the chemical structures of their flavors. Then these groups split and one representative from each group joined another group, so that each new group contained one Flavor Expert, Marketer, and Chemist. These new groups then negotiated
their flavors and made podcasts advertising them. Through every stage of this small group work, Anna nurtured students' ideas by constantly asking them questions, such as "Will that sell?" or "Is that the most healthy choice for your consumers?"

In addition to the main teacher subjects selected, I chose two groups of students in each class that routinely engaged in group work together in the classes I observed. Before beginning data collection, I had planned to choose two student groups in each class that worked together routinely and ideally on the problem-based learning scenario to observe and interview. My goal for this data was to see how small groups learned together in each of the teachers' classrooms, in order to triangulate the data and help me answer Research Question #3, which states "If students are judged to be more or less creative within the teachers' classrooms, what are some possible relationships between their exhibited creativity and teacher practices and beliefs?" The rationale was that by focusing on small groups and individual students, I could more closely observe their exhibited creativity and how the teachers responded to them. I assumed that there might be small group variations in classrooms, but I also assumed that student groups would ideally have 3 members each (for a total of six students per class and a total of 30 students in the study). However, this was not the case in real practice, as student group sizes varied between classrooms. In Bill's class, he organized his students in primarily partner groups, although there were a couple of groups of three students. So, I selected six students from these partner groups to interview. Ginny let the students choose their own small groups, but limited them to no more than four students in each group. Due to uneven amounts of students in her classroom, groups of both three and four students emerged. I choose 6 students from these groups to interview. Kraig did not use small group work specifically
in his curriculum, so I selected six students to interview that seemed to engage in social, collaboration with each other more than others. Both Rob and Anna let their small groups emerge of three to four students; however, they did not limit the groups, so there were students working individually, in partners, and in small groups of three, four, and five students in their classrooms. To keep a uniform amount of student interviews, I chose six students from each of their classes to interview. In sum, I selected and interviewed 30 students in all five classrooms.

Because data from the students was collected mainly to address Research Question #3, group selection occurred as small groups emerged from observation data that produced the largest amount of creative products or ideas. My assessment of this amount of creativity in their class work was based on the frequency to which I saw that they produced class products and contributed to class discussions in ways that showed creativity. I defined creativity as those learning artifacts or student ideas that seemed novel and relevant (Kaufman & Sternberg, 2007) to the class topic or assignment. To collect student artifact data, I observed student group behaviors closely, collected learning artifacts from them as much as possible, and conducted a set of semi-structured interviews with each of the students. This work with the students helped to triangulate the teacher interview data and provide a richer set of case studies of the five teachers and the learning environments they created. By looking not only at teacher curriculum, but at what sorts of creative artifacts are produced in their classrooms, I was able to construct a more complete picture of what creative learning looks like in each of their classes and thus, create more robust case studies (Yin, 2003).
3.5 Data Collection

Focused observations, student and teacher interviews, and student artifact data for this study were collected through September 2009-June, 2011. Classroom observations as part of data collection for the ITEST-Nano project were also collected from September, 2009-June, 2011 and were used during the Data Analysis phase to enrich the data set. I was a member of the ITEST-Nano research team, participated in the summer professional development session in the role of a researcher, and served as a facilitator for the five teachers being studied. It was orchestrated for me to observe these five specific teachers chosen for the study knowing that they would be subjects in my dissertation study. As a paid graduate research assistant to the ITEST-Nano project, I also fulfilled my work requirements as a facilitator through these observations. Observations during September, 2009-June, 2011 were covered under the ITEST-Nano IRB (Protocol # 807207). The ITEST-Nano IRB procedures heavily overlapped with this study’s IRB procedures. With participating teachers, I conducted focused observations using the lens of the Small ‘c’ Creativity Framework as a scaffold, conducted interviews, and collected student work. Methods of participant observation and case study research were in line with those proposed by Yin (2003) and Maxwell (2005). Data was collected so as to provide the richest set of case studies possible and allow for enough data so as to make inferences about teacher practices and beliefs surrounding creativity. Also, my participation as a researcher was made explicit to all of the student participants, so their involvement in my study was both consented and fair.
3.6 Focused Observations

Classroom observations were conducted as part of the ITEST-Nano project. There were integrated into the study to provide additional data for a richer case study set. For this study, focused observations were completed. The purpose of these observations was to uncover not only what constitutes creative teaching, but also how well students respond to teaching that seeks to nurture their creativity. The Small ‘c’ Creativity Framework served as a partial frame for my observations, as I tested how these constructs translated into practice. I largely recorded my observations using an ethnographic approach, listing the scope and sequence of events and activities. I also collected audiotaped discussions of two student groups (see selection process in the Participants section) to compare student and teacher interactions. These observations helped me to answer Research Question #1 ("To what extent does a small ‘c’ creativity framework reveal how teacher practice allows for creativity to occur in classrooms") in particular, because I was able to see the choices teachers made in their classrooms towards fostering small ‘c’ creativity in their students.

The amount of time spent within each teacher’s classroom and the amount of problem-based learning scenarios observed can be seen in the following table:

<table>
<thead>
<tr>
<th>Table 3</th>
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<tbody>
<tr>
<td>Hours and Class Periods in Teachers’ Classrooms</td>
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</tbody>
</table>

55
<table>
<thead>
<tr>
<th>Participant</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bill</td>
<td>18.25</td>
<td>17</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ginny</td>
<td>17.75</td>
<td>17</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kraig</td>
<td>17.5</td>
<td>11</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rob</td>
<td>18</td>
<td>19</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anna</td>
<td>17</td>
<td>17</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

I spent at least 17 hours in each of the five teacher’s classrooms over the course of one school year each. There is some slight variation in the amount of hours in teachers’ classrooms due to class period lengths. Class period lengths varied between schools, ranging from 45-minute periods to 1 hour and a half periods. In some cases, class period lengths varied within Bill and Rob’s school depending on the particular day and the week. For example, the same class period visited on a Monday at their school one week might be 45 minutes long, but the next week it could be an hour long. This was due to a school-wide practice the administration had instated of lettering the days of the week (e.g., A days, B days, C days) and then distributing these days over each school month.

At the start of the research project, I intended on doing focused observations through the course of one problem-based learning scenario in each classroom, so as to create a uniform data set that could be compared across cases. Ginny and Anna both did one problem-based learning scenario and this fit well with the study’s design. However, once I was in the classroom, the other teachers had different practice styles and some variation in the classroom data I was able to collect occurred. After his first problem-based learning scenario, Bill decided to do another scenario with his students and so, I was able to observe this second one. This was important for the study, as he had lost the
products from the first scenario. Rob did one problem-based learning scenario with his students. Then when he did a lesson with his classes on “Nanofabric” (fabric that utilizes advances in nanotechnology to prevent staining), students from two class periods decided that they wanted to make an infomercial about the Gap brand pants made from the fabric. Thus, there were two problem-based learning scenarios that I observed in his classroom. I intended on observing a problem-based learning scenario while visiting Kraig’s class, but he did not understand how to construct one and so, I did not observe any in his classroom. Nevertheless, I decided to include him in the study regardless, because it was important to have a teacher participant that clearly did not foster creativity as much as the other teachers and because I wanted to have more than one teacher in the study from a low performing school.

3.7 Interviews

Semi-structured interviews with the five teachers were conducted after the focused observations. These were approximately 30-40 minutes in length. Interview protocols were created and measured against quality standards of fair interviewing of human subjects (Weiss, 1994), in that interviewees understood they could stop the interview at any time if they found the questions too intrusive. Questions were chosen to illuminate teacher beliefs on promoting creativity in their classrooms and were compared to their actual curriculum observed during the Data Analysis phase. The set of questions were previously constructed for a pilot study for this dissertation, which was conducted during Spring 2008. Results of this study were presented in (Lasky & Yoon 2009; Lasky & Yoon, 2011). Interview responses most closely aligned with issues surrounding
Research Question #2, which seeks to reveal: “How do science teachers’ beliefs about creativity and their practical strategies interact to support creativity in the science classroom?” By asking teachers’ about their beliefs regarding creativity in the interviews, I was able to compare their beliefs to their practice I observed in their classrooms. For example, interview questions included: 1) *How is creativity important in science?*; 2) *Do you think creativity has a place in the science classroom? Why or why not?*; and 3) *What do you do when you suspect a student is creative?* From their responses to interview question #1 and #2, I ascertained whether or not they believed creativity to be important to the field of science and to the teaching of science. Then I compared their responses to the ways in which I observed them foster their students’ creativity in their science classrooms. Related to interview question #3, it was pertinent to note what they said they would do if they suspected a student was creative and compare to what I actually saw them do in their classrooms. The complete teacher interview protocol can be found in Appendix A. Teachers were also interviewed regarding their curricular choices as part of the ITEST-Nano research project and any relevant responses were used for this study. Specifically, Kraig’s (Participant C) responses to this interview were used in his Case Study Narrative (see Results chapter), as his Creativity interview was spare. This ITEST-Nano interview protocol can be found in Appendix B.

Additional semi-structured student interviews (approximately 20 minutes each) with 30 student participants were completed to triangulate the data and help me gain a richer data set to make inferences comparing and constructing the cases. These questions align most closely with issues surrounding Research Question #3, which attempts to uncover: “If students are judged to be more or less creative within the teachers’ classrooms, what
are some possible relationships between their exhibited creativity and teacher practices and beliefs?” By asking students’ about how their teachers fostered creativity in their classrooms, I was able to better understand the teachers’ practice from their students’ perspective. For example, sample questions included: 1) Do you think you have you ever been creative?; 2) Do you think any of the lessons you are doing in [teacher’s name] classroom ask you to be creative? Why or why not?; 3) When you are learning in this class, do you like the activities in which you can work with other students? Explain. Have you ever had a new idea or made something you might consider creative when working with other students? From student responses to interview question #1, I could see how they defined their own creative behaviors and if they saw themselves as creative, so as to equate these beliefs to what I saw them exhibit in the classroom and in their problem-based learning products. Their answers to question #2 allowed them to mention any of their teacher’s lessons that they thought nurtured their creativity. This was important to compare to how I saw the teachers’ practice fostering their students’ creativity. Their responses to question #3 gave me a better understanding about how they valued the group work the teachers may or may not have assigned in the class. Student interview questions were also piloted in the Lasky and Yoon (2011) study and found to be successful in generating responses. The complete student interview protocol can be found in Appendix C.

3.8 Artifact Collection

Student work (e.g., podcasts, final papers, posters, worksheets, powerpoints, and blogs) was collected during classroom observations when appropriate. When it was not
feasible to collect the physical artifacts, photographs that showed the artifacts clearly were taken. Whenever possible, lesson plans were collected. Other documentation from teachers (such as email communication), as well as impressions from the summer workshop and anecdotal conversations, were used in order to further triangulate interview and observation data.

The artifacts produced by students as a result of the teachers’ problem-based learning scenarios were collected and scored using Consensual Assessment Technique (CAT) (see Section 3.10.2). Problem-based learning scenarios were the culminating projects of the teachers’ ITEST-Nano units. In the scenarios, teachers asked their students to solve a problem using nanotechnology and to present their work in the form of a product (e.g., a podcast, a poster, or a powerpoint presentation). These scenarios were collected and used during the Data Analysis phase. Only four of the five teachers (Bill, Ginny, Rob, and Anna) gave their students problem-based learning scenarios to complete, so only products from these teachers were scored. Appendices D-G include the problem-based learning scenarios of these four teachers. Table 4 shows the types and numbers of products that were created as a result of their problem-based learning scenarios and were collected from each teacher:

Table 4

*Amount and Types of Student Problem-Based Learning Scenario Products*

| Participant A: Bill | 9 | 9 |
There were a total of 32 student artifacts produced in the teachers’ classroom. The breakdown of products is 9 products in Bill’s classroom, 8 products in Ginny’s classroom, 9 products in Rob’s classroom, and 6 products in Anna’s classroom. Kraig did not include a problem-based learning scenario in his lessons, so there were no products to score using CAT; thus, he has 0 products represented in the Table 4. In constructing their problem-based learning scenarios, teachers could choose what types of artifacts they wanted their students to create; thus, there was variation in the products produced in the different classrooms. The types of products varied between classrooms, but only Rob let students complete the assignment with multiple types of products within his classroom. To illustrate the different types of products created by the students, I will include a few sample screenshots. Here are two powerpoint slides from one of Bill’s student products:

<table>
<thead>
<tr>
<th>Participant</th>
<th>Number</th>
<th>Artifacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant B: Ginny</td>
<td>8</td>
<td>8 video podcasts</td>
</tr>
<tr>
<td>Participant C: Kraig</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>Participant D: Rob</td>
<td>9</td>
<td>4 video podcasts; 1 animation; 3 posters; 1 video infomercial</td>
</tr>
<tr>
<td>Participant E: Anna</td>
<td>6</td>
<td>6 audio podcasts</td>
</tr>
</tbody>
</table>
In Bill’s problem-based learning scenario (see Appendix D), he asked the students to research the devastating 2010 British Petroleum oil spill in the Gulf of Mexico and find out how nanotechnology might be used to solve the problem. In Figure 2, the students have included pictures of animals that were affected by the spill and in Figure 3, they outline how current advances in nanotechnology could be used to clean up the spill.
Figures 4 and 5 illustrate screenshots from two of Ginny’s student’s video podcasts:

Figure 4. Ginny student product #1.

Figure 5. Ginny student product #2.

For Ginny’s problem-based learning scenario (Appendix E), she asked her students to use nanotechnology to solve the air pollution problem in Philadelphia. Figure 4 is a screenshot from a student group who made a video they titled, “Adventures of Nanoman.” In the movie, “Nanoman” combats air pollution. Figure 4 shows the student playing “Nanoman” struggling to overcome the student playing “Air Pollution.” Figure 5
is a screenshot from a video another group in Ginny’s class made of a puppet show. In the show, puppet representations of the four students combat air pollution using advances in nanotechnology.

Figures 6 and 7 illustrate two of Rob’s student products:

*Figure 6. Rob student product #1.*

*Figure 7. Rob student product #2.*

Rob did two main problem-based learning scenarios. In the first, he asked students to come up with a new flavor of Rita’s Water Ice that used a particular sweetener of their choosing (see Appendix F). Figure 6 is a poster made by students to illustrate their new
flavor of water ice called “Skittles.” He also allowed students from different class periods to collaborate and create a problem-based learning scenario together. Figure 7 is a screenshot from this product. It is a video infomercial students made about the benefits of fabric that utilizes advances in nanotechnology to repel stains. In the movie, a girl has just spilled soda on another girl’s pants, which prompts them to discuss how they should buy pants made with the special fabric. More information about how these products were analyzed using CAT will be discussed in Section 3.10.2.

3.9 Logic Model

Below is a logic model, which demonstrates how the data sources address the study’s research questions, so as to yield a focused data set from which to analyze and make conclusions regarding teacher practice.

Table 5

Logic Model

| There is a dearth of practical strategies for teachers. Studies that do outline practical strategies for teaching creativity are highly theoretical and hard to implement into practice. | To see how a framework that fosters small ‘c’ creativity reveals how teacher practice allows for creativity to occur in classrooms? | Classroom observations | A clear and concrete set of practical recommendations based on the analytical framework |
There needs to be a better understanding of teachers’ beliefs about the importance of creativity and how these beliefs are instantiated in practice.

To construct a set of cases of teacher practices and the ways in which they interact with teacher beliefs.

Classroom observations; Teacher interviews

Understanding of how teachers’ beliefs influence practice

Creativity as a 21st century learning skill needs to be taught for workforce development, student scientific literacy, and to increase student creativity.

To compare and contrast a range of teacher practices.

Student artifacts; Student interviews

Understanding of how creativity is fostered in students in different styles of teacher practice.

### 3.10 Data Analyses

In this section, I will outline the methods of analysis for the study. This will include presenting how I constructed cases out of my data sources, Consensual Assessment Technique (CAT) methodology, my training of CAT raters, small ‘c’ creativity scoring of cases along the Small ‘c’ Creativity Framework, my training of framework raters, and my construction of case study narratives.

### 3.10.1 Case Study Construction

Following Eisenwine and Hadley (2011), data sources were drawn together to construct cases of each teacher. These cases represent a kind of creativity in practice portfolio intended to provide information about the teacher’s creativity stance. For each teacher, I collected classroom observations, two interviews (a Creativity interview done for the study and a Nanotechnology interview done for the ITEST-Nano project), 6 student interviews, problem-based learning scenario, and student products together. Once
the data was organized for each teacher, I went through a process of indexing the data. Ritchie and Lewis (2003) describe indexing case study data as when the researcher labels key issues that emerge across a set of data. I mined each individual teacher case and found themes in their practice and beliefs, which I triangulated with data from their students.

3.10.2 Consensual Assessment Technique

In this study, Consensual Assessment Technique (CAT) was used to score the 32 total student products in all of the teachers’ classrooms. This technique was the first of two types of ratings used in this dissertation. The second method of rating, scoring along the Small ‘c’ Creativity Framework, is described in Section 3.10.3. In terms of CAT, the technique is based on the idea that the amount of creativity in a learning artifact is determined by experts in a given field (Baer & McKool 2009). Its validity does not rely on any particular theory of creativity like other past creativity assessment techniques (for example, tests of divergent thinking). Instead the criteria for high and low assessment is based on what the group of experts agree upon constitutes these levels. Although methods can vary depending on the setting the technique is used within, a common practice is give the raters a range to score the products within (for example, 1.0-5.0). They are asked to rate the products and use their expertise to define the creative products in relation to each other (Baer, Kaufman, & Gentile 2004). Raters are asked to compare artifacts within a group, to ensure that not every artifact is given the same score, and to create a set of comparative creativity scores per class. As Baer and McKool (2009) assert, the “goal is to get ratings of comparative creativity of the things being judged…a poem that might be...
judged to be highly creative in one group of rather pedestrian poems might receive a much lower creativity rating if it were included in a group of much more creative poems” (p. 4).

The rationale behind using CAT methodology for this study was that it asks for products to be compared within classes. Because each teacher used a different problem-based learning scenario to prompt their students’ products (with the exception of Rob and Anna, who used the same prompt for her only and his first problem-based learning scenario), having raters score products comparatively within each class allows for comparisons to be made across the cases during analysis. Since this multiple case study’s goal, in part, is to create a realistic portrayal of each of the teachers’ classrooms, it would not be sound to score student products across cases (i.e., to ask raters to score the products comparatively across all of the teachers’ classrooms), as they were each created in response to their particular teacher’s problem-based learning scenario. Taking the guidelines of CAT methodology into account, raters in this study were asked to score comparatively within classes during CAT scoring sessions, but not across classes. For example, a rater could not compare a product they scored a 5.0 in Ginny’s class in order to determine a score in Bill’s class. However, they could use the 5.0 in Ginny’s class in order to determine a score on another of Ginny’s class products.

3.10.2.1 Training of CAT Raters

CAT was used in this study to provide a unit of analysis in which to understand the amount of creativity produced in each classroom. Two raters were trained in the methodology. They were chosen because they were expert science educators and
graduate students in education with a familiarity in coding data, the ITEST-Nano research project, the particular study, and in CAT methodology. Although they were familiar with the methodology in theory, they had never used it before in practice. The first rater had four years of teaching experience in Biology, Physics, and Chemistry. The second rater had eight years of teaching experience in Physics and also had five years of educational leadership experience. The scoring occurred in two 2 hour-long sessions, three weeks apart, during the Spring 2011 semester. During the first session, the raters were given information about the methodology and the study and then scored products in two teachers’ classrooms. In the second session, raters scored products in two teachers’ classrooms and the scoring was completed. Kraig did not complete a problem-based learning scenario, so there were no products to collect and score using CAT for his class during either session.

In the first session, the raters and I spent 20 minutes discussing the idea that the methodology was asking them to give a numerical value to the amount of creativity in the student products. Both raters needed clarification that they were not being asked to give a numerical value to how closely the products followed the guidelines in each teacher’s problem-based learning scenario, because creativity often involves creating a product that diverges from the assignment guidelines. After the group discussion, both raters understood that they should only measure the amount of creativity in what the students produced, in response to their given scenarios. They also understood that they did not have to consider if the students followed the guidelines exactly, but more that they demonstrated their creativity through their products. After this discussion, the raters scored two sample products from Ginny’s classroom. They were given her problem-
based learning scenario, so that they could see what the students used to create their products. In her scenario, she asked her students to do research in how nanotechnology could be used to solve the air pollution problem in Philadelphia and present their findings in the form of a video podcast. The raters were asked to score the products on a scale from 1.0 to 5.0. They were told they could use any number gradation they wanted between 1.0-5.0, (i.e., 2.5 or 3.7). After giving each score for two video podcasts, raters discussed why they gave their scores. I determined that they understood they were measuring how much creativity they saw in the products.

After these first two products were scored and scores were discussed, raters were asked to score the rest of Ginny’s class’s products comparatively and as a separate set from the other classes’ products. They were asked to distribute scores only within her class (i.e., to make sure that they were not giving every product a 4.0 or a 2.0). They then scored the products in Bill’s class. During the second session, they scored Rob’s and Anna’s class products. After these scores were collected, averages of CAT scores per class were calculated. These can be seen in the Results chapter and are discussed in the Discussion chapter.

3.10.2.2 CAT Scoring Example

In this section, I will give an example of two average CAT scores in Ginny’s classroom to clarify the process further. The scores the raters gave Ginny’s student products range from 3.0 to 4.65. The two products I will discuss in this section are the videos with these two scores, so they represent both ends of the range. The first product is the one with the highest score (4.65). It is a puppet show that was briefly mentioned in
Section 3.8 (see Figure 5). In the video, four students discuss how the air pollution problem in Philadelphia is a result of using cars, because car exhaust contains many pollutants (sees). They tell a story in puppets, creating puppet representations for each of the group members and the car (Figure 9). The car puppet discusses his pollutants in detail (see Figure 10). The puppets come up with nanofilters as a solution to the air pollution problem and go around the world to spread their solution in a montage of the puppets in various landmarks (Figure 11). The movie also includes a monkey puppet (Figure 12), who tells the girls about how nanotechnology can further solve the air pollution problem by using military carbon, while exclaiming “oooh oooh ahhh ahhh” after every word. The raters explained that they were impressed that the students creatively thought to use puppets and to create new characters to enhance their story (the car and the monkey), while still integrating a high level of content into their video. They were also visibly amused while watching the video, often laughing at the puppets’ decoration, language, and voices and particularly at the monkey’s exclamations.

*Figure 8. CAT scoring example #1 (first screenshot).*
Figure 9. CAT scoring example #1 (second screenshot).

Figure 10. CAT scoring example #1 (third screenshot).

Figure 11. CAT scoring example #1 (fourth screenshot).
The second video received an average score of 3.0 by the raters. This was the lowest score the raters gave for a product created in Ginny’s classroom. The video podcast was a dramatic narration of the air pollution problem in Philadelphia told in four separate scenes and acted by the students themselves. The video follows a girl, who acts as if she does not understand the air pollution problem (see Figure 13). She is playing in the park and suffers a headache and a cough. The other group members try to explain how big of a problem the air pollution problem is in the city throughout the video, such as telling her that the Delaware Valley does not meet the Environmental Protection Agency’s (EPA) standards for particulate matter and ground level ozone (see Figure 14) and that air pollution causes major health problems (see Figure 15). Despite the information already given about air pollution from her friends, she is still confused why air pollution is such a problem. Group members all sit together and discuss how nanobots could be used to solve air pollution (see Figure 16). They discuss the inherent dangers of using an invention in a new field like nanotechnology, because people may be scared of it and not ready to accept the ways in which it could help them. One student offers an alternative solution that people use corn-based ethanol and other different kinds of fuels
to run their cars and thus, prevent air pollution. The video ends with a set of bloopers and outtakes (see Figure 17).

Figure 13. CAT scoring example #2 (first screenshot).

Figure 14. CAT scoring example #2 (second screenshot).

Figure 15. CAT scoring example #2 (third screenshot).
The raters explained that the students had used humor and their acting skills to convey content creatively in the second video. However, whereas the product that scored a 4.65 used puppets created by the students, surprising narrative jumps, and humor, the second video was not as creative because it did not use all of these elements. They expressed this belief by giving it lower scores (with an average score of 3.0). The students who made the second video could have included more surprising narrative jumps and constructed alternate characters, like puppets, to tell the story. The raters found the end scene of bloopers and outtakes slightly amusing, but not as humorous as many parts of the higher-scoring video (e.g., the monkey, the student puppets, and the car puppet). In
addition, the second video did not incorporate as much nanotechnology content into its storyline. It discussed some potential advantages in nanotechnology that might solve the air pollution problem in Philadelphia (like nanobots and corn-based ethanol), but it did not provide a solution like the higher-scoring video (nanofilters) and did not present this solution in as interesting a presentation.

### 3.10.3 Case Study Scoring Along 5-Part Small 'c’ Creativity Analytical Framework

For this phase of analysis, the study’s analytical framework was used a theoretical lens to interpret the case study data. A Small ‘c’ Creativity categorization manual was written (Appendix I) and applied to the case study data, in order to create a set of teacher’s scores along the five-part framework. A similar analytic methodology was piloted in a previous study (Lasky & Yoon, 2011), in which qualitative data regarding teacher beliefs and practices were scored and placed as a continuum (i.e., high, medium, and low) along a set of theoretical constructs. The purpose of this was to better understand the complex phenomena of teacher beliefs and practice comparatively in the case set, so as to make conclusions from and across them. In Lasky and Yoon, 2011, vignettes were provided to give examples for continua scores. For this study, case study narratives versus vignettes were created and will be presented in the following Results chapter to provide evidence for continua scores. The Small ‘c’ Creativity Framework categorization manual will be discussed in the following section. This manual was validated through four external raters and this process will also be presented in the following section.
3.10.3.1 Teacher Portfolios and Small ‘c’ Creativity Categorization Manual

A Small ‘c’ Creativity Framework categorization manual was created and scores were given ranging from high to medium-high to medium to medium-low to low. The five scores along the five framework components were created to bring out subtle differences in teacher practice and beliefs regarding creativity. For example, for the first framework component, which states that teachers who foster small ‘c’ creativity, Support divergent thinking that is grounded in the lesson’s activities or concepts, distinctions in teachers’ data placed them differently along the continua. A teacher, with a high score on the first framework component, gave students open-ended assignments that required them to create a product completely on their own. In his or her interview, he or she expressed that he or she valued divergent thinking and gave clear examples of past and present students who exhibited creativity. A teacher who scored medium-high on this component provided loose guidelines and valued work that was created within a certain amount of constraint. These teachers referred to students either in past or present classes who exhibited creativity. A teacher who scored medium on the component provided guidelines that allowed for some divergent thinking, but the assignment necessitated a majority of conformity to the guidelines. This teacher could name a student in their present classes who exhibited creativity. A low-medium scoring teacher on this component provided assignment guidelines that most of time had one correct answer and did not explicitly ask students to think creatively. He or she might have an assignment that allowed for students to have novel thinking or to create a novel product. These teachers could think of a student who exhibited creativity in their present class, although the description was...
unspecific. Finally, a teacher who scored low on this component presented assignments to students that included guidelines that were looking for one correct answer and did not ask students to think creatively. These teachers could not name a student who exhibited creativity in their interview.

Scores on the first framework component ranged from high to low-medium. Rob is a teacher who scored high on this part of the framework. He gave his students open-ended assignments that allowed them to create a product completely on their own. He had them work in small groups to come up with a new flavor of Rita’s Water Ice that used a sweetener of their choosing. He let a cross-class collaboration problem-based learning scenario emerge, in which students made an infomercial about fabric that utilized advances in nanotechnology by repelling liquids and other staining agents. He expressed that he valued divergent thinking in his interview. His practice also demonstrated his value of divergent thinking, as he let students respond to the first problem-based learning scenario in multiple ways (e.g., video podcasts, audio podcasts, posters, and animations). In his interview, he gave clear examples of past and present students who exhibited creativity in his classroom. In contrast, Kraig is a teacher who scored low-medium on the first framework component. Because most of his assignments were worksheets or assigned textbook questions and he did not complete a problem-based learning scenario, he only allowed students one correct answer and did not explicitly ask students to think creatively. He did have one vector assignment that asked students to construct a novel product that exemplified their understanding of the concept with rubber bands and paper clips. In his interview, Kraig could not name a specific student in a past or present class.
that stood out for him as creative, but did refer briefly to an unnamed student in a past class who had exhibited creativity, although his description was unspecific.

In order to obtain interrater reliability for the Small ‘c’ Creativity Framework scores, a selection of the raw data collected for each teacher was given to four external raters. The selection of the entire data set was termed a Teacher Portfolio. Teacher Portfolios were created for all of the teachers and were representative of 50% of the total data collected. For each of the five teachers, they included a full-length Creativity interview transcript (approximately 10 pages long), eight classroom observations (approximately 30 pages long), three student interviews (approximately 15 pages long), and a problem-based learning scenario (approximately one page long). Each Teacher Portfolio was a total of 56 pages long, with a total of 280 pages in all five portfolios. The Creativity interview transcript was included in its entirety. It would have been ideal to randomize the classroom observations in the portfolio (e.g., alternating observations, so all odd or even numbered observations); however, because one of the teachers (Kraig) only had 11 observations in total (with 17.5 hours spent in the classroom), I had to somehow be able to stop at the 11th observation. This necessitated both odd and even numbered observations in the set. Thus, the 1st, 3rd, 4th, 5th, 7th, 8th, 9th, and 11th classroom observations were included from each teacher in their portfolios. Three student interviews were chosen at random. To select these, I chose the 1st, 3rd, and 5th interviews I did in each teacher’s classroom. In addition, the problem-based learning scenario or scenarios were included in each Teacher Portfolio. Raters were asked to score Teacher Portfolios along the framework. The method of training the raters is described in the following section.
3.10.3.2 Training of Small ‘c’ Creativity Framework Raters

Four external raters were trained to score raw data from each of the teacher’s cases along the Small ‘c’ Creativity Framework. All of the raters had backgrounds in qualitative research and some understanding of theories in creativity research. The first rater was a doctoral student studying creativity and writing and was a high school teacher for two years. The second rater was a professor of English and Education, with a doctorate in education. The third rater was a Masters student in educational administration and also a high level administrator in a university Creative Writing department. The fourth held a Masters in Education, had six years of elementary and middle school teaching experience, was a Teach for America Fellow, and was currently working for an educational professional development corporation.

Two three-hour long training sessions were held in person two days apart during February 2012. In the first session, the raters were trained in the constructs and scoring definitions of the categorization manual (see Appendix I). First, the manual was read aloud together. Raters were asked if they had questions and they all agreed verbally that the categories were clear to them. They were given Bill’s Teacher Portfolio and asked to use the manual to give the teacher one score (low, low-medium, medium, medium-high, and high) for his first framework component independently. Next a think-aloud (Lochhead, 2001) was used. A think-aloud is a learning strategy traditionally used to help educators better understand their students’ thinking processes. It was used for training the raters, because it allowed the entire group (the raters and the trainer) to better understand the raters’ decision-making. In the session, after the raters had scored Bill’s Teacher Portfolio, the group went through each of the framework components and their scores.
asked each rater to verbalize their rationales for their scores for the first part of the framework (titled the Support Divergent Thinking Framework Component) to the group, i.e. the raters were asked to each explain to the group the reasons why they gave the scores they did for this component. This part of the training most closely resembles the step of “constant vocalization” in a think-aloud exercise (Lochhead, 2001), as the raters were able to “communicate” their thinking and I was able to “monitor” it (p. 14). Finally, I stated my justification for the 5 scores I had given Bill’s portfolio. I allowed the raters to ask questions. The raters’ difficulties in interpretation of the raw data were deliberated. Scores were negotiated and some of the raters chose to change scores as a result of this discussion. This process was replicated for Bill’s four remaining framework components.

After this session, part of the manual was slightly revised to reflect raters’ suggestions. The raters were sent home with Ginny’s Teacher Portfolio and asked to rate it independently. During the second in-person session, raters came back with their scores. Scores were again discussed and negotiated among the group using a think-aloud exercise until all members felt confident with the categorization process. The raters were sent home with the last three Teacher Portfolios (Kraig’s, Rob’s, and Anna’s) and were given a week to send their scores to me. Scores were collected and the frequency of agreement of framework scores between raters for each teacher was tabulated. For example, when constructing the case study narratives, Bill had scored a medium-high for the Support Divergent Thinking Framework Component, a medium-high for the Accept All Artifacts Framework Component, a medium for the Nurture Collaboration Framework Component, a medium-high for the Provide Choices Framework Component, and a medium-high for the Enhance Self-Confidence Framework Component. All 4 raters scored Bill medium-
high for the Support Divergent Thinking Framework Component, 3 of the 4 raters scored him medium-high on the Accept All Artifacts Framework Component, all 4 raters scored him medium for the Nurture Collaboration Framework Component, 2 of the raters scored him medium-high for the Provide Choices Framework Component, and all 4 raters scored him medium-high for the Enhance Self-Confidence Framework Component. When the number of raters in agreement with my score is added together (4+3+4+2+4), there is 85% agreement (17/20) just for Bill’s scores. The frequency of agreement was added up for all the teachers. After this process, there was an 80% agreement on all 25 (5 scores for each of the 5 teachers) framework scores.

3.10.3.3 Case Study Narratives

After 80% agreement on Small ‘c’ Creativity Framework scores were established, case study narratives were written. These narratives are presented alongside framework scores in the Results chapter. As Yin (2003) writes, a case study report “should indicate how and why a particular proposition was demonstrated” (p. 50) within real world contexts. Narratives were written to provide rationales for scores and to present evidence that corresponded to details outlined in the categorization manual (i.e., to provide a “how” and “why” for the ways in which the teachers’ practice adhered to the framework). Narrative structure was not only dependent on the organization of the framework constructs, but also took some of its form from recommendations outlined in Lawrence-Lightfoot and Davis’ (1997) The Art and Science of Portraiture. In this methodology text, the authors define the ethnographic researcher as a “portraittist” who views real world “context as a dynamic framework—changing and evolving, shaping and being
shaped by” (p. 59) study participants. They also explain that in the writing of an ethnographic account, the researcher should “scrutinize[] the connections (and disconnections) between the theoretical predispositions” and the participants’ “realities, seeking to accommodate the former to the latter, monitoring the growing convergence between scientific abstractions” and the participants’ “empirical categories” (p. 59).

Lawrence-Lightfoot (1983) exemplifies this methodology in her portrait of a teacher in George Washington Carver High School in *The Good High School: Portraits of Character and Culture*, as she writes:

> Mr. Parrot, a slow-talking, slight man with a deep Southern accent, teaches a social science course to juniors and seniors. The late-afternoon class is depleted by the absence of the seniors, who have gone off to rehearse for graduation. Five students, who have all straggled in well after the bell, are scattered throughout the large, well-equipped classroom. One has her head on the desk and is nodding off to sleep; another girl is chewing gum vigorously and leafing through a magazine; a third student stares straight ahead with glazed eyes. These three never respond to the teacher’s questions and remain glumly silent during the class discussion. (p. 38)

In this portrait of Mr. Parrot’s class, Lawrence-Lightfoot presents an account of the real life occurrences of the classroom (e.g., his pedagogy, the students’ interest, the classroom set-up) in an engaging manner and the reader is left with a clear picture of the experience of being in the room. Her account is more aesthetically-driven than the narratives presented in the following Results chapter. For example, she uses terms that are subjective to her experience as a researcher, such as “slow-talking,” “straggled,” and “vigorously”; whereas, all of the terms in this study’s narratives are defined and as objectively as possible. However, because of the success in her portraits in demonstrating the “how” and “why” of a “changing and evolving” real world context, such as a
classroom, her methodology underpinned the writing of the case study narratives. They provided helpful recommendations in gleaning data to construct rich narratives that could also illustrate the framework.

3.10.3.4 Trustworthiness

In *Qualitative Inquiry & Research Design: Choosing Among Five Approaches*, Creswell (2007) outlines validation strategies for establishing trustworthiness with qualitative research studies, such as this one. He presents eight procedures that can possibly be used to ensure that conclusions made from a qualitative study are sound. He recommends that researchers choose at least two of the eight listed for any study. This study involves five of them. They include: 1) prolonged and persistent observation in the field; 2) triangulation through multiple and different sources; 3) clarifying researcher bias from the outset of the study; 4) rich, thick description; 5) and external audits. I have addressed these five recommendations in the following ways. First, I have spent at least 17 hours in each of the teacher's classrooms. Second, I have collected multiple and different sources of data from a variety of participants within the case. Third, I have clarified my bias, as a researcher interested in how teachers foster small 'c' creativity, but also, as a research assistant and facilitator in the professional development program that the teachers were attending through their participation. Fourth, I have provided rich, thick description of the data, most evidently through my case study narratives. Fifth, I have created external audits not only through CAT scoring, but also by having four external raters validate my Small 'c' Creativity Framework scores.
3.11 Chapter Summary

This chapter provided information about how the study methodology was constructed to help me answer my main research questions. It presented my research strategies, including data sources, data collection, a logic model, and analysis. Specifically, I offered information about the research site, teacher participants, student participants, and case study methodology. I outlined data sources, such as focused observations, interviews with teachers and students, student learning products, and problem-based learning scenarios. I also explained my data analyses methods, which included scoring student products using Consensual Assessment Technique (CAT) with a set of external raters and scoring the entire data set using the Small ‘c’ Creativity framework with another set of external raters. The goal of this chapter was to detail my methodology for the study, so as to provide the reader with enough evidence to consider the results and conclusions of my study sound.
4. Results

4.1 Chapter Overview

In this chapter, I will present the results of my data analysis. First, I will outline the background information of each teacher. I will also provide information about their classroom and problem-based learning scenario. These will be presented as case study narratives for each of the five teachers, as a table and graphic presentation of the CAT scores of student products in each of the teachers' classrooms, graphic presentations of teacher scores along the five parts of the study's analytical framework, and individual and global trends. In the following section, I will provide case study narratives that include evidence to support the teachers' framework scores.

4.2 Background of Case Study Participants

Participant A: Bill

Bill is a Biology, Physical Science, and Environmental Science teacher with fifteen years of teaching experience. I observed one section of his 10th grade Chemistry class from 03/2010-6/2010. During the observation period, he taught at the same arts-focused magnet high school as Rob (Participant D). He is a mid-career changer from a career in business. Aside from teaching, he is currently pursuing a Masters degree in Psychology and Counseling from a local university. He expressed interest in transitioning to a career in family therapy within the next few years. He also is an avid guitar player and hosted his school's poetry contests and readings, one of which I observed. Since the time of my observation, he has been placed in disciplinary hold at school and is not doing any classroom teaching.
I spent 18.25 hours in Bill’s classroom over one school year. In the class I focused my observations on, Bill completed two sequential problem-based learning scenarios. For these units, Bill broke the students into partners and had them work together clustered along six long lab tables that ran horizontally through the room. The students did some of their work in the school computer lab and partner groups then shared one computer. Attendance was consistent in Bill’s class, with 25 students in total. The door was usually kept unlocked and students could leave the class to work on a project or in the library, if they got a hall pass from Bill. Most classes, students stayed in the classroom and did not ask to leave. Students completed problem-based learning products for two units; however, Bill lost the products for the first unit, so there were only 9 powerpoint products to score using CAT. His CAT score average was 2.86 (on a scale of 1.0-5.0), with scores ranging from 1.5 to 4. In Bill’s school, his units are called LAPs (Learning Activity Packets) and are noted in this way in the following sections. Also, his school is project-based, which is different than the other three schools visited. For the other teachers, using problem-based learning pedagogy was a new process. Likewise, working on a problem-based learning scenario was new for their students. However, for Bill, and the students in his school, using problem-based pedagogy for projects happened regularly.

Participant B: Ginny

Ginny is a Physical Science and Chemistry teacher with 5 years of teaching experience. I observed one section of her 10th grade Chemistry class during the 9/2009-6/2010 school year. She taught at a religious school for two years and currently teaches at one of the best public high schools in Philadelphia (determined at least in part by their
state-sponsored standardized test scores and high graduation rates). She is an African-American female, holds a Masters in Education from Temple University, and has Board Certification.

I spent 17.75 hours in Ginny’s classroom over one school year. In the class I focused my observations on, her class was broken up in 8 groups of 3-4 students each for their problem-based learning scenario. Due to the classroom set-up (small lab tables organized in the center for the room), students had a natural space in the classroom to collaborate and work on projects. Ginny allowed the students to form their own “Nanogroups,” which were different than their regular small groups used for other units. All of the small groups completed final products for their nanotechnology problem-based learning scenarios. Attendance was consistent and there were 31 students in total in the period I observed. Ginny kept the classroom door unlocked. Most classes, students stayed in the classroom and did not ask to leave. During their work on the problem-based learning assignment, Ginny let some groups leave to have a quiet space in the hallway. For the problem-based learning scenario, she asked them to find a solution to the pollution problem in Philadelphia. There were 8 video podcast products produced in the classroom. Products were scored using CAT and the average score for her classroom was a 3.84 (on a scale of 1.0-5.0), with scores ranging from 2.5 to 4.8.

Participant C: Kraig

Kraig is a male Chemistry and Math teacher with 35 years of teaching experience. I observed his 11th-12th grade Physics class from 9/2009-6/2010. Originally from India (where he ran a school and published several textbooks in Math and Physics), he had
been teaching at the high school I observed him in for seven years. This high school was
determined to be a Renaissance school by the Philadelphia School District during Spring
2010. This district-wide practice mandates that if a school is designated a Renaissance
school, they must fire or relocate at least one-half of their faculty before the next school
year. Because of this, Kraig was transferred to another school for the following school
year.

I spent 17.5 hours in Kraig’s class over one school year. Although it was required as
participation in the ITEST-Nano project that Kraig have his students complete problem-
based learning projects, Kraig did not create a problem-based learning scenario and so
his students did not produce products that could be scored using CAT. In the classroom,
Kraig organized front-facing desks and had the students watch (and sometimes copy)
labs that he presented in the front of the room, as well as complete worksheets and
textbook question and answer sets. Students sat in self-formed clusters. Students who
were less likely to engage with the lessons either sat in groups of 2-5 students and talked
during class time or sat by themselves and listened to music on their iPods. Students
who engaged with class lessons sat in the front of the room usually by themselves. These
students were often teased by the students in the back of the room, to which Kraig did
not forcibly intervene. Attendance was consistent for a handful of students and sporadic
for the majority of the 26 students enrolled in the class. During any random class, there
were usually 10 students in attendance. The classroom door was kept locked and most
students who attended were often late to class. Students were not allowed to leave class,
unless for an official reason (for example, if a career counselor needed to meet with
them or if they needed to see the principal).
Participant D: Rob

Rob is a Chemistry teacher with 14 years of teaching experience. I focused my observations on one section of his 10th grade Chemistry class from 9/2010-6/2011. While I was completing my observations, he taught in the same arts-focused magnet high school as Bill (Participant A). Prior to teaching, Rob had a career in the Air Force as an Engineer and also worked as a Carpenter and a Medical Technician. He co-founded an afterschool program for children in his neighborhood of West Philadelphia that was sports-focused and geared towards, as he said, "getting them off the streets." After my observational period, he was placed in another school, due to what the school termed as his poor performance as a teacher and the low scores of his students on state-mandated standardized tests.

I spent 18 hours in Rob's classroom over one school year. Rob completed two problem-based learning scenarios in the class I visited. For these units, Rob had the students form their own groups in 3-6 students each. There were three large, long tables that Rob allowed the students to work on. There were 25 students in total in the class I observed and attendance was consistent. The door was kept unlocked and Rob let students leave the classroom if necessary to work on their problem-based learning assignments or to work on another project in the library. He purchased a hand-held digital video camera on his own for the problem-based learning projects and he allowed the students use the camera around the school, in order to film for their projects. Rob completed two problem-based learning assignments, with a total of 9 products (4 video podcasts; 1 animation; 3 posters; 1 video infomercial) in total. Eight of these products came from the class I observed. The ninth product was a video collaboration produced by
a small group in the class I observed and a few students from another class period. The average CAT score of these products was a 2.51, with scores ranging from 1.1 to 4. In Rob and Bill's school, units are called LAPs (Learning Activity Packets) and these are noted this way below. As explained in Bill's biographical section, Rob's school is project-based, which is different than the other three schools visited. For the other teachers, using problem-based learning pedagogy was a new process. Likewise, working on a problem-based learning scenario was new for their students. However, for Rob and the students in his school, using problem-based pedagogy for projects happens regularly.

Participant E: Anna

Anna is a Physical Science and Chemistry teacher, with one year of teaching experience. I observed one section of her 10th and 11th grade Chemistry class from 09/2010-06/2011. She taught at a school that was determined to be a Renaissance School by the Philadelphia School District after the observational year. She had completed her first year of teaching at the same school the year prior. She did not have any other substantial work experience, as she had just graduated from college before starting to teach. Anna left her teaching position to pursue a Ph.D. in Chemistry at a state university after the 2010-2011 school year.

I spent 17.25 hours in Anna's classroom over one school year. Anna completed one problem-based learning scenario in her class. For this unit, Anna let small groups emerge to complete an audio podcast that advertised a new flavor of Rita's Water Ice. It was the same problem-based learning scenario she and Rob (Participant D) co-created during the summer ITEST-Nano professional development session and the same one that
Rob used. There were five medium-sized tables in her classroom, where students worked individually and in small groups. Students were not allowed to leave class, unless for an official circumstance and the door was kept locked during class sessions. The school had a laptop cart. When the class began the problem-based learning assignment, each group had its own computer to use to record their audio in the Garageband application. The laptop cart was stolen in the middle of the year, so Anna allowed the students to share her personal laptop to record their podcasts. Class attendance was low, especially after the holiday break in December and January. Anna’s roster changed twice during my observation year and by the end of the year, only approximately 9 students (out of a possible 24) came to class regularly. Anna’s students produced 6 products in her class. These products received an average CAT score of 1.78, with scores ranging from 1 to 3.5.

4.3 CAT Scores

Below is a table that shows the total amount of problem-based learning products produced in each teacher’s classroom and the average CAT scores of these products:

<table>
<thead>
<tr>
<th>Participant</th>
<th>Average CAT Score</th>
<th>Total Product Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Bill</td>
<td>2.86</td>
<td>9</td>
</tr>
<tr>
<td>B: Ginny</td>
<td>3.84</td>
<td>8</td>
</tr>
<tr>
<td>C: Kraig</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 6 shows that students produced 9 products in Bill’s classroom, 8 products in Ginny’s classroom, 0 products in Kraig’s classroom, 9 products in Rob’s classroom, and 6 products in Anna’s classroom during the observational periods. The 9 products in Bill’s classroom were done in response to one problem-based learning scenario. He did two sequential problem-based learning scenarios, but lost the products for the first one, so only there was only set available to score using CAT. Ginny’s 8 products were done in response to one problem-based learning scenario. Kraig did not include a problem-based learning scenario in his lessons, so there were no products to score using CAT; thus, he has 0 products represented in the table. Rob’s students produced 9 products in response to two problem-based learning scenarios. 8 of the products were done in response to the first problem-based learning scenario and 1 was done as a cross-class period collaboration. Anna’s students produced 6 products in response to one problem-based learning scenario.

Each product received two scores from the two raters using CAT. These two scores were averaged, so that each product itself had an average score. These average scores for each product were added up for each teacher’s classroom and produced a total product score. Then these total product scores were divided by the number of products produced, so as to come up with an average CAT score for each teacher. For example, Table 7 displays the two rater’s CAT scores for Anna’s audio podcast products, along with averages for each product:
Table 7

*Example of Calculation Process of Average CAT Score*

| Product #1 | 2  | 1.4 | 1.7 |
| Product #2 | 2  | 1.2 | 1.6 |
| Product #3 | 2.5 | 1.5 | 2.0 |
| Product #4 | 3.5 | 2.0 | 2.75|
| Product #5 | 1.5 | 1.3 | 1.4 |
| Product #6 | 1  | 1.5 | 1.25|
| Total Product Score | | | 10.7 |

The total product score for Anna’s products was 10.7. When 10.7 is divided by the number of products in her classroom (6), her average CAT score becomes 1.78. The same process was done to each teacher’s set of scores. Because Kraig did not have any problem-based learning products to score using CAT, his average CAT score is 0.

Below is a graphic representation of average CAT scores in each teacher’s classroom, ranging from lowest to highest:

![Graphic representation of average CAT scores]

*Figure 18. Continuum of average CAT scores.*
In Figure 18, average CAT scores are displayed along a continuum. The scores range from 0 (Kraig) to 1.78 (Anna) to 2.51 (Rob) to 2.86 (Bill) to 3.84 (Ginny). Ginny’s products received the highest average CAT score. There is a difference of 3.84 between the lowest average CAT score (Kraig) and the highest (Ginny), but only a difference of 2.06 between the lowest CAT score actually scored (Anna) and the highest (Ginny). The second highest average CAT score, (Bill), is almost 1.0 less than the highest (Ginny). Bill’s average CAT score (2.86) is the closest to Rob’s average CAT score (2.51) of any other two scores (.35).

4.4 Small ‘c’ Creativity Framework Scores and Narratives

In this section, I will present Small ‘c’ Creativity Framework scores, organized by framework components and gradating from the highest to the lowest scores. Each continuum of scores is displayed in graphic representations and then includes a narrative that presents evidence for the scores. In the following sub-section, I will discuss the Support Divergent Thinking Framework Component.

4.4.1 Support Divergent Thinking Framework Component

This sub-section addresses the Support Divergent Thinking Framework Component. Below is a graphic representation of the teachers’ scores along the continuum:
The Support Divergent Thinking Framework Component states that teachers who foster small 'c' creativity: *Support divergent thinking that is grounded in the lesson's activities or concepts.* In terms of this part of the framework, Rob scored the highest with a *high* score. Bill and Ginny both scored a *medium-high.* Anna scored a *medium* and Kraig scored a *low-medium.* None of the teachers scored *low* on this part of the framework.

The categorization manual specifies a *high* score for the Support Divergent Thinking Framework Component as when:

The teacher gave students open-ended assignments that required them to create a product completely on their own. In his or her interview, he or she expressed that he or she valued divergent thinking and gave clear examples of past and present students who exhibited creativity.

For this part of the framework, Rob scored a *high.* He completed two open-ended problem-based learning scenarios in the classes I observed that required his students to create a product completely on their own. For example, for the first problem-based learning scenario, Rob had his students form their own small groups and had them imagine a new flavor of Rita's Water Ice, using either an artificial sweetener (e.g., Equal, Splenda, or Stevia) or regular sugar. He connected this to another LAP on determining the chemical properties of foods, in which students had to record all of the foods they ate for a day, figure out the caloric content, and then write an essay about their food intake.
He called this the calorimeter project. For the sweetener problem-based learning scenario, he allowed the groups to create audio podcasts, video commercials, posters, or animations to show their new flavor. For the second problem-based learning scenario, he allowed a small group of the students in the class I observed and some other students in another class to film a video infomercial on the benefits of "Nanopants," a type of pants produced by the Gap corporation that used nanotechnology to prevent staining. This infomercial was sent to the Gap by Rob. He accepted all student products for the first problem-based learning scenario and gave credits to those students involved in the second problem-based learning scenario.

The categorization manual also defines a high score for the Support Divergent Thinking Framework Component as when a teacher expresses that he values divergent thinking in his interview and gives clear examples of past and present students who exhibited creativity. Rob had no problem naming several students, in both past and present classes, he recalled as exhibiting creativity. One student he mentioned was a past student who had a high proficiency at computer skills. During a unit on chemical reactions, he allowed the student to make an animation to display his knowledge. The student completed this animation and then helped Rob create a class website, in which to upload it. This website also included videos of Rob performing experiments, such as a carbon transformation demonstration, inside and outside of the classroom environment. Rob remarked that this particular student seemed to "really like Chemistry" and was creative within class and that he knew him to exhibit creativity in his art class as well. Another creative student in the class I observed was named Victor. Rob noted that Victor would "extend anything" he gave him. Rob explained that often in class, as he would
demonstrate a chemical reaction, Victor would ask questions about how the reaction might be done differently. As Rob explained, he would tell Victor to do research to discover the reasons why for himself. He also mentioned that he would channel Victor's inquisitive nature and creativity by making him a leader and allowing him to help other students with the assignments. I witnessed Victor helping other students in several classes. In his interview, Victor discussed how Rob "engaged" his creativity. He said that Rob allowed him to create products for lab assignments in "many formats, such as "presentations or websites" and especially the LAP (calorimeter project) allowed him to use creative writing to present his data. Of the six students interviewed in Rob's class, four students mentioned that Rob inspired their creativity through his use of open-ended assignments. Like Victor, another student, Sade, discussed how Rob's open-ended assignments inspired her creativity. She explained how working on the "Nanopants" informercial was a worthwhile experience for her, because in the beginning of the assignment, "we didn't know how we wanted to do it, so we had to put our minds to it.”

Bill and Ginny both scored medium-high the Support Divergent Thinking Framework Component. The categorization manual characterizes a medium-high score as when:

Teachers provided loose guidelines and valued work that was created within a certain amount of constraint. In their interview, teachers referred to students either in past or present classes who exhibited creativity.

While Rob had his students complete open-ended assignments on their own, Bill and Ginny provided more constraints for their students. For example, Bill did two problem-based learning scenarios in his class that provided students with loose guidelines and valued work that was created within a certain amount of constraint. In his first problem-
based learning scenario, Bill broke the students up into heterogeneous partners and had them imagine a baby they might have together. Depending on what diseases ran in each of their families (i.e., what genes they carried for these diseases), he requested that they find a solution through some sort of current advancement in nanotechnology. All of the students created the same products, which were audio podcasts (with corresponding scripts) that discussed this solution, after they completed several weeks of research, writing, and recording. According to Bill, he saved the audio podcasts on a zip drive and then lost the drive, so these products where not scored using CAT. Also, he lost the podcast scripts, so these could not be scored. He completed a second problem-based learning scenario on how nanotechnology might be used to combat the British Petroleum leak in the Gulf of Mexico (which occurred April 20, 2010). The students stayed in the same partner groups and produced powerpoint slides that outlined their solutions. Bill required all students to complete powerpoint slides and did not allow for students to turn in any other product.

The manual also states that teachers, who receive a medium-high score on the Support Divergent Thinking Framework Component, refer to students in their interview either in past or present classes who exhibited creativity. This is distinct from those teachers who receive high scores, such as Rob, who had no problem naming students in both his past and present classes. In his Creativity interview. Bill had no problem naming several students in just his past classes (not his present) that he recalled as exhibiting creativity. The first was a student who produced an animal cell pendant, six to seven inches across, for a cell unit a few years prior. He explained in full detail the materials she used for the pendant (pipe cleaners for the endoplasmic reticulum, a giant cotton ball
for the nucleus) and that he still had it. He seemed particularly impressed that the model was three-dimensional and that it could be worn as jewelry. He named another student who made a cell model that was so carefully constructed that it contained the level of detail of the protein sensors of a cell. He expressed that the level of detail was "intense." A third student also did a model, but instead of a cell she did a model of Boron, complete with intricate displays of the protons and neutrons. He described the irony he saw that these three students had engaged with the concepts in science so creatively, despite not being science majors. When asked if he thought non-science majors were the most creative, he said "yes." Bill thought that he fostered creativity because he "got to know his students, got to know what interested them" from the beginning of the year. As he discussed, getting to know "what they are doing" outside of class allows you to "tailor the assignment and the assessment" towards their interests. To him, when students are creative they go "beyond an assignment and make it their own." He explained that it was very important to his teaching practice for him to give space for students to have ownership over their own work through open-ended assignments. Four of the six students interviewed mentioned that Bob gave them open-ended assignments, which stimulated their creativity. For example, one student, Calvin, mentioned that "In this class, he always gives you time to do something of your own. And that is a good thing." Another student, Hank, acknowledged that in "every assignment he asks you to do, he tells you to be creative. He doesn’t tell you how to do it. He wants you to do it your own way. For example, in the last LAP we done, he told us how he wanted us to format it, but he gave us freedom to put whatever we wanted in it."
For Support Divergent Thinking Framework Component, Ginny also scored a medium-high. The manual states that medium-high scoring teachers “provided loose guidelines and valued work that was created within a certain amount of constraint.” Ginny’s lessons exemplify this definition. Her lessons were not completely open-ended assignments that the students did entirely on their own, like in Rob’s classes. For a lesson on size and scale, Ginny had the students cut out pictures of objects (for example, the width of a wedding ring and the height of a 5 year old) and order them by scale on a posterboard. As long as they loosely followed the goal of the lesson (to order the objects by scale), she allowed any visual organization of the elements. There were variations in the products produced and she seemed to encourage these variations. For her problem-based learning scenario, she asked students to research how nanotechnology might be used to solve the air pollution problem in Philadelphia. They had to present their findings in a video podcast. As long as the students actually produced a video podcast, their work was accepted. One group presented an audio podcast and was reprimanded. Four out of the six students interviewed mentioned that Ginny’s open-ended assignments helped them to be creative in class. A student, John, who completed a video podcast noted in his interview the problem-based learning project and the science fair project were the most creative assignments in the class. He explained how he understood how it might have been “difficult” for Ginny to allow for students to be creative in other class assignments. He acknowledged what he saw were intrinsic limitations in the subject matter and class activities, as he said that “it’s difficult to create a controlled, safe experiment that is scientifically accurate and allows us to be creative.” Another student, Kathy, echoed his opinion of the difficulty to be creative in Chemistry, as she stated that Chemistry was the
class that required “the least creativity, or at least this course in chemistry.” She explained this was due to all of the lab work, but she also mentioned that the problem-based learning scenario helped to foster her creativity.

The manual also defines a medium-high score, as when “teachers refer to students either in past or present classes who exhibited creativity” in their interviews. Unlike Rob, who referred to past and present students who exhibited creativity, Ginny (like Bill), only discussed a past student. In her Creativity interview, Ginny described her most creative student as a girl she had in a Physics class during her time teaching at another school. She said she was artistic and that “you could tell by looking at her that she lived her life outside of the box by the way that she dressed.” She explained that this student “had trouble with some of the laws in Physics...because so many laws are already set.” She ended up getting a B in the class. If there was a project in class, however, Ginny explained, “she would always put her own spin.” Ginny offered projects in this past class, so that students like this one would have space to be creative. A project Ginny remembered having the students in this class do was one dealing with electrical circuits, in which students constructed a game involving the circuits. She described that the game this creative student did was “really good.” In the class I observed, she thought that she “encouraged creativity in the problem-based learning projects.” Originally, she thought there would be one correct solution to the project’s problem (the nanofilters that were being using by scientists and companies currently); however, during the year she decided it would be better to give them the space to “come up with something on their own.”

For this part of the framework, Anna scored a medium. The manual delineates medium scoring teachers as those who, in their classes, “provided guidelines that allowed
for some divergent thinking, but whose “assignments necessitated a majority of conformity to the guidelines.” This is different than teachers who scored *medium-high* with assignments that provided students with “loose guidelines.” Whereas Ginny and Bill gave their students problem-based learning scenarios with loose guidelines, Anna’s scenario necessitated conformity to her guidelines. Anna completed one problem-based learning scenario in her class. She let her students choose their own groups and had them conceive of a new flavor of Rita’s Water Ice that used an artificial sweetener or regular sugar. She let students come up with their own flavor, but she did limit the types of sweeteners. For the beginning part of the unit, she explained the molecular structure of various sweeteners. Next she had the students make powerpoints in their small groups that outlined some information about their chosen sweeteners. While the students were working on this part of the assignment, the laptops (kept on a rotating laptop cart in the school) were stolen and never recovered. Because of this, Anna’s students lost their powerpoint slides. Anna continued with the unit despite this setback and had them create scripts on worksheets to make audio podcasts advertising their new flavor of Rita’s Water Ice. These worksheets asked them to list the name of their new flavor, what sweetener it used, the price of the ice, and the health benefits of the sweeteners. Six audio podcasts were created. Anna did not allow any other product to count for credit for the assignment and as far as I observed, no student asked to create an alternative product.

The manual also defines a *medium* score as when teachers “could name a student in their present classes who exhibited creativity,” not in “past or present classes” as *medium-high* scoring teachers could, like Ginny or Bill. During her Creativity interview, Anna mentioned a current student in another current class that exhibited creativity, but
she did not offer her name specifically. She remarked that this student was “very good artistically” and “very good at thinking outside of the box and drawing her own conclusions and so she’ll often like jump ahead of where we are at.” She did not discuss any specific product that she made that exhibited her creativity. After being prompted, she also referred to two students in the class I observed, a rapper named John, and a poet, named Monica, and another student who was good at drawing. Both John and Monica had advanced interests in their particular creative disciplines. They were not the only students interested in creative writing, as four of the six students interviewed said that they wrote poetry or hip hop songs. John had created two CDs on his own record label and was selling them among his family and friends. During many of the lessons I observed, Monica expressed her major interest in pursuing a career as a poet. She attended several writing groups outside of school, participated in “open mic” readings around Philadelphia, and was often writing poems in class (which she shared with me and others). Anna did not discuss any lessons that she created that tried to harness these students’ particular creative strengths. She explicitly said that she had not “done a lot with” these creative students this year, but if she were advising teachers how to foster creativity she might give a student like Monica creative writing prompts in class. John did not create a podcast with the others, due to the class’s shifting roster, but Anna expressed that she “wished he had been here from the very beginning, so he could have done the podcast project.” Three of the six students interviewed mentioned instances where Anna’s open-ended assignments helped to inspire their creativity. Despite the fact that Anna did not have assignments that utilized his creative writing skills, John, described a project in class where they made their own sugar cookies. He said, “She
would bring in a like a regular cookie, but we would like mix stuff, like flavors and stuff, and we basically would make our own flavor cookie...it worked well, it was a good thing.” Another student, Amy, mentioned the problem-based learning scenario as an open-ended assignment that fostered her creativity. She described a powerpoint she made for the assignment that was “colorful and had lots of pictures.” Unfortunately, this powerpoint presentation was lost when the laptops were stolen and could not be scored using CAT.

The categorization manual defines *low-medium* scores on Support Divergent Thinking Framework Component as when:

Teachers provided assignment guidelines that most of time have one correct answer and/or did not ask students to think creatively. They might have an assignment, which allowed for students to have novel thinking or to create a novel product. Teachers could think of a student who exhibited creativity in their present class, although the description was unspecific.

For this part of the framework, Kraig scored a *low-medium*. Whereas a *medium* scoring teacher, like Anna, provided her students with a problem-based learning scenario that allowed for some divergent thinking (e.g., coming up with a new flavor), yet necessitated some conformity (e.g. for types of sweeteners), most of Kraig’s assignments were worksheets or assigned questions in the textbook. These did not allow for much divergent thinking. For example, when he performed a dilution experiment, he used an overhead projector, presented his ideas, and asked for the students to watch quietly at their desks. He had gotten the lesson idea from the ITEST-Nano professional development summer session. It involved diluting a liquid infused with color until the liquid appeared clear in order to illustrate size and scale. The students watched the experiment at their desks and filled out worksheets. There was only one possible correct answer and Kraig was in
charge of demonstrating it. After the demonstration, students had to replicate Kraig’s answers on their worksheets. In another assignment in which students were given paper clips and rubber bands in order to construct vectors at their desks, some variations of construction were allowed, as long as the vector was the number Kraig specified.

These lessons were in contrast to the way he described how he fostered creativity in his classroom during his Creativity interview. He discussed how he started his “lesson with some new idea,” as he did not believe in “spoon-feeding” ideas to his students, since “creativity is the beginning of a new idea, born in the minds of kids.” The manual states that low-medium scoring teachers as those who might be able to think of a student who exhibited creativity in their present class, but that the description would not be specific. While Anna could refer to a student in a present class who exhibited creativity, Kraig could not name a specific student in a past or present class that stood out for him as creative. In his interview, he did refer briefly to a “kid” who “exhibited his ideas using different type [sic] of glass slabs for verification of laws of refraction.” Additionally, in his Nanotechnology interview, Kraig explained that “I wanted to do more experiments with the students, but I couldn’t because of the resources. So, I will have to save that for next year.” He also said that “because I am physically not close to the lab,” he could not complete the labs he wanted to do during the school year. The labs he had in mind might have been more conducive to promoting divergent thinking, but unfortunately, I did not observe these labs. Only one of the students interviewed mentioned that Kraig’s assignments nurtured their creativity. This student, Kasey, said that when they had to draw graphs, he was using his creative skills. Another student, Paul, said that he was creative in other classes, but in Kraig’s class he was not creative. He stated that there
were not any open-ended assignments in Kraig’s class, as “when we start doing the lab, we just follow the direction he give us and then we just do it.”

4.4.2 Accept All Artifacts Framework Component

This sub-section addresses the Accept All Artifacts Framework Component. Below is a graphic representation of the continua:

Figure 20. Accept All Artifacts Framework Component continuum.

The Accept All Artifacts Framework Component states that teachers who foster small ‘c’ creativity: *Accept learning artifacts that are novel and relevant to the lesson.* In terms of this part of the framework, Figure 20 illustrates that Rob scored the highest with a high score, with Bill and Ginny both scoring a medium-high. Anna scored a medium and Kraig scored a low-medium. None of the teachers scored low on this part of the framework.

The categorization manual defines a high score on the Accept All Artifacts Framework Component as when:

Teachers accept all learning artifacts that were novel and relevant to the lesson. Relevancy went beyond disciplinary and/or assignment constraints.

For this part of the framework, Rob scored a high. For his two problem-based learning assignments, he accepted all products, as long as they were novel and relevant to the lesson. Relevancy went beyond disciplinary and assignment constraints. Students did not just create products that were suggested by Rob, but developed alternative ways to
complete the assignment on their own accord. For example, one group created an animation to serve as a commercial for their new flavor of Rita's Water ice for a flavor they had named "Gummy Grizzlies" with moving images of bears, along with the kind of sweetener it contained (Neotame), with no formal prompting from Rob to do so. In his Creativity interview, he discussed how he accepted all artifacts that used materials the students "felt comfortable being creative with."

Five of the six students interviewed described how Rob's lessons helped to encourage their creativity because of his acceptance of novel and relevant products. In her interview, one student, Katie, cited the "Nanopants" informercial as a project that inspired her creativity, because they had to create the video "on their own," "brainstorm how they wanted the video to look," and that Rob pushed them to make it "attention-grabbing." She also discussed an assignment on the periodic table, where they all made posters of specific elements. She noted how Rob told them to make them "all colorful and different from each other, so they won't be all dull." In her interview, another student, Alia, explained that all of Rob's lessons asked her to be creative. She was also one of the students who had worked on the collaborative "Nanopants" informercial with Katie. She said that the project inspired her creativity because they had to make the video "entirely on their own." She also gave an example of a hot air balloon project that asked them to make balloons in small groups, which I did not observe. She discussed how this project encouraged her creativity, because "even though they had to all follow the same steps," Rob inspired them to all work to make their balloons "different from everyone else's" or "to go the highest."
Both Bill and Ginny scored a *medium-high* for the Accept All Artifacts Framework Component. The categorization manual delineates a *medium-high* score as when teachers:

Accepted all learning artifacts that were novel and relevant to the lesson, as long as the learning artifacts produced kept within the assignment guidelines. Disciplinary boundaries could be crossed.

While Rob accepted all of the products students produced in the class, Bill only accepted products that fell within assignment guidelines for the problem-based learning scenario. He also demonstrated his tolerance for products to cross disciplinary boundaries. For his two problem-based learning scenarios, Bill accepted all of his students’ products, as long as they were relevant to the lesson. For the first problem-based learning scenario, he supposedly accepted audio podcasts (although I never got to collect them, as Bill said that he lost them). For the second problem-based learning scenario, he accepted all powerpoints the students produced. In his Creativity interview, he discussed how he accepted artifacts that might come from different disciplines, as long as they were related to the lessons; however, I did not see this occur in the classes I observed. All of the assignments collected and scored (powerpoints) were in the form asked for by the assignment guidelines. Four of the six students interviewed mentioned that they appreciated how they were allowed to cross disciplinary boundaries in Bill’s assignments. For example, a student, Mondrian, expressed how he appreciated that he could use his creative writing skills to “write a script” for the first problem-based learning scenario, as long as he “tied it to Biology.” Another student, Jenny, explained how she enjoyed “using cartoons” in her second problem-based learning scenario, because Bill allowed her to “make it funny and not be boring.”
In his Creativity interview, Bill expressed other times when he accepted products that deviated from assignment guidelines. He defined creativity as “how you can take what is being presented, the assignment given, and how you might put your own spin or your own flair to what has been assigned.” He discussed how even if students were to complete an assignment with a product from a different discipline (for example, a painting for a science assignment that asked for a report), he would accept it and create an “alternative assessment” to support its inclusion in the student’s final grade. He explained, “what a teacher has to do is recognize the need for creativity and be able to implement things or get creative and come up with some creative ways to take assessments. Especially for those kids who may not succeed in the ‘traditional’ way.”

Bill also mentioned a past student in his interview, named Jim, who cheated on an assignment by copying his answers from a textbook. Instead of failing Jim, Bill created an alternative assignment for him. He knew he had a strong interest in music (Bill described him as a “metalhead”), so he told him to listen to audio found online of the planets in the solar system. As Bill explained, this audio “is like a symphony and has no words, but is music.” He had Jim “interpret” the sound musically and write a paper on how this relates to the solar system “as we know it.” According to Bill, Jim produced a great paper, which made Bill feel like a successful teacher, as he “wanted to see the kid succeed.”

For this part of the framework, Ginny scored a medium-high. Her case provides an alternate example to Bill’s of a medium-high score, as she as well only accepted products that fell within assignment guidelines and was tolerant of products that crossed disciplinary boundaries. For the problem-based learning project, Ginny accepted all the
students’ video podcasts, as long as they all were novel and relevant to the lesson (i.e., they all exhibited small ‘c’ creativity). Unlike in Rob’s class, where students had freedom to create products out of the assignment’s guidelines, a group of Ginny’s students who completed an audio, versus video, podcast, were reprimanded. It may have been interesting to see what kinds of audio podcasts, or other types of products, students might have produced if they had not had to make a video podcast for the assignment. Nevertheless, she did make space in her class for students to apply their science knowledge to new ideas. For example, Ginny had volunteer students complete individual entries to the school science fair. She accepted everyone’s projects that were complete and gave them extra credit. She was proud of their work and displayed them in her classroom and made a point of showing them to visitors (like me). These projects showed a great deal of engagement with science concepts, such as one entitled “The Effects of Nanosilver on Microbial Bacteria.” This particular project tested how administering nanosilver on E.Coli bacteria could slow its growth.

In looking for creativity in her classroom, Ginny explained she “would be looking for something that doesn’t fit the norm. Looking for my kids to look outside themselves and do something different. I’m always pushing them to go outside the assignment and put in a little of themselves.” In presenting their problem-based learning scenario’s solution, she told them to “come up with something interesting, something you would want to watch” when making their video podcasts, because as she explained later in her interview, she wanted to give them “creative license.” Four of the six students interviewed discussed how they appreciated how Ginny incorporated assignments in the class that nurtured their creativity by allowing for novel and relevant products. One student, Hannah, discussed
how she especially enjoyed working on the science fair project, as she was able to make a “new discovery” about planarian regeneration.” Another student, Shaun, reiterated this idea in his interview. He acknowledged, “the Nanovideo was fun, because mostly when I think of a video, it’s mostly facts and figures, but she basically said, ‘Guys, if you make something that you don’t want to watch, I don’t want to see it.’ So, she made us make something fun.” In her Creativity interview, Ginny cited his project, “The Adventures of Nanoman,” as one of the most creative products created from the unit. It received an average score of 4.05 out of 5 using CAT.

For this part of the framework, Anna scored a medium. The categorization manual defines a medium score as when the:

Teacher was moderately accepting of learning artifacts that were novel and relevant to the lesson. However, “relevant” was defined strictly as falling within the assignment guidelines and students may have been only moderately allowed to cross disciplinary boundaries.

Whereas Ginny and Bill accepted novel and relevant products that fell within assignment guidelines and may have crossed disciplinary boundaries, Anna accepted all the student products only in the form of audio podcasts. In her Creativity interview, she discussed how it was important to “identify” her students’ creative “strengths” and give them a “variety of experiences” in order to harness these skills into potential career paths. She gave the example of the field of graphic design or a career as a musician as paths that creative students might be interested in. She suggested that creative writing assignments may have been good for a students like Monica, who had such a strong interest in poetry, but that she did not get a chance to give her such assignments in the class. She also gave the example of John, who had experience as a rapper. Ideally, the podcast assignment
would have been a good way to give him an opportunity to interact with the nanotechnology content; however, he entered the class too late, due the shifting roster. Anna could have given him alternative assignments that utilized his skills at language and music, but she did not. It is important to note again that I did not observe any students asking her to complete an assignment with an alternate product, nor did she state that it had it occurred in a past class. Three of the six students interviewed mentioned that Anna was accepting of novel and relevant products that fell within the assignment’s guidelines. In her interview, a student, Anya, explained that when Anna had the class do projects “she’ll try to make us have something creative,” but that it depended on “what they were doing.” Anya felt as if they were studying for the PSSA testing a lot and that it was hard for her to “think” of when she last “had to be like very creative” in Anna’s class. Another student Don, described a cookie making project, where Anna had her students make new flavors for sugar cookies. Don said that he thought coming up with his new flavor, Blue Vanilla, was a process in class that utilized his creativity.

Anna defined creativity as “using your knowledge and like your own imagination to create something new and original that is different from what other people create.” She discussed that creativity can occur in different disciplines and gave examples of how students could be creative in music, visual art, and writing. She remarked that she saw creativity occur in response to her own lessons, when students all had different responses to the lesson’s guidelines. She gave the example of a poster project, where “everyone’s poster” looked “different” and the problem-based learning scenario, since the groups “came up with their own flavors and used different sweeteners.” She also noted that sometimes during a “problem-solving” assignment, if “someone finds a new way to think
about the problem to get their answer, they are thinking outside the box.” These beliefs show that she could be open to accept alternative assignments as long as they were novel and relevant to the lesson, but that she had not had the opportunity to do so yet in her teaching career.

For this part of the framework, Kraig scored a low-medium. The categorization manual specifies a low-medium as when teachers construct “assignments mostly only allowed space for one correct answer and do not ask for students to create novel and relevant learning artifacts.” It also states that low-medium scoring teacher for the Accept All Artifacts Framework Component may have included “one assignment that asked for students to create a novel and relevant learning artifact in response to the assignment.” While a teacher like Anna allowed for students to turn in novel and relevant products that strictly followed assignment guidelines, Kraig’s classroom assignments were for the most part call and response from the textbook and worksheets. There was no space for more than one right answer, which was always the one Kraig demonstrated, as most of the problems involved one interpretation of Physics formulas. Kraig worked with a few interested and invested students in how to complete the problem and stressed one right way of solving them. His student, Paul, was a more engaged student and Kraig was often at his desk, discussing a problem with him. However, Paul did not feel he was being creative when working on these problems, as he explained, “in this class, we mostly read from the book. We do the math on it. We read from a formula and do what he does. We just follow the steps and do it in class.” None of his students interviewed mentioned assignments in which they created novel and relevant products to demonstrate their
learning in Kraig's class. His student, Kai, said Kraig's lessons did not allow him to use his creativity and he “just did them cause [he] had to.”

In the vectors' assignment, there was space for students to create different vectors with their paper clips and rubber bands. In his Nanotechnology interview, he explained that, “I tried to find the nanotechnology concepts and I tried to embed them in my curriculum.” He also said that he tried to “always encourage and promote” creativity in his students “through indirect hints.” I unfortunately did not see this happen. Had it occurred, he might have accepted different kinds of learning artifacts that the students produced from open-ended assignments.

4.4.3 Nurture Collaboration Framework Component

This sub-section addresses the Nurture Collaboration Framework Component. Below is a graphic representation of the continuum:

![Figure 21. Nurture Collaboration Framework Component continuum.](image)

The Nurture Collaboration Framework Component states that teachers who foster small 'c' creativity: *Nurture collaboration among small group members in which individual kinds of creativity within the group are supported.* In terms of this part of the framework, Ginny scored the highest with a medium-high score. Bill, Anna, and Rob all scored
Kraig scored low. None of the teachers scored high or low-medium on this part of the framework.

The categorization manual defines a medium-high score as when in a teacher’s classroom:

The teacher let small groups emerge within the class and gave ample time both in and out of class for students to self-organize and demonstrate their individual creative strengths within small group projects. The teacher might have done things in class to aid small groups to form, like arrange desk in small groups, assign small group projects, etc.

For this part of the framework, Ginny scored a medium-high. She had her students complete their problem-based learning projects in groups. She let them pick their own groups, which they kept throughout the entire Nanotechnology unit and problem-based learning project. She termed these groups their “Nanogroups” as they worked in different small groups for other class assignments. She did not particularly construct groups, so that students with different strengths or interests would work with others. The manual specifies that a high score on the Nurture Collaboration Framework Component is when a teacher, “constructed” small groups “consciously,” in order to “assemble students together with various creative strengths.” Ginny did not appear to deliberately construct groups. Groups in which individual kinds of creativity (for example, scriptwriting, acting, or science content knowledge) were exemplified in their problem-based learning products were only so due to chance or self-organization (arguably, the self-organization is due to her support of collaboration).

She did, however, encourage them to take particular roles in groups. From my first observation, when the “Nanogroups” first started working together, she told them to take particular roles, such as “Recorder, Reporter, and Materials Person.” She also stressed the
importance of group work in science verbally. For example, during one class session, she told her students, “Scientists have to work together to solve unknown things in our world.” She gave them ample amounts of time in class to collaborate in small groups on various class assignments. She also organized her classroom in small group tables, which aided their collaboration. In addition, even as she gave them plentiful amounts of time to work on their project, the video component of the assignment necessitated that the students meet outside of class to finish their problem-based learning projects and furthered their interaction.

Four of the six students interviewed mentioned that small group work in Ginny’s class helped them to come up with new ideas. In her interview, a student, Ellen, described how she enjoyed collaborating with her group, as she was able to “bounce...ideas off of each other...and hear what they’re thinking, and that’s really fun.” She described how when working on her problem-based learning project, a video podcast of a puppet show called “The Making of the Magic Nanofilter,” their ideas started out as a joke. She explained how they were writing a story for puppets together to be funny, but then they decided to go with it for this final product. As she said, Ginny gave them “a list of requirements, a beginning and an end” and then they could “be free and it is really fun.” Another student, John, explained that working in small groups helped him to see other students’ “different perspectives.” In her Creativity interview, Ginny defined creativity as “putting your own spin on whatever it is you are creating” and that it was important to her for students to collaborate in groups. She also explained that creativity “might look different for different people.” During observation, she attempted to form small, collaborative groups where group members might contribute to their own individual
types of creativity to group goals by giving them lots of time and license to work together.

Bill, Rob, and Anna all scored medium on the Nurture Collaboration Framework Component. The categorization manual specifies that medium scoring teachers:

- encouraged small groups to work together and supported their emergence, but did little to construct them (for example, assign groups with members exhibiting various creative strengths together) or to maintain them (for example, did not enforce groups working together on small group projects, even if they were assigned to do so)

While Ginny let small groups emerge and self-organize in her classroom and did things to aid their emergence (arrange small groups and assign small group projects), Bill, Rob, and Anna all encouraged small groups to work together, but did little to maintain them. Thus, all three cases provide alternate portraits of what a medium score looks like in different classrooms. For example, Bill scored a medium on the Nurture Collaboration Framework Component. For the two problem-based learning scenarios observed, Bill had his students complete them in groups of two to three students. The first assignment involved the students pairing up to imagine a baby produced by their combined DNA, he broke up the students into assigned different gender pairs. As there were more girls in the classes observed, he created groups, where the two female students “shared” the male member. These groups seemed to be constructed entirely based on gender versus any instinct to break them up due to their creative strengths. He verbally encouraged the students to continue with these assigned groups for the second problem-based learning scenario; however, in the written assignment he said they could “work solo, 2, or 3 in a group.” From the first problem-based learning scenario to the second, groups shifted
slightly, when a few students dropped out of school entirely or stopped showing up for class, but generally students stayed in the same pairs.

Bill gave time in class (several class periods) for students to work together on their problem-based learning scenarios. The amount of work required to complete the assignments did not necessitate that the students work on it outside of class. After assigning the groups, Bill did not do much to maintain the small groups, except to reiterate that students should “WORK!” when he noticed that they seemed to be talking about other topics than the assignment or to tease them for not working. That being said, Bill’s classroom had a general jovial atmosphere during group work time, with an open door policy for students not in the class to visit during the period. As Bill explained to me, he was the unofficial “therapist” of many of the students in the school who did not fit in or relate to their other teachers. There were always a few students hanging around during class time, who would either sit in the room and do their work, or would interact with the other students. Bill let students walk around the class freely during group time. One student in the class I observed, Dan, had a dancing background, and would walk around and dance with other female class members not in his group. Bill did not seem to care if Dan was off task and would sometimes dance at the front of the room or sing a song to Dan’s dancing. When the students went to the computer lab to do research for their problem-based learning assignments, Bill had the students sit in their partner groups, but did not do much to enforce them sitting together. Nevertheless, students who completed their problem-based learning assignments sat together long enough to record their podcasts and complete their powerpoints. Three of the six students interviewed mentioned that they liked working in groups in Bill’s class. In his interview, Dan
described how he and other students worked on a song for an assignment and it helped that everyone had their "own part" to contribute to the whole song. Another student, Jenny, said it was beneficial to work in groups in Bill's class, because "sometimes you don't understand things and working with other people...they can help you."

Rob also scored a medium. Rob encouraged his students working in small groups for the problem-based learning assignments, but he did little to maintain them. For the first problem-based learning scenario, he encouraged the students to form groups of approximately three to four students, but he did not assign particular students together in groups, nor was there any evidence that he was constructing these groups based on students' creative strengths. He had a similar approach to group work on lessons other than the problem-based learning scenarios. When students worked on lab work, he encouraged them to work together in partners or groups of three, but he did not assign specific students together. When they worked on worksheets or individual writing assignments in class, he did not reprimand them for working together, but he did not do anything to create the groups. His second problem-based learning scenario was evidence that he did successfully allow for collaboration to emerge in his classrooms, as two class periods joined forces to create the video infomercial. This was something that did not happen in any other teacher's classroom in this study and was something that Rob explained was "the kids' idea."

Rob gave them ample time to work on their group projects and the class periods often contained a "free" component where students could work in the classroom on class assignments or work for their other classes. He was particularly lenient with letting students go to the library to work or to leave the classroom to do work on their problem-
based learning projects. All a student or group of students had to do was ask to leave and Rob gave them a hall pass during this free time. Three of the six students interviewed mentioned that they particularly liked doing group work in Rob's class. One student, Kay, said working on the video infomercial was an especially rewarding experience, because she got to work with other students. Alia discussed the benefit of working in groups in Rob's class in terms of nurturing her creativity and learning how to be creative with other students. She explained:

It was challenge, working as a group. You may like something, Someone else may not like that. We have to find something everyone can agree on. It helped us on how to accept each other's creativity.

Even though he did little to maintain and construct small groups, he did have a sense of the importance of assigning creative students particular roles in class to foster their strengths. In his Creativity interview, Rob said that he often gave his most creative students the role of "leader. For example, he labeled his student, Victor, as both "brilliant" and "creative," and encouraged him to act as a leader, help other students, and use the classroom lab equipment and materials to experiment with new ideas.

For this part of the framework, Anna was a third teacher who scored a medium. For the problem-based learning scenario, Anna let the students form small groups ranging from two to five students on their own. The class roster changed twice and so, some of these groups shifted. She encouraged new students to join the groups and did not prohibit students collaborating across groups. For example, one student, Shawna, was left without her group when the roster changed and was feeling nervous when it was time to record her podcast. She remarked in class that she was "embarrassed to hear her own voice" and was not feeling confident about her commercial. Two students, Tegre and Don, saw she
was struggling with the assignment and went over to help her. They read at first from her script, but then started improvising some text and also helped her to add some music to the podcast. Anna seemed proud of this collaboration. After Tegre and Don had helped Shawna feel more comfortable recording, she and a friend in the class, Ruth, decided to record her commercial. Anna accepted these two versions and was open to allowing these groups to emerge and reconfigure themselves.

Anna gave the students time in class to work on their podcasts. They had their nanotechnology lessons once a week. On the days when students were working on their problem-based learning assignment, Anna usually began with a lecture on concepts outlined on a set of powerpoint slides and then gave the students at least 20 minutes to work towards the end of class. She did not ask the students to meet outside of class to work on the problem-based learning scenario. Anna also used small group work for other assignments. During a lesson on states of matter, she outlined some concepts in a large group lecture. Then she had the students form their own small groups and draw what they thought molecules looked like during states of liquid, gas, and solid. She asked a representative from each group to draw their depictions on the white board and then they came back together as a large group to have a discussion about the drawings and related ideas regarding matter.

Three of the six students interviewed mentioned that they thought small groups were helpful in fostering their creativity. In his interview, Tegre said that Anna often separated them in small groups and that this helped him think of new ideas. He said that collaborating with other students was enjoyable while making his podcast; however, his group members transferred to other schools halfway through the project, so this was
disappointing. Monica said that she did not like to work with other students in Anna's
class. She explained that it was not anyone particularly in the class's fault, but that "This
school is crazy. If you want to get something done, you've got to do it yourself." During
group time, Anna traveled from group to group and sat at the small tables with the
students. She had an easygoing manner during this part of class and would guide the
students to finish their scripts or begin recording in a calm tone. When they were not
recording, she played Hip Hop or Top 40 hits from her laptop while the students worked.
A few times, a student, Amy, would dance around the room while the music played. One
time, during the molecule lesson, Don started dancing with her. Anna did not lose her
temper that Amy and Don were off-task in dancing. In response, she told them "I
appreciate your dancing, but I'd also appreciate you drawing molecules." After her
remark, they went back to their assignment.

Kraig scored a low on this part of the framework. The categorization manual defines a
low score, as when the teacher "discouraged small group work." Whereas the other four
teacher did various things to foster small groups collaborating together, he did not assign
any small group work. Some groups sat near each other and discussed issues relevant to
their age group (dating, sex, etc.), but did not engage in any substantial small group work.
Oftentimes, students sat by themselves and listened to their iPods, texted on their cell
phones, or ate snack foods. Kraig either presented his lesson from the front of the
classroom or sat at his desk in the front of the room and graded papers. The classroom
was organized with individual desks facing the front chalkboard. The desks could be
moved and clusters of students sat near each other, but Kraig did not do anything to
inspire or promote group work. In his Creativity interview, he did not bring up any
instinct to construct curriculum that promoted small group work. All of the students interviewed mentioned that Kraig did not include assignments in his class where they could work with other students. His student, Montel, said that he liked working in groups in other classes, since “everybody got a different mindset, got different answers,” but that there was not any group work in Kraig’s class. Another student, Kai, said, “it is difficult to work with other students, like everything in this class. I don’t like working with other people in this class cause sometimes they don’t know what they doing” and he would feel his thinking was being held back.

4.4.4 Provide Choices Framework Component

This sub-section addresses the Provide Choices Framework Component. Below is a graphic representation of the continuum:

![Provide Choices Framework Component Continuum](image)

*Figure 22. Provide Choices Framework Component continuum.*

The Provide Choices Framework Component states that teachers who foster small 'c' creativity: *Provide choices on what is an acceptable response (learning artifact or discussion point) to a lesson.* In terms of this part of the framework, Bill and Rob both scored the highest with *medium-high scores*. Ginny and Anna both scored *medium*. Kraig scored *low*. None of the teachers scored *high* or *low-medium* on this part of the framework.
For this part of the framework, Bill and Rob both scored a *medium-high*. The categorization manual characterizes a *medium-high* score as when a teacher gives his or her students "a list of two or more acceptable assignment responses" and the teacher "was open to negotiating with the student for an alternative assignment." For example, in Bill's problem-based learning scenario guidelines, he clearly outlined what he wanted the students to do to complete the assignment. For example, he asked them to be specific about what advancement in nanotechnology might be used to cure their baby of its disorder. He also asked that they produce audio podcasts and powerpoints and did not present alternatives or choices the students might select. In his interview, he explained that he always allowed alternative products; however, this was not directly observed in the classes I visited. In her interview, his student, Tina, remarked how the powerpoint assignment bored her because all they had to do was create a set of slides, so she focused on what colors to use in her powerpoint to keep her interest in the assignment. During observation, I had witnessed a conversation between her and her partner, in which she considered powerpoint colors closely.

In the class discussions I observed, Bill allowed for students to respond in discussion points with whatever ideas they wanted to. He always structured the first part of his class sessions with a "News" discussion. He presented a digest (written each day) of current crime, sports, weather, and popular culture news, along with events at the school (for example, changes in the schedule or an upcoming dance). As he went through the list of events, he allowed students to express their ideas freely as a large group, even when their comments were off topic. During class discussions about other topics (for example, genetics), he let students contribute to the discussion freely. As he mentioned in
his interview, it was most important to him that the students make the class topics and assignment “relevant” to them.

For this part of the framework, Rob also scored a medium-high. Like Bill, he gave his students a list of two or more acceptable assignment responses and was open to negotiating with the student for an alternative assignment. For his first problem-based learning scenario, he verbally provided a list of more than two choices of acceptable responses to the first problem-based learning assignment (e.g., a video, an audio podcast, a poster and so forth). Also, by allowing students to come up with their second collaborative problem-based learning scenario, he showed his openness towards negotiating alternative assignments. In his interview, he acknowledged an instance in a past class, where he helped a student who had dropped out of school for a while and re-entered his class. The student was in need of credits, so Rob gave him an individual project to get credits. The project involved the student researching an additive in gasoline that is polluting, as Rob explained, “every underground water system in America.” There is a specific scientist in Iran who is doing research on a zinc-based nanoparticle method, which can be used to clean the additive from water systems. Rob asked him to find one of the scientist’s articles in order to earn some extra credits. The student found the article and Rob was pleased. This is another good example of Rob’s generosity towards his students and openness to negotiation for alternative assignments.

Other parts of his practice displayed instances where he did not provide as many choices for acceptable responses. Rob’s technique of fostering class discussion was different than Bill’s. I witnessed a few classes where Rob expected only one kind of response from students. During one class, Rob had prepared a 30-minute powerpoint
presentation on atoms and molecules. While he presented the material, Rob did not allow for the class discussion to veer from the topic and became agitated when students tried to ask questions during the presentation. In another class that occurred in the lab classroom, Rob was very concerned that the students follow the steps of the experiment closely and exactly. This may have been necessary due to the inherent danger of varying the order of the chemicals; however, it did demonstrate another instance where Rob had only one acceptable response to a lesson.

For this part of the framework, both Ginny and Anna scored a medium. The categorization manual delineates a medium score as when:

Students had the freedom to respond to an assignment, as long as the outcome was a certain type of product. For example, students in a class were allowed to create any sort of response they wanted to in regards to an assignment, as long as it took a particular form. Students could complete a diagram of a certain concept, as long as it is a poster or powerpoint slide. The teacher’s definitions of these forms were clearly defined.

While Bill and Rob gave their students a list of two or more acceptable assignment responses and were open to negotiating with their students for alternative assignments, Ginny and Anna gave students freedom to respond to assignments in ways that expressed their creativity, as long as their students produced a certain kind of product. For example, in Ginny’s problem-based learning project, her students had to construct a video podcast. There was no other option and students were reprimanded for not following these specific instructions. For their size and scale assignment, students had to make posters that presented the objects they ordered (which were all the same images). There was no other option for this assignment as well. For their science fair projects, students had to make
posters outlining their research. There was no optional assignment or form that these projects could have been presented in.

In her interview, Ginny explained that she sees creativity as important in science. She said that “people see scientists as these weird geeks, but it takes a lot of creative thought to be innovative and to figure out how to apply this knowledge to something that will help humanity....Problem-based learning is helpful...to help develop the skill of thinking creatively to solve problems.” She also discussed that she valued student interests as, “When the students had to do a project that involved nanotechnology, I allowed them to choose something they were interested in.” When originally crafting her problem-based learning scenario, she had thought that she was going to have the students all use nanofilters as a solution to the problem, but then she decided it would be better for them to come up with “their solution on their own.” In her interview, her student, Helen (who worked on the puppet video podcast with Ellen), discussed how she “didn’t like doing the nano in class when we were trying to think of it,” but that she “liked doing the puppet show, because it was fun to make puppets and stuff.” She further explained that she “didn’t like the Chemistry part, trying to solve asthma,” that “it didn’t sound fun,” and “it wasn’t fun researching it, but that “it was fun to make the project.”

Anna’s class assignments also exemplified a medium score on the Provide Choices Framework Component. In her problem-based learning scenario, she allowed students to make an audio podcast and did not give any other options. She did give them the freedom to create any sort of audio podcast that they wanted. The six products varied from students just speaking to a combination of their speaking and music. No students asked to compete an alternative assignment, so there was not an opportunity to negotiate.
Also, students were given script templates. Anna asked the students to fill them out and use them during their podcast recording, but she did not enforce this step during the recording process. I observed that a few groups put their papers aside while they spoke and noticed that Anna saw this happening and did not say anything.

In her interview, Anna discussed that she would have liked to harness some of John and Monica's poetry and rapping abilities more with writing prompts. Monica wrote poems often in class, usually by herself, during small group or individual work periods. After her interview, Monica asked me to listen and record one of poems she had written in class that day, where she took the perspective of an African woman being sold in the slave trade in 19th century America. In her interview, Anna stated that Monica shared her poems with her as well sometimes in class. These instances demonstrate that Monica was a student who loved to write. Nevertheless, she did not prepare much writing for her podcast. When it was her turn to speak, she did not use her notes or script template and simply spoke into the microphone. Her podcast was scored an average CAT score of 1.6 out of 5.0 by the raters. In her interview, Monica said that Anna's lessons did not ask her to be creative, but she "just wants her answer to the question or whatever, or to do whatever project she wants us to get done, and maybe if I am creative, it's because I add my own creativity to it."

Anna let her students contribute to class discussions with their own ideas and tried to connect content ideas to their own lives and interests. A particular example discussion illustrates this well. During a lecture on the steps of the scientific process, Anna presented a powerpoint and tried to make sure all of the students followed her main points by relating concepts to things that interested them. She compared creating a hypothesis as
the same process as "choosing their clothes." She allowed students to contribute to the discussion by bringing up some tangential topics regarding their daily clothing selection and then went on to outline the process of experimentation. As the discussion continued to move on, she asked them if they ever watched the popular television show, *CSI*, and most of the students started talking very loudly about the show itself, about other shows they preferred, and particular episodes of the show they liked for about five minutes. After this eruption, Anna expressed frustration that the conversation had veered off into such a tangential topic. As it became clear that she could not connect their comments back easily, she stopped her set of slides in the middle and started passing around some worksheets for the students to fill out.

The categorization manual defines a low score on the Provide Choices Framework Component as when, in teachers’ classrooms:

> There was no student choice in terms of what was an acceptable response to a lesson. Form and components of acceptable student products are clearly defined and students are reprimanded for even slight deviations.

Kraig scored low on this part of the framework. Whereas the other four teachers gave their students varying degrees of freedom to respond to their assignments, for most lessons observed, Kraig only provided one kind of acceptable response to a lesson. As most of the work was textbook work, students needed to answer questions in the book on worksheets or their own notebook paper. Aside from the vector assignment, students did not create their own learning products and did not complete a problem-based learning project (although one was a requirement for the ITEST-Nano program). In his Nanotechnology interview, Kraig expressed that he wanted to incorporate nanotechnology more into his curriculum the following year (explaining that he did not
as much the year I observed because it “was his first year”), but he did not express an interest in changing his curriculum to allow for choices on acceptable responses to a lesson.

In his Creativity interview, Kraig also remarked that “students have lot [sic] of hidden potentials in them and exploration of these potentials is always through creativity.” I did not observe Kraig attempt to understand his students’ “hidden potentials,” in order to utilize their creative talents in the classroom. An example of one student with “hidden potentials” was Kai, who gave me a postcard during class, advertising a Hip Hop show he was performing in that week. Also, his student, Montel, told me about how he was an avid visual artist and that he spent much of his free time drawing and painting, as well as “thinking of different ways to draw stuff.” He said that he did not feel like he was creative in Krishan’s class, because he didn’t “understand what he was doing.” When asked if Kraig could name a creative student in the class I observed, he could not name one student. Arguably, Kai had at the very least a “hidden potential” at Hip Hop (if not actualized potential, as he was performing) as well as Montel, who worked daily at his art; however, neither student was named by Kraig.

4.4.5 Enhance Self-Confidence Framework Component

This sub-section addresses the Enhance Self-Confidence Framework Component. Below is a graphic representation of the continuum:
Figure 23. Enhance Self-Confidence Framework Component continuum.

The Enhance Self-Confidence Framework Component states that teachers who foster small 'c' creativity: *Include lesson guidelines that enhance, rather than restrict, learning and self-confidence*. In terms of this part of the framework, Ginny scored the highest with *high* score. Bill and Rob both scored *medium-high*. Anna scored *medium* and Kraig scored *low*. None of the teachers scored *low-medium* on this part of the framework.

For this part of the framework, Ginny scored a *high*. The manual defines a *high* score as when:

The teacher created open-ended assignments that were grounded in core concepts. The teacher expressed and explained these concepts, but gave students the freedom to synthesize them into their learning artifacts however they wished. He/she gave students sufficient time (both in and out of class) to complete the assignment and scaffolded this time with check-ins to ensure student success. The teacher stressed the importance of being creative and may have defined what this means to him/her during class.

Ginny’s practice exemplifies this description. For her problem-based learning scenario, she provided an open-ended assignment that was grounded in core concepts. Students had to find a solution to solving the air pollution problem in Philadelphia, but not only was any solution (that could be supported through their research) accepted and any presentation of this solution (as long as it was a video podcast) was accepted. In addition, she had students participate in science fair projects individually (unrelated to the nanotechnology unit) and present their data on poster boards, which were displayed
prominently in her classroom. The students in her class seemed particularly proud of their science fair projects. Three of the six students interviewed mentioned their new discoveries for the fair.

The guidelines for her class assignments were open and simply asked them to work on a project that was an extension of something they learned in class that interested them. She often told them to “be creative” and to “make something new and exciting,” especially when working on their problem-based learning project. She also expressed how much she valued her students’ creativity during interview. All six of the students interviewed mentioned that Ginny nurtured their creativity through her assignments. As her student Katy said, the Nano project “required some creativity” and it allowed them to imagine new ideas. She further explained that, “we just started learning about Nano, and you know, we don’t really know what’s possible, so [we] really had to pull things out of thin air and find out if it is possible.” Hannah corroborated this, as she stated, “you can’t solve a problem” in this class “without thinking creatively.”

In her Creativity interview, Ginny explained, “It is important to get the kids more active and involved.” For a stoichiometry lesson (not one I observed), she had students “dramatize” the chemical process using S’mores. As she said, “Some people were crackers, some people were marshmallows, some people were chocolates. And they were like representing the beginning of a reaction and they had to rearrange themselves to fall as a S’more. And then I could say ‘Oh, we didn’t have enough marshmallows. So, that is what we call limiting reactants.’” She also explained, “I think you stifle creativity when you give too many directives. Like, choose a product here in this area. I think it
helps to develop creative thought when you give people license to go outside the box and try something different.” During many points in observations and interview, she expressed her commitment to making lesson guidelines that did not restrict student creativity.

For this part of the framework, Bill and Rob both scored medium-high. The categorization manual specifies that a medium-high score as when:

The teacher created open-ended assignments that were grounded in core concepts. The teacher expressed and explained these concepts, but gave students the freedom to synthesize them into their learning artifacts. He/she gave students ample time (both in and out of class) to complete the assignment; however, this time was largely unstructured. The teacher stressed the importance of being creative; however, what this meant may have been undefined by him/her.

Bill’s practice exemplifies this definition. His problem-based learning scenarios were open-ended and gave students ownership over finding new solutions to real-world problems. He gave students ample time to complete their assignments; however, this time was largely unstructured and he did not check-in with them, like Ginny. In one of his assignment handouts, he told them to “Be creative and have some fun with this,” but what this meant to him was undefined, while, Ginny, a high scoring teacher, defined the term for her students. He suggested that his students write scripts for their audio podcasts, so that they would “feel prepared” not because he wanted to check up on them and see that they were working. When students wrote scripts for their podcasts (again not collected), he let them write about whatever they wanted. His student, Mondrian, had an interest in poetry. Because Bill was a faculty advisor on the school’s literary magazine and served as a judge for the school’s poetry slam contest, he knew of Mondrian’s love of poetry, as they worked together on both the journal and in preparation for the slam. As
Bill described to me in his interview, Mondrian also had a learning disability and could best learn through his writing. On several occasions, when Mondrian seemed to be struggling with an idea being discussed, Bill would tell him to write a poem about what he thought about the idea. During Bill's first problem-based learning project, Mondrian spent a good deal of time writing his script for the podcast. Bill often gave him encouraging words as he wrote and crafted his language. Also, one of Bill's sons had an expertise in technology. He had his son come in to record the students' podcasts, so that they "would not feel overwhelmed" with learning technology for this part of the assignment. Four of the six students interviewed mentioned that Bill's assignments enhanced their learning. For example, in her student interview, Tina, described her excitement over learning new science concepts in the class and telling her parents about them: "I always talk to my parents about this class. I be telling them, 'Did you know this? And then they'd be like, 'For real, how did you know?' And I be like 'I learned it in Biology.'"

Bill was particularly free with the amount of time he gave students to complete the assignments. When it took certain students longer than others to complete their work, he did not penalize them in any way. However, he did not have check-ins with the students during group time, so this time was unstructured. He did appear to be genuinely interested in his students' interests and often asked them about the creative projects they were working on outside of class. He gave me a copy of the school's literary journal and showed me his students' work in the issue. He served as a judge for the school's poetry slam and invited me to the school-sponsored reading, which I attended. The reading featured the contest winners, as well as an open mic (where any student was free to go up
and read his or her own poems). Bill expressed his pride at the students' pieces and with the caliber of the general artistic talent at the school.

For this part of the framework, Rob also scored medium-high. Rob's first problem-based learning scenario was open-ended and he gave the students the freedom to synthesize the concepts of the lesson in a variety of ways. He gave the students ample time in and out of class to finish the assignment, although much of it was unstructured. Like Bill, he did not scaffold check-ins to ensure student success, which was in contrast to a high-scoring teacher, like Ginny. He often stressed the importance of being creative, as in many observations, he told the students to use their creativity on their problem-based learning products; however, like Bill, he did not define what this might mean during class. In his interview, he expressed that asking students to "extend" their thinking was important to his practice. Rob believed that asking students to "extend" his lessons into students' lives outside the classroom was intrinsically tied to inspiring their creativity. He explained:

> If you can extend what you’ve taught them to their personal lives—that is creativity. They are solving internal problems. They are solving social problems. They are solving community problems. So, by taking what they’ve learned and extending—that’s the ultimate in creativity right there. How can you take what you’ve learned here and use it in your neighborhood? How can you take what you’ve learned here and use it to give yourself a place of value in your family or your community?

An example of this belief seen in his practice was his calorimeter assignment. In his interview, he expressed how disturbed he was by the high instance of poverty and obesity present in Philadelphians. He asked, “How is it that in a city where 70% of the kids are below the poverty line, do we have so much obesity?” By giving the students a project where they actually calculated the ill effects of junk food (e.g., how the heat burned off
quickly within the body and did not provide sustained energy), he was able to empower them to better understand how to modify their diet.

Rob often seemed proud of his students' creative leaps. In a class I observed, a student, Jo, decorated her staining agents in a heart design on the Gap “Nanopants.” Although I had already noticed and was impressed at the beauty of her creation, Rob still called me over and had me take a picture of her work. This gesture seemed to increase Jo’s pride in her decoration in turn, as she asked me for a copy of the picture to show her friends and family. In her interview, she discussed how in Rob’s class “the labs ask you to be creative.” Her statement echoed most of the beliefs students described in their interviews, as four of the six interviewed students mentioned how Rob’s assignments stimulated their self-confidence. Also, Rob took an interest in his student, Victor, who he saw as not just creative, but a “real STEM” and someone who would likely have a future career in a science field. Rob, on his own initiative, contacted a scientist through the ITEST-Nano program to see if Victor might get a summer position in one of the labs at the University of Pennsylvania. In addition, he also extended the “Nanopants” infomercial, as he sent the video to The Gap Corporation in the hopes that they might want to use it and feature the students in one of their future advertisements.

For this part of the framework, Anna scored a **medium**. The categorization manual delineates a **medium** score as when:

The teacher created lesson guidelines that were meant to be followed closely; however there was some room for student creativity to be expressed.

While Ginny, Bill and Rob all created open-ended assignments that allowed for students freedom to express their creativity and encouraged them to be creativity, Anna’s practice
generally exemplified the definition of a medium score. For example, her lesson guidelines allowed for some student creativity to be expressed, even though guidelines were meant to be followed. Her problem-based learning scenario did allow for some student ownership in that the podcasts could take any aesthetic form (e.g., could mix any amount of voices and music in any way the students wished), as long as it was an audio podcast and contained certain elements. In her interview, she described the assignment as “not entirely open-ended, like there was a focus to the project. You were supposed to design a flavor. I tried to give them a couple of sweeteners to choose from.”

Three of the six students interviewed discussed how they enjoyed her assignments that contained open-ended components. For example, her student, John, noted that he particularly enjoyed the worksheets Anna had them do with open-ended questions, because they asked him to use his own ideas to consider ideas in science closely versus a multiple-choice worksheet where “the answers are given to you.” Another student, Tegre, who had future plans to become a registered nurse, acknowledged several projects that were open-ended that inspired his creativity, such as the problem-based learning scenario, a discussion on genetics, and a cookie-making experiment. In her interview, Anna cited a project that I did not observe, where students had to choose their own objects and “do their own calculations to get to the final answer of how big a mole that object would be.” There was student ownership that they had to choose whatever object interested them, but they still had to follow particular guidelines for the assignment. When they did a lesson on molecules, she had them draw their depictions of the molecules in small groups and then had a representative group member draw these on the board. She did not give constraints as to what these drawings would look like, but she did
ask that the drawings be of molecules. She did not explicitly ask them to use their creativity to make their drawings. Arguably, this assignment could have been one where student creativity might have been utilized.

Kraig scored low on this part of the framework. The manual defines a low score on the Enhance Self-Confidence Framework Component as when:

There were very little to no lesson guidelines and/or the guidelines were so restrictive that all expressions of individual learning leaps and self-confidence were reprimanded. For example, in a class like this, the majority of the classwork would be done as worksheets or tests.

While Anna created lessons where there were guidelines to be followed, but that still allowed for student creativity, Kraig gave his students lesson guidelines that were sparse and did ask for student creativity to be expressed. During each class I observed, there was a goal listed on the board. When the class period started, there were usually only one or two students present. As students trickled in (students were often late and came in a staggered fashion), Kraig would tell each student what pages in the textbook they could find the assigned question on or would hand them a worksheet. There was often a good deal of disruption in class, whether it be a fight or a loud discussion about inappropriate topics (graphic descriptions of sex and violence, etc.). Fights would often break out for seemingly little reason. For example, one time a girl and boy got into a near brawl over a pencil (she said he had hers). Kraig never did much to break up these fights, except scream loudly for the students to stop and call security to throw the students out of the classroom.

In his Nanotechnology interview, he said that he stressed STEM (Science, Technology, Engineering, and Mathematics) careers in his classes, because “my students
are the seniors and most of them are going for the career-oriented classes, so I explained that nanotechnology was a fast-growing technology in which they could choose their career.” I did not hear him mention this during the classes I observed. Also, in his Creativity interview, he explained that he “observed creativity in a student, [he] always encouraged and promoted it through indirect hints.” Unfortunately, I did not hear him refer to or support a student’s creativity either directly or indirectly during observation. None of the students interviewed mentioned that Kraig inspired their creativity in his class. One of his students, Tina, was creative out of school. In her interview, she told me about how she liked to make clothes with her father. An example she gave of a creative product she was proud of was when she and her father made her prom dress together. She explained that “Creativity makes you feel strong, like you can do something, like if you can do that, you can do more.” She explained that Kraig’s classes did not ask her to be creative, because all they did in class was “use formulas and solve the problems.” She noted that “whoever designed” the formulas was creative, but that all she was doing was “using her common sense” by “plugging numbers into a formula” and that she was not using her creativity in Kraig’s class.

4.5 Teacher Profile Summary

Below is a table that presents a summary of the teachers’ case study profiles:

Table 8

Teacher Profile Summary

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Overall Score</th>
<th>Knowledge</th>
<th>Teaching</th>
<th>CB Scores</th>
<th>attitudes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ginny</td>
<td>3.84</td>
<td>Medium-High</td>
<td>Medium-High</td>
<td>Medium-High</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Table 8 orders the teachers from highest average CAT score to lowest. It also displays their framework scores. From the table, it is evident that there are no teachers who received the same average CAT scores or array of framework scores. Each teacher has a distinct profile and set of scores. In addition, there are some missing framework scores in the set of profiles. For example, none of the teachers scored low on Support Divergent Thinking Framework Component, low on the Accept All Artifacts Framework Component, high or low-medium on the Nurture Collaboration Framework Component, high or low-medium on the Provide Choices Framework Component, or low-medium on Enhance Self-Confidence Framework Component. No direct correlation between the sets of scores can be established, because no particular score can give an exact prediction for another score. For example, the teacher with the highest CAT score (Ginny) did not receive the highest framework scores, nor are all her framework scores the same. However, there are some trends and relationships within the scores that can be teased out. In the following sections, these trends and relationships across the scores will be discussed.

### 4.6 Individual and Global Trends Across Case Studies

The preceding sections and the above table exemplify that each teacher’s case provides a multifaceted and unique way to see how a teacher can foster small ‘c’ creativity in their science classroom. No one teacher in the study received the same
average CAT score or set of framework scores, nor can a direct correlation between the scores be determined. Nevertheless, there are relationships between teachers’ scores and practice that are prudent to both present and tease out in this chapter in order to address my three main research goals. My three main research questions seek to uncover: 1) To what extent does a small ‘c’ creativity framework reveal how teacher practice allows for creativity to occur in classrooms?; 2) How do science teachers’ beliefs about creativity and their practical strategies interact to support creativity in science classrooms?; 3) If students are judged to be more or less creative within the teachers’ classrooms, what are some possible relationships between their exhibited creativity and teacher practices and beliefs? Trends emerged across the cases that address these research goals and they will be represented in the following sub-sections. Related to Research Question #1 (which seeks to discover the relevance of the framework to teacher practice), I will address the relationship between the CAT and Framework scores and its connection to school context. With respect to Research Question #2, (which relates the interaction of teacher beliefs and practice to support creativity in the classroom), I will address how teachers’ knowledge of their students and how open teachers were to cross disciplinary boundaries in their projects. Lastly, connected to Research Question #3 (which connects exhibited student creativity to teacher practice and beliefs), I will discuss how teacher beliefs about the importance of student creativity in the teaching of science affected the amount of small ‘c’ creativity fostered in their classrooms. In stating these trends, I will provide additional explanation for the multifaceted teacher profiles that have emerged from the set of cases.
4.6.1 Relationship Between CAT Scores, Framework Scores, and School Context

Although no direct correlation can be established from the data, there appears to be a relationship between CAT scores and framework scores. Teachers with lower CAT scores generally had lower framework scores (Anna and Kraig). Teachers with higher CAT scores tended to have higher framework scores (Ginny, Rob, and Bill). However, the relationship seems to be complicated and complex. For example, Ginny received the highest average CAT score (3.84) and relatively high framework scores (three medium-high, one high, and one medium), but Bill and Rob also received relatively similar high framework scores and average CAT scores that were substantially less than Ginny’s (e.g., almost 1.0 less in the case of Bill and over 1.3 in the case of Rob). In addition, Rob was the only teacher with two high framework scores; however his average CAT score is distributed as the middle score (2.51) in the group. Kraig received an average CAT score of 0, because he did not complete a problem-based learning project. He was the only teacher with low to low-medium scores, which are the lowest framework scores of the set of cases. This also demonstrates the relationship. Finally, Anna had five medium framework scores, but had a low average CAT score (1.78) of those calculated.

There are differences in the school contexts that these teachers taught in that may be related to the relationships between CAT and framework scores and variations between the teacher profiles. For example, Ginny received the highest CAT score and relatively high framework scores. She also taught within a school that has the reputation to be one of the best public high schools in Philadelphia, in terms of college preparation. The school has a 100% on-track-to-graduation rate and has PSSA scores in both reading
and math in the top 25% of schools in the city (School District of Philadelphia, 2010).

Bill and Rob received similarly high framework scores to Ginny. As well, they had average CAT scores that were substantially less than Ginny’s, substantially more than Anna’s, and relatively close to each other. In addition, they had framework scores that were relatively similar, with three framework scores (the Nurture Collaboration Framework Component, the Provide Choices Framework Component, and the Enhance Self-Confidence Framework Component) in common. Bill had four medium-high scores and a medium score. Rob had two high scores, two medium-high scores, and a medium. They also taught at the same high-performing arts-focused magnet school, with a 99% on-track-to-graduation rate and PSSA scores in both reading and math in the top 25% of schools in the city (School District of Philadelphia, 2010). From this data, there seems to be a relationship between high-performing school and higher framework and CAT scores.

Likewise, the relationship appears to go the other direction for teachers in lower-performing schools and lower framework and CAT scores. Anna had the lowest average CAT score of those calculated and five medium scores. Anna’s high school was determined to be a Renaissance school by the Philadelphia School District. This district-wide practice mandated that if a school is designated a Renaissance school, they must fire or relocate at least one-half of their faculty before the next school year. Their on-track-to-graduation rate is at 54.8% and their reading and math PSSA scores are in the bottom 25% of schools in the city (Philadelphia School District, 2010). Even though her consistent medium scores on the framework component might suggest a higher average CAT score than the lowest (for example, in the middle range), her CAT scores may have been dragged down by the school context she was teaching in where there was a shifting
roster, low attendance, and necessary project supplies, (i.e., the laptops), were stolen. Kraig’s school was also determined to be a Renaissance school by the Philadelphia School District. His school has a 17.1% on-track-to-graduation rate and has PSSA scores in the bottom 25% of schools in the city (Philadelphia School District, 2010). He had the lowest framework scores and it was not possible to calculate CAT scores, as his students did not complete a problem-based learning scenario. In sum, it seems, from the data seen in Table 8, that relationships go in both directions between high and low framework and CAT scores and high and low performing schools.

4.6.2 Teachers’ Student Knowledge

One trend emerged from the data that may provide a further explanation for the relationships between high framework scores, higher CAT scores, and high performing schools. In their Creativity interviews, two of the teachers, Bill and Ginny, discussed how important it was for teachers to have knowledge of their students and their interests, in order to foster their creativity. Bill explained:

If you get to know your students, you get to know what interests them. So, you see what they are doing and how they turn things in. And that starts with the very first LAP of the year....And then what you can do, as you go on, you can tailor the assessment. I mean, you give everybody the packet, but you may stop by certain people and say listen, ‘I know you enjoy this, you can do that if you want because I know you enjoy it.’

Ginny presented a similar idea in her interview, as she said:

I would say that it is really important that you know your students. And that you tailor instructions to meet their needs. And just as if you had a kid who had a learning disability, you would provide certain accommodations for them, you should do the same for the kids that were very creative. And if they had an idea that fit within the scope of your class, let them run with it. One of the things that the district was pushing was differentiation. And
when I tried it out in the previous year, it didn't work that well. I had some kids that were really really smart, but didn't feel comfortable expressing their creativity and their brilliance in front of the other kids. And so they would always choose the activity that, you know, like I would try to provide three levels of activity, but they would always choose the activity that was below them, in my opinion.

Bill and Ginny were teachers with the highest CAT scores and had high framework scores. They also taught at the higher performing schools, with arguably more agency and resources to get to know their students’ interests. In addition, they both mentioned the idea of customizing assessments to meet these interests. Bill discussed that once a teacher gets to know a student, he or she can “tailor the assessment.” Ginny also connected a teacher’s knowledge of his or her students, by connecting it back to creating alternative assessments:

I think just having, just creating an environment where kids feel free to express themselves, and maybe if you as a teacher, think about ways to foster creativity and to make your class interesting, and you know a particular kid that has a gift in a particular area, you know, pull them in to help you to do that. You know pull them in to help you with demonstrations. Pull them in to help you with presenting the material in a new way. You know, create assignments where kids can present the materials in multiple ways. Like somebody could create a song to present their presentation. Somebody could create a poem. Somebody could create a skit. Or, if they prefer to write a paper, you know have them write a paper. Just give multiple ways that they can present the same information.

The other three teachers did not discuss this idea as explicitly as Bill and Ginny, so there appears to be a trend in their beliefs that is important to consider. If there was an overwhelming relationship between high framework scores, high CAT scores, and higher performing schools, then Rob might have mentioned a teacher’s student knowledge as well. Rob was a teacher with similarly high framework and taught in the same high performing school as Bill, although his CAT score was lower than Bill’s and Ginny’s. In
his interview, he expressed his belief that a teacher should accept “a variety of assessments” in class “cause not everybody expresses what you’ve learned the same way;” however, in his interview responses, he did not place an emphasis on a teacher being proactive and getting to know student interests, only that the teacher should be accepting of them. Anna and Kraig did not mention the importance of a teacher’s knowledge of his or her students in their interviews. Anna expressed that she had wished she had created more opportunities for students she knew to be creative in a particular discipline (Monica and John, in poetry and rapping, respectively) and that ideally she would have allowed for more opportunities for them to use writing to understand concepts in her class. Kraig did not refer to this idea at all in his Creativity interview. Since they were the two teachers who both taught in Renaissance schools and had the lowest framework and CAT scores, there seems to be a trend that the higher the CAT and framework scores and the higher performing the school, the more the teacher values knowing his or her students’ interests.

4.6.3 Crossing Disciplinary Boundaries

Another trend in the data demonstrates a relationship between disciplinary crossing and framework scores. Four of the five teachers allowed students to cross disciplinary boundaries in their science classrooms. Crossing disciplinary boundaries is defined as permitting students to create a learning artifact in response to a lesson that is not in the lesson’s discipline. For example, a teacher might allow his student to write a poem in response to a lesson of the scientific process. This trend did not correspond neatly to average CAT scores, but there seems to be a relationship between disciplinary
crossing and framework scores. CAT scores ranged from Ginny (3.84) to Bill (2.86) to Rob (2.51) to Anna (1.78) to Kraig (0). In general, Ginny, Bill, and Rob had higher framework scores, Anna had medium scores, and Kraig had low scores. Ginny, Bill, Rob, and Anna all allowed students to use a variety of disciplines (visual art, video, dancing, and music) to engage with science concepts both in their problem-based learning projects and in other classwork, albeit in different and complicated ways. They all had framework scores ranging from medium to high. Rob’s problem-based learning products had the greatest range in the form he allowed them to be in. For example, these products came in the form of posters, audio podcasts, video podcasts, a collaborative infomercial, and an animation. Bill’s problem-based learning products were all powerpoint slides, Ginny’s problem-based learning products were all video podcasts, and Anna’s were all audio podcasts Rob’s allowance for a variety of disciplinary responses to the project prompt is not reflected in his average CAT (which falls in the middle of the range), but he also the only teacher who had two high framework scores. In addition, Kraig had the lowest framework and CAT scores and did not provide any disciplinary crossing opportunities for students in his assignments. While Rob’s framework scores are not quantifiably different than Bill’s or Ginny’s, there seems to be an interesting trend, with four of the five teachers allowing for disciplinary crossing, to examine in the Discussion chapter.

4.6.4 Time and Small Group Formation

The ways that the five teachers structured time in in their classes (both in terms of the problem-based learning project(s) and regular class work) is important to note. The
three teachers with the highest average CAT and framework scores (Ginny, Bill, and Rob) structured their class with large blocks of free time. The other two teachers, Anna and Kraig, gave students time to work in class, but these blocks of time were often shorter than the other three teachers (usually around 20 minutes) and were prefaced by lecture. In terms of the problem-based learning scenario, Ginny gave students large blocks of unstructured time (several 30-40 minute blocks) in class to work on research for the project, but she necessitated that they work at home to create their video podcasts. She did not provide them with video cameras in class, only laptops to do research, so they had to meet outside of class to finish their work. During the classes that they were working on their projects, she generally would say a few remarks about upcoming assignments and then give the students the time for the rest of the class.

This was similar to the way Rob and Bill structured time for their problem-based learning scenarios. Rob would often start class mentioning a few pertinent points (for example, due dates for upcoming assignments) and then give the student the rest of the class period (usually 40 minutes) to work on their problem-based learning projects or whatever other work they wanted to (for example, I often saw students working on projects for other classes during this time). Rob provided them with a video camera in class and he also allowed for their projects to take whatever form they wished. Thus, he did not necessitate that students necessarily meet outside of class to finish their problem-based learning projects, the way Ginny did. Bill often started class with a “News” segment. He would spend about 15 minutes going over national and local news, across a wide range of topics. Then he would give the students large blocks of unstructured time to work on their problem-based learning projects. He provided them with access to the
computer lab. Since their CAT-scored problem-based learning products took the form of powerpoint slides and there was ample time to complete them in class, there was no need for students to meet outside of class to finish their work.

Although these three teachers structured large blocks of free time in class, their students' group formations took different shapes. Ginny had them choose their "Nanogroups" and these groups stayed together throughout the project. Since her project necessitated that they meet outside of class to complete it, these groups had extra time to allow for members to take on specific roles within the group. Bill partnered the students according to heterogeneous pairs or groups of three, with no obvious consideration to put students with various creative strengths together. The students kept these groups for both problem-based learning scenarios. They did not meet outside of class to do their projects. Rob did not necessitate that his students meet outside of class to complete their projects. He allowed for groups to emerge for his first problem-based learning assignment and then let one of these groups collaborate with another class, which seems related to the large amount of unstructured time he included in his class periods. Of the three teachers, he also enforced that they work on the designated problem-based learning assignment during this class time. Ginny and Bill made sure students were on task during these blocks of time, but Rob did not enforce that students keep to the problem-based learning project the entire time. It is possible that this unstructured time allowed for more collaboration, range of product forms, and higher CAT scores. This will be considered further in the Discussion chapter.
4.6.5 Creativity in Science

A question in the Creativity interview asked teachers to express their belief about the importance of creativity in the field of science and within the science classroom. All five teachers expressed that they thought creativity was important in the context of science; however, they all had differing types of responses. Their responses related to the ways in which they approached fostering creativity in their classrooms. Kraig’s was the least developed, as he explained:

Creativity is most important in science because we have enough material in science lab or science classroom to testify our hypothesis.

This type of belief was demonstrated in his practice, as he was unable to conceive of a relevant problem-based learning scenario to engage his students with the nanotechnology curriculum. In his classes, it seemed important to him that he keep to the science content he wanted to convey and not to deviate from it.

Bill’s answer to the question was also connected to his practice, as it demonstrated his commitment to engaging students in science content, even if it meant connecting it to them through different disciplinary lenses. He responded to the question, “Is creativity important in science?” this way:

Absolutely. Cause for those students who are creative, if I don’t allow their creativity to show through, I feel I lose them early in the year. And so they are thinking, ‘Why am I here? I can’t express my creativity. I don’t want to be creative in here. He’s telling me science is only this.’ And so, I feel I would inhibit some kids and lose some kids early if I didn’t allow them to be creative. Period.

His belief in linking student interests to science could be seen in the various ways he related allowing students to turn in alternative products for class assignments (e.g., the
student who responded to an astronomy symphony and the two students who made visual model of chemical and biological structures).

Rob’s response to the question showed a similar approach as Bill. He seemed concerned with making the class content relevant to students. His response showed how much he valued instilling creativity, so as to improve his students’ lives:

[Creativity] is everything in science. That’s how you know when you are thinking. If you can get them to extend what you’ve taught them to their personal lives—that is creativity. They are solving internal problems. They are solving social problems. They are solving community problems. So, by taking what they’ve learned and extending. That’s the ultimate in creativity right there. How can you take what you’ve learned here and use it in your neighborhood? How can you take what you’ve learned here and use it to give yourself a place of value in your family or your community?

His belief in connecting opportunities for students to be creative in projects that might help their lives could be seen in his curriculum. For example, his calorimeter project asked students to figure out the amount of calories they consumed not just to test their content knowledge, but also to make them consider what their food choices mean for their own health and that of their “family” or “community.” For Rob, solving a problem in science using creativity also meant the potential to solve a “social problem.”

Anna left teaching after my observational year to pursue a doctorate in Chemistry. Her expertise in her content area and her knowledge of creativity in advanced science courses fueled her response to the interview question, “Is creativity important in science?”:

Creativity is what science is all about, I feel like. It’s a little bit less obvious to see that, at this level, for high school and middle school students. Because so much of the curriculum is mandated and this is what you teach. All of these theories and everything came up hundreds of years ago. And so, it is like, applying that in labs. And then in higher science classes that really comes creativity. Because with creativity there is no right or wrong answer.
And that’s all the science issues that researchers and developers are working on. There is no right or wrong answer. They are just trying to try something until it works.

Her belief that there is “no right or wrong answer” in science was not evident in the ways she approached her practice. Although her problem-based learning scenario did ask students to make an audio podcast that could take any particular form they wished, many times during her class work, she seemed concerned that her students master the content. Perhaps this connects to her belief that creativity only occurs in “higher science classes” and that because “so much of the curriculum was mandated,” it was not possible for her to foster creativity more within her high school classroom.

Ginny’s response to the interview question is a hybrid of Bill’s, Rob’s, and Anna’s response. She explained:

I think creativity is very important and unfortunately a lot of science is taught just like facts. And these are the facts that you need to know. And I think that defeats the whole purpose of science. Because I think that, even though you have people think that scientists are like these weird geeks, I think it takes a lot of creative thought to be innovative and to figure out, "how can I apply this knowledge to something that would help humanity." So, you know, sometimes it's hard in the classroom to balance giving, helping kids to develop that with giving them all the content that they need. And that's why I think things like problem-based learning would be helpful. And you would find at first that some kids don't like it, because they are so used to being in that structure. Give me the facts. I will take the notes. I will study for the test. I will get an A. But I think it is important that they develop that skill of being able to think. And to think creatively is to solve problems.

This response shows a synthesis of strands of the ideas that Bill, Rob, and Anna presented in their respective responses. Like Bill, she believed that science is more than “the facts you need to know” and that it is important to teach student to be “able to think” about the ideas in the units, more than just master these facts. Like Rob, she believed that
creativity should be used “to solve problems” towards a social function and to “help humanity.” Lastly, just as Anna believed higher-level scientists used creativity, Ginny thought scientists were more than just “weird geeks.” Instead she believed them to be “creative” and “innovative” thinkers. This set of beliefs was evident in Ginny’s practice. In her problem-based learning scenario, she asked the students to solve a real world problem (air pollution in Philadelphia) and gave them an opportunity to use creative thought beyond a set of “facts” to “study for the test.”

4.7 Chapter Summary

This chapter presents results that investigate the three study goals. I have included different presentations of the data, such as visual representations of CAT and framework scores and case study narratives presented as rationales for framework scores. This data offers five distinct case studies and shows that the set of cases provide a multifaceted and unique way to see how five high school science teachers fostered small ‘c’ creativity in their science classrooms. There is evidence to suggest that there are relationships between high and low framework and CAT scores and high and low performing schools (i.e., that teachers in higher performing schools tend to have higher framework and CAT scores and that teachers in lower performing schools tend to have lower framework and CAT scores). Finally, other trends emerged that provided evidence that teachers’ knowledge of their students’ interests, teachers’ openness to allow their students to cross disciplinary boundaries in their projects, and their beliefs about the importance of student creativity in the teaching of science affected the amount of small ‘c’ creativity fostered in their
classrooms. These results and trends will be discussed in the context of relevant theories within creativity scholarship in the following chapter.
5. DISCUSSION

5.1 Chapter Overview: Interpretation of Trends in Context of Research Goals

In this chapter, I will interpret individual and global trends in the data in terms of the three main research questions. Then I will discuss the implications for research of the study, which connects to an awareness of small 'c' creativity. Lastly, I will include a set of practical recommendations for teachers that have emerged from the application of the small 'c' creativity framework to teacher practice through this study. The questions are:

1. To what extent does a small 'c' creativity framework reveal how teacher practice allows for creativity to occur in classrooms?

2. How do science teachers’ beliefs about creativity and their practical strategies interact to support creativity in science classrooms?

3. If students are judged to be more or less creative within the teachers’ classrooms, what are some possible relationships between their exhibited creativity and teacher practices and beliefs?

5.2 To what extent does a small ‘c’ creativity framework reveal how teacher practice allows for creativity to occur in classrooms?

One of the main goals of this dissertation was to demonstrate how a small ‘c’
creativity framework might reveal how teacher practice allows for creativity to occur in the classrooms. This framework, which arose out of a review of the literature, was used as both a filter for data collection (e.g., it was used to scaffold in part some of the observations and it was used to determine interview questions) and as an analytic tool. The categorization manual (Appendix I), which was based on the framework, was used to help better understand the cases as discrete units. Four external raters were trained to score teacher portfolio data using this manual and it was determined to be successful in helping them define how small ‘c’ creativity occurred in each of the teacher’s classrooms. The manual was an effective tool, working in tandem with the analytical framework, as there was 80% agreement among the raters.

The Small ‘c’ Creativity framework states that teachers who foster small ‘c’ creativity in their classrooms:

1) Support divergent thinking that is grounded in the lesson’s activities or concepts
2) Accept learning artifacts that are novel and relevant to the lesson
3) Nurture collaboration among small group members in which individual kinds of creativity within the group are supported
4) Provide choices on what is an acceptable response (learning artifact or discussion point) to a lesson
5) Include lesson guidelines that enhance, rather than restrict, learning and self-confidence

The study framework arose out of the work of scholars studying the science classroom, social, collaborative learning, complex systems theory, teacher beliefs, theoretical
constructs of ideal practice, and definitions of creative products (Fleith, 2000; Kaufman & Sternberg, 2007; McWilliam & Dawson, 2008; Newton & Newton, 2009; Sawyer, 1999; Sternberg, 2005). All of these theorists gave suggestions to teachers to support divergent thinking (Sternberg, 2005), provide choices for completing assignments (Fleith, 2000), foster “productive thought” (Newton, 2009), utilize small groups, where power is distributed equally, for social, collaborative learning (Sawyer, 1999), and begin to value small ‘c’ creativity in their students (McWilliam & Dawson, 2008). When combined, their theories represent a current set of recommendations in the field for teachers to help their students be more creative and produce learning artifacts that demonstrate their creativity in the subject they are studying.

Each of the five components of the framework revealed how teacher practice allowed for creativity to occur in the classrooms in different ways. Looking at the teacher profiles (Table 8), teachers’ practice reflected strengths in certain framework components. For example, scores tended to be the highest for the Support Divergent Thinking Framework Component and Accept All Artifacts Framework Component. The Support Divergent Thinking Framework Component looked at how well teachers supported their students’ divergent thinking that was grounded in the lesson’s activities or concepts. Four of the teachers were successful in creating problem-based learning scenarios that gave space for their students to incorporate their own ideas into the assignments, with Rob being the most successful in creating open-ended assignments and being able to name past and present students who exhibited creativity. The scores for the Accept All Artifacts Framework Component were also high. Rob was again the most successful in being open to accepting learning artifacts that were novel and relevant to the
lesson and may have exceeded his assignment guidelines; however, four of the five teachers (everyone except Kraig) were successful at accepting students' novel and relevant products. I would hypothesize that these framework components may have been easiest for Rob, because of both the nature of his school, his practice of supporting students to go into STEM careers (for example, Victor), and his desire to make science relevant to his students' everyday lives. Perhaps because he wanted his students to engage in the science concepts he was teaching, he was willing to be permissive in accepting their divergent thinking and novel learning artifacts. The second highest framework was the Enhance Self-Confidence Framework Component. According to the study results, four of the five teachers were able to construct assignments that enhanced learning and self-confidence, but Ginny was the best at balancing open-ended assignments with ample time to complete them, scaffolding this time with check-ins to ensure student success, mentioning the importance of creativity in class, and defining creativity. I hypothesize that she was the most successful, because her school was the most traditionally academically-focused, so the practice of scaffolding time and defining terms fit more within her regular practice.

The two framework components with the lowest scores were the Nurture Collaboration Framework Component and the Provide Choices Framework Component. The Provide Choices Framework Component was the second lowest set of aggregate scores, with both Bill and Rob being the most successful at providing students with alternatives for assignment. I hypothesize that this connects to the fact that their school is an arts-focused magnet school and as science teachers, they are used to students having a greater interest in the arts than their subjects. The lowest set of scores was the Nurture
Collaboration Framework Component, which was the framework that measured how well teachers nurtured collaboration among small groups in which individual kinds of creativity are supported. Ginny was the most successful, as she let her small “Nanogroups” self-organize, aiding this process by giving them time in class to do so, necessitating that they meet outside of school for their project, arranging her room in small group tables, and even suggesting that they take particular roles that emphasized their individual creative strengths. However, none of the teachers’ practice could be scored high, as none of them encouraged and constructed groups consciously in order to assemble students together with various creative strengths. It may be that the manual’s definition of a high score is unrealistic and should be revised. It would take the teachers a good deal of time and effort to consciously construct groups and teachers would have to know all of their students’ creative strengths extremely well. With most of the teachers having around 175 (25 students multiplied by seven class periods) students in any given school year, this could be asking too much of teachers who are already burdened by their workloads.

Although the framework did not address it directly, time became an important element in considering how the teachers sought to nurture individual and collaborative creativity. Each teacher compartmentalized the time allotted for their class sessions in his or her own way. Even though they were not asked questions directly about this in their interviews, their choices in this regard reflected their pedagogical beliefs about how time might be used to allow students to collaborate in small groups for a creative project (i.e., the problem-based learning project). In Creativity: Flow and the Psychology of Discovery and Invention, Czikszentmihalyi (1996) discusses that when constructing creative
environments, it is important to allow for creative individuals to be “master’s of one’s own time” (p. 145). He explains how particular schedules are not important. In creative environments, time should not necessarily be highly scheduled, nor should it be completely free. Instead, it is most important for the teacher to create scaffolds where time is free enough, so that individuals can “personalize patterns of action” which can help “free the mind from the expectations that make demands on attention and allows intense concentration on matters that count” (p. 145). Likewise, Craft (2005) addresses the importance of time in relation to fostering creativity in schools, as she explains how learners need the “possibility space” where they can “internalize propositional knowledge” for “potential transformation” (p. 38). She explains how learners’ ownership of their time is key to creativity, because it is in this time or “dreaming space” where individuals can “play around with the ideas, processes and procedures of that domain, ...develop technical mastery, and then to move into finding one’s own voice in the domain” (p. 38).

These recommendations do not suggest that small ‘c’ creativity classrooms contain large blocks of free time. However, examining the three most successful classrooms in this study, it is evident that giving students ownership over their time is pertinent to fostering creativity. In the case of Ginny’s classroom, she had substantial blocks of free time during the class day, but she also necessitated that small groups work outside of class, which helped to create time ownership for her learners and seemed to produce successful collaboration (i.e., students reported this in their interviews and her CAT scores were highest). Rob also employed blocks of free time and gave the students the tools necessary to collaborate (i.e., access to equipment like the video camera, use of
computers to do animation, and materials for making posters). This gave the students ownership over their own time and work. During the problem-based learning assignment, Bill included blocks of free time for partner groups to work together, but he also scaffolded the classes with routines (like his daily “News” segment and having nicknames for his students). In doing so, he helped to create a collaborative environment and complex system, where creativity could emerge. All three teacher’s classrooms (Bill’s, Rob’s and Ginny’s) were permissive enough for the allotment of time to allow for students to have the time possible to create small groups that could collaborate successfully (albeit to varying degrees) on a project. In many ways, their classrooms mimic the complex systems community that Lemke (2000) writes about:

Are there emergent processes and patterns in classrooms? I think every teacher and student knows that there are. There are new routines that emerge, new social groupings and the typical interactions that sustain them, class in-jokes, informal rituals, typical sayings and phrasings, favorite word usages with special meanings, and so forth. These in turn can become the raw material for more complex new patterns unique to the classroom, and they certainly constrain the probabilities of actions and utterances that would invoke these special meanings or contribute positively or negatively to social relationships. A classroom, and indeed every human community, is an individual at its own scale of organization. It has a unique historical trajectory, a unique development through time. (p. 278)

The teachers’ distribution of time for small group work in their classrooms can be seen as a gesture towards constructing classrooms, which are not only places to master content, but more closely resemble a “human community.”

The framework was a helpful lens in looking at the study’s data, but it only gave a limited amount of information. It did not take into account how teachers structured time and how this related to the way they fostered collaboration. An emergent piece that it also did not capture was the importance of school context. There are relationships in both
directions between high and low framework and CAT scores and high and low performing schools (i.e., that teachers in higher performing schools tend to have higher framework and CAT scores and that teachers in lower performing schools tend to have lower framework and CAT scores). Because Ginny, Bill, and Rob were in higher performing schools, they had the resources, administrative support, and student engagement (e.g., attendance and a desire to earn high grades) to foster creativity in their classrooms. Bill and Rob taught in the same magnet high school and their CAT scores were the closest of any of the teachers. There was only a .35 difference between their scores. The second closest set of average CAT scores were Rob and Anna’s, which have a difference of more than twice as much (.73). They also shared three of the five Framework scores (the Nurture Collaboration Framework Component, the Provide Choices Framework Component, and the Enhance Self-Confidence Framework Component). Arguably, there is a relationship between both of them teaching within the same project-oriented, high performing school and the similarity in their CAT and framework scores.

Angle and Foster (2011) argue that science-learning environments should be inquiry-based, interdisciplinary, and collaborative spaces. Educators like Benedis-Grab (2011), Merten (2011), and Maurer, Tokarsky, and Zalewsky (2011) suggest that science educators use arts-based curriculum to convey science content. Ginny had the resources available to give her students the time and space to engage in inquiry-based learning for her problem-based learning scenario (i.e., ample laptops for each small group and a fully-stocked lab within her classroom). The focus of Bill and Rob’s school was interdisciplinary and they had the resources to aid their students in inquiry-based learning.
(e.g., computers and fully-stocked lab spaces readily available). Anna and Kraig were both in Renaissance schools and they suffered from lack of administrative support, low attendance, and lack of supplies (e.g., computers and a fully accessible lab space). These burdens inhibited their ability to foster small 'c' creativity, despite expressing their beliefs about the importance of fostering creativity in their classrooms in their interviews.

Creativity scholars give recommendations to teachers (Fleith, 2000; Kaufman & Sternberg, 2007; McWilliam & Dawson, 2008; Newton & Newton, 2009; Sawyer, 1999; Sternberg, 2005); however, these recommendations are not concrete enough, as they do not integrate the creative products students produce as a result of following these recommendations. Kaufman and Sternberg's (2007) definition of creative learning artifacts is not appropriate for a classroom that cultivates small 'c' creativity, as their definition necessitates the products be new, good, and relevant to the field or domain (i.e., in the case of this study, science) and thus, is dependent on viewing only large 'C' products as creative. The Small 'c' Creativity Framework combined the recommendations of these authors with Kaufman and Sternberg's (2007) definition, synthesized a small 'c' definition of creativity from McWilliam & Dawon's (2008) theoretical constructs, and incorporated the student products created in classrooms. In this study, it did not capture all of the phenomena occurring in the teacher's classroom (for example, the importance of time allotment and school context), but it did build on the creativity literature. In addition, it is an important step towards a better understanding how teacher practice allows for creativity to occur in classrooms.
5.3 How do science teachers’ beliefs about creativity and their practical strategies interact to support creativity in science classrooms?

Researchers studying fostering creativity in K-12 settings have discovered that the major challenges are teachers’ lack of understanding of the importance of creativity to learning. Kaufman and Sternberg reported that many teachers believe creativity is “irrelevant to educational practice” (p. 55). Other scholars like Newton and Newton (2009) found that many science teachers in particular have misconceptions about creativity. For example, many of the teachers they studied believed that it is not important in the science classroom, because the scientific process does not use learners’ imaginations, despite the fact that scientists agree that it does.

The five science teachers in this study responded affirmatively to the Creativity interview question that asked them whether or not creativity was important in science. Their answers show that these teachers’ valued the importance of creativity in science in various ways. Kraig’s response showed a lack of complex understanding of creativity, as he said “Creativity is most important in science because we have enough material in science lab or science classroom to testify our hypothesis.” Anna expressed her belief that creativity was important in high-level science, after a student has mastered a certain level of content. She explained, “it’s a little bit less obvious to see that, at this level, for high school and middle school students...in higher science classes that really comes creativity.” Bill thought creativity was important, because it allowed for all students in a classroom to be engaged in the content. He said, “I feel I would inhibit some kids and lose some kids early if I didn’t allow them to be creative. Period.” Rob stated that creativity was important in science, because it could aid in solving social problems, as he
explained: “If you can get them to extend what you’ve taught them to their personal lives—that is creativity. They are solving internal problems. They are solving social problems. They are solving community problems.” Finally, Ginny’s response was a hybrid of Bill’s, Rob’s, Anna’s, as she discussed that problem-based learning pedagogy could use high-level science concepts to engage all students in the classroom to solve social problems. As she stated, “I think creativity is very important and unfortunately a lot of science is taught just like facts. And these are the facts that you need to know. And I think that defeats the whole purpose of science…it takes a lot of creative thought to be innovative and to figure out, ‘how can I apply this knowledge to something that would help humanity.’”

All of these teacher beliefs could be seen reflected in their practice. Kraig did not utilize his students’ creativity in his assignments. Anna put a lot of effort in her classes to help her students’ master content knowledge and put this mastery before avenues of accessing their creative skills. Bill and Rob found ways to connect their students’ creativity in their classes, with Rob being particularly interested in making his assignments relevant to his students’ lives (for example, his calorimeter project). Ginny’s problem-based learning scenario exemplified her beliefs, as she engaged her students’ creativity in solving the air pollution problem through nanotechnology research.

In their study, Newton and Newton (2009) found that some of the teachers they studied were only able to conceive of creativity as occurring in an arts context and not in a science classroom. To address these teacher beliefs, the researchers argued that 21st century science teachers should start to see creativity in the sciences more in the realm of “productive thought,” i.e., a combination of creative and critical thinking, versus
irrelevant thinking. For example, if students are conducting science experiments in class, if a student has a new and divergent hypothesis for a natural phenomenon, this is both productive thought and creative. In this situation, according to Newton and Newton's ideas about 21st century creativity, a teacher should allow his student to test out this new hypothesis in order to further his creative thought.

In her chapter “Creativity and Pedagogy,” Boden (cited in Craft, 2001), recommends that teachers today support creative thinking by allowing students to connect ideas that are usually seen as discrete ideas from different disciplines or ways of thinking. She encourages teachers to see how their students’ ideas fit not only into their classroom-specific and field-specific learning environments, but also into the larger world body of knowledge. A simple example of how this might work in the classroom, which is not from the case studies, is for a teacher to encourage students to examine a particular fact (for example, a moment in history such as the Battle of Gettysburg in the American Civil War) as not bound to any one discipline, but as part of every discipline. This kind of teaching is risky, Boden (2001) explains, because just as students can make substantial creative insights by exploring ideas across disciplines there is always the risk that these new juxtapositions can produce nonsense. According to Boden (2001), it is up to the teacher to have a sensitive enough understanding of his or her students to support both kinds of thinking, in the hopes that this validation gives confidence for students to always seek new ideas.

Four of the five teachers (Bill, Ginny, Rob, and Anna) used the problem-based learning project to allow students to cross disciplinary boundaries in order to engage in science content. Teachers, like Bob, Ginny, and Rob, brought up other classroom projects
that also allowed for disciplinary boundary crossing (for example, Ginny’s “S’mores” lesson, Bill’s individualized “Astronomy symphony” project for a failing student, and Rob’s calorimeter project). The ITEST-Nano project seemed to aid in this boundary crossing in terms of the problem-based learning curriculum, as it trained teachers in using tools like Garageband to create products. If these science teachers asked students to turn in a podcast, even an audio one, they were asking them to use writing and music to engage with nanotechnology concepts, i.e., cross disciplinary boundaries. This practice seemed to overall be successful in getting students to engage with the content.

Historically, creativity has been seen as belonging more to the arts and humanities more than other fields like mathematics or the practical sciences, such as engineering (McWilliam & Dawson, 2008). As discussed in the literature review, there are now many educators who believe creativity occurs across disciplines. In a collection of essays by a variety of creativity scholars, called *Creativity Across Domains: Faces of the Muse*, Kaufman & Baer (2005) argue for domain generality, in terms of the creative process itself. This study’s Small ‘c’ Creativity Framework is an ideal guide for domain general creativity. In terms of the study, it was an informative tool in better understanding these science teachers’ classrooms. In future settings, it could also be applied to fostering small ‘c’ creativity in students in other disciplines, because it asserts that creative leaps need only to be novel for the learner and not dependent on the current advances of the field. Lunn and Noble (2008) argue for thinking of creativity as a domain general process, as they suggest that thinking of art and science as interconnected disciplines helps support the creative process in schools. Interdisciplinary ways of thinking about creativity support
creative thinking in classrooms, because they free teachers to connect ideas that may not normally cohere together; thus, they are not domain-bound (Boden, 2001).

Moreover, Boden (2001) argues that creativity is not so much an immutable or innate process, but one that includes the reconfiguring of ideas or elements. These elements need not come from the same disciplines. Boix-Mansilla and Gardner (2004) and McWilliam et al. (2008) have explored the ways in which transdisciplinary learning can be used to give multiple perspectives on an idea from several disciplines. They differentiate transdisciplinary learning from interdisciplinary learning, since the latter involves two or more disciplines brought together to form new knowledge. In the case of transdisciplinary learning, disciplines are used as access points to one idea versus combining two distinct ideas from different disciplines to form a new one. In the successful problem-based learning projects in the teachers’ classrooms, particularly Ginny’s, Bill’s, and Rob’s, students were engaging in transdisciplinary learning. For example, as students in Rob’s classes used their skills in video, writing, and acting to create their Gap “Nanopants” infomercial, they used a variety of disciplines to better understand how nanotechnology concepts were utilized to make the pants repel water or other staining agents. Arising from the study, it is my hypothesis that when teachers use transdisciplinary learning to engage students with science content, they are effective in fostering their students’ small ‘c’ creativity. This is not explicitly reflected in the framework, but it is implicitly present in the framework’s domain generality. The Small ‘c’ Creativity Framework could be a helpful lens in enriching the pedagogical practice of teachers in both the sciences and the arts. Hopefully, it could bridge pathways of collaboration between teachers and students in different disciplines.
5.4 If students are judged to be more or less creative within the teachers’ classrooms, what are some possible relationships between their exhibited creativity and teacher practices and beliefs?

Teacher interviews and classroom observations responded to Research Question #3 in terms of both teachers’ student knowledge and classroom culture. In their interviews, both Ginny and Bill pointed out how important it is for teachers to know their students when nurturing their creativity. This knowledge allowed them to tailor assignments towards their students’ interests and in turn, modify their assessments to fit their students’ creations. An example of this occurring in the class of Bill’s I observed was in his student, Mondrian, who had an interest in poetry. Because Bill was an active member of the school’s poetry community, he knew of Mondrian’s skills in writing. He also knew about Mondrian’s learning disability and that he could best learn through his writing. On several occasions and in his problem-based learning assignments, Bill would help Mondrian engage with the science content knowledge through poetry.

Juxtaposed to Bill’s practice are the ways in which a teacher such as Anna did not use her knowledge of her students’ interests to help them engage in the content. Anna had two poets in her classroom, Monica and John. Anna knew about this interest, but as she explained, she did not harness it to help them with class content. She was permissive in letting Monica write her poems in class and allowed her to share them with her and others; however, she did not use this interest as a tool to get Monica engaged in the problem-based learning project, which used writing. Possibly she could have extended the assignment and asked Monica to write something poetic for the podcast. This would have varied the form of the podcast from a commercial to a poem and could have engaged Monica more in the assignment. Also, John did come in late to the class due to
registration issues at the school, but Anna could have used her knowledge of his strong interest in poetry and rap to have him complete the project. Both of these were missed opportunities for these two students to engage in the knowledge Anna wished to convey. Similarly, in his Creativity interview, Kraig could not specifically name a student in a past or present class who he remembered as being creative. Still, as discussed in his case study narrative, there were creative students in his classroom. Certainly, if Kraig had had this knowledge of these students, he might have found ways to engage them in the science concepts he wanted to teach.

Creativity scholars have written about the importance of connecting creative learning with students’ interests and strengths. Pahl (2007) suggests that creativity comes out of students’ interests and experiences. She recommends that teachers should explore how the artifacts students create are actually grounded in real world experiences and use these connections to encourage continued creative learning. According to Annarella (2000), students’ imaginations are natural sources of realistic solutions to problems, because they are grounded in what learners have actually experienced. In other words, a learner has to imagine what they have already been through in order to imagine what could be. A teacher practice that contains knowledge of students’ interests and experiences allows for teachers to find disciplinary entry points for students to engage with class content.

Results from the study showed that there was relationship between CAT scores, framework scores, and school context. Csikszentmihalyi (1996) distinguishes between the microenvironment or the “immediate setting in which a person lives” (i.e., a creative individual or student’s home life) and the “macroenvironment” that a person lives, which
includes the “social, cultural, and institutional context” (p. 139). He argues that the macroenvironment is key in generating creative thinking. For a student, this macroenvironment is his or her school context. Hong and Milgram (2010) discuss how school culture affects the amount of creativity that can be fostered in classrooms. I observed how the schools’ cultures affected the amount of creativity the five teachers fostered in their classrooms and how they, in turn, created their own classroom cultures.

For example, Ginny had the highest average CAT score of the five teachers and had high framework scores. Her school also was traditionally the best school of the four I visited, in terms of college preparation and selectivity of students admitted. In order to be admitted to her school, students had to have a minimum PSSA score in the 88th percentile and only A’s and B’s. Ginny also established an inquiry-based atmosphere within her classroom. Her classroom connected to what McWilliam et al. (2008) explained occurred in an inquiry-based science learning environment, which promotes active tasks versus a passive consumption of core concepts. In addition, even though I closely observed her students’ work on an open-ended assignment like the problem-based learning scenario using an inquiry model, Ginny often drilled her students and gave them pop quizzes and tests to measure their content knowledge. Ginny’s students were able to build their content knowledge into their problem-based learning products and this likely affected her high average CAT score. Her school’s focus on student academic success affected her classroom culture towards fostering creativity, in that it was important for her to allow her students to be creative in building their content knowledge.

The other three schools I visited did not have similar academic cultures as Ginny’s school. Two of the schools (Anna’s and Kraig’s) were labeled as Renaissance
schools by the Philadelphia School District during my observational period, which meant that they were low-performing and needed transformative change. Their students also produced creative products with the lowest average CAT scores and had lower scores than the other three teachers along the framework. While Kraig and Anna had different teaching styles, they both seemed to struggle with similar classroom problems: low and varying enrollment, disciplinary issues, and their schools’ lack of academic focus.

Rob and Bill’s school was different than these three other schools, as it was an art-focused learning environment. It is a high-performing school, but there is an emphasis in the students’ maximizing their artistic talents. All of the students at their school had to submit an arts portfolio in order to be admitted. Many of the students I observed and interviewed had strong, (if not career), interests in arts-related fields. Using Ludwig’s (1998) disciplinary framework as a theoretical lens, this may have caused many of the students to approach their science classes with a similarly to their arts classes (i.e., emotive, subjective, imprecise, and informal). While Rob and Bill responded to their students’ dispositions and needs by giving them opportunities (more directly observed by me in Rob’s case) to cross disciplinary boundaries with their projects, they still produced projects with lower average CAT scores than Ginny despite having the same range of high scores along the framework (medium to high). Part of this could be attributed to the different teaching styles among the teachers, but at least another part could be attributed to the culture of Ginny’s school being more conducive to science learning.

Related to school and classroom culture was students’ access to equipment. In terms of technological and experimental supplies, they were plentiful in Ginny’s classroom. There was an accessible laptop cart in her classroom on all the days it was
needed for her student’s problem-based learning scenario research and a fully stocked set of lab tables within the room. Rob and Bill’s classrooms were both equipped with lab equipment and had a nearby computer lab, where the students were able to work on their problem-based learning research and assignments. These supplies aided these teachers’ students in completing their work. In contrast, Anna had a laptop cart in her room for part of the year, but in the middle of the year, the laptops were stolen. Not only was her students’ work on their podcasts and powerpoints stolen, it caused her to have to have the students take turns recording their podcasts on her own computer. Likewise, Kraig did not have access to laptops in his classroom and had to book the lab room many weeks in advance and so, did not get to use it often. In his Nanotechnology interview, he cited this as a reason that he did not get a chance to do the experiments he wanted to do with his students. Taking the various circumstances of these five teachers into account, it follows that access to science and technology equipment helped some teachers complete their problem-based learning scenarios successfully and that lack of these materials inhibited the other teachers. It also demonstrated the importance of how importance having access to science and technology supplies are to fostering creativity in science classrooms.

Scholars like Sawyer (1999; 2006) and Czikszentmihalyi (1988) combine complex systems theory with creativity in their research. In doing so, they acknowledge that a classroom is a complex social learning environment and that creativity can emerge in unpredictable ways within it. As Sawyer (1999) explains, new ideas arise in emergent learning systems that are greater than a mere sum of their parts or are predictable from considering individual learners or ideas in the environment. Likewise, McWilliam et al. (2008) argues for inquiry-based learning environments where learners actively engage
with these environments and form new ideas in novel and unpredictable ways. Similar to the ways in which teachers allocated time in their classroom, classroom culture affected the ways that the teachers fostered successful small group work and a general collaborative environment, where unpredictable new ideas might emerge. Although she did not consciously construct them, Ginny let her students choose their problem-based learning scenario groups and suggested that they all take certain roles in their groups (e.g., a Researcher, a Notetaker, a Performer). This encouragement led to members utilizing their strengths within their groups and integrating and synthesizing concepts into their products. Bill organized the problem-based learning partner groups and did not stress that each member take a role. This led to some groups working together better than others and his overall average CAT score to be lower. Rob let his groups emerge entirely themselves and suggested that group members take particular roles (but did not stress it). His approach allowed for collaboration between classrooms and a wide range of creative products, but his average CAT score was lower than Bill’s and Ginny’s. Kraig and Anna both struggled with low attendance and an inability to control disciplinary problems (e.g., students acting out, the threat of violence, apathy towards learning). This factored into how they approached group work and their ability to create and maintain an emergent learning system. Anna let students form groups of two to three students, but due to sporadic attendance and shifting class enrollment, it was hard to maintain these groups. These circumstances, among other factors, likely caused her students’ products to receive lower CAT scores. Kraig did not attempt to construct groups at all and if they emerged among a couple of students in working on a worksheet or textbook problem, this formation was short-lived. The lack of cohesive group work seemed to have some effect
as Kraig’s students did not produce products that could be scored via CAT. In sum, the
ability of each of the teachers to develop classroom cultures that mimicked complex
systems where new learning and thinking could emerge appeared to relate to the overall
cultures of their schools. The teachers that were able to foster the most creativity in their
classrooms were the teachers in the schools that were higher performing, had the most
resources, and gave their teachers the most support.

5.5 Implications for Research: Awareness of Small ‘c’ Creativity

This dissertation has applied the Small ‘c’ Creativity Framework to the study of
teacher practice in science classrooms in the beginning of the 21st century. The
framework combined complex systems theory with creativity in order to consider how
real high school science classrooms were fostering small ‘c’ creativity in emergent
learning systems. Using complex systems theory as a lens was important for this study,
because it suggested that creativity is not a mystical process or trait inherent in specific
learners. Instead the study asserted that creativity is a learning process that can be
nurtured in all students within classrooms. This is in line with current shifts of thinking
about fostering creativity in K-12 classrooms and other similar learning environments,
like university classrooms and workplaces. McWilliam and Dawson (2008) explain the
"democratizing turn" (p. 634) that creativity research has taken of late. They write:

We have seen a shift away from the type of creativity that Johnson (2007),
in his book Creators: From Chaucer to Walt Disney, characterises as “a
painful and often terrifying experience to be endured rather than relished
and preferable only to not being a creator at all.” By contrast, a new wave of
‘little c’ literature (second generation thinking) focuses typically on the
thinking and doing of a much greater proportion of the population than a few towering historical figures possessing "the most ferocious self-discipline" (Slattery 2007, p. 20). Weisberg's (1999) *Creativity and Knowledge*, Jonathon Feinstein's (2006) *Nature of Creative Development*, and *Creativity and Development* (Sawyer et al. 2003), a round table discussion of experts in the field—all reflect this democratising turn. (p. 634)

According to their research, thinking about creativity has shifted from only considering the creative leaps of certain, rare individuals who have advanced their fields to considering how every individual has the capacity to be creative. This shift, they contend, is key to 21st century learning and working, which necessitates a malleability of thinking and communicating. In this study, the five teachers fostered small 'c' creativity in various ways and to varying degrees. The study data showed that teachers' student knowledge, teachers' openness to allow for students to cross disciplinary boundaries in their assignments, allotment of time and organization of small groups, and belief in the importance of cultivating creativity in the science classroom all related to the amount of creativity fostered in classrooms. It also suggested that school context has as critical a role in fostering creativity as pedagogical training and teacher beliefs do.

In her article, "Unlearning how to teach," McWilliam (2008) writes:

The twenty-first century demands not only that we learn new forms of social engagement but also that we unlearn habits that have been useful in the past but may no longer be valuable to the future. Teachers have 'un-learned' the role of *Sage-on-the-stage* as the dominant model of teaching, and the shift to *Guide-on-the-side* has served an important function in changing the focus of pedagogy from the teacher to the learner. However, *Guide-on-the-side* is no longer sufficient for our times. This paper argues the importance of a further shift to *Meddler-in-the-middle*. *Meddler-in-the middle* positions the teacher and student as mutually involved in assembling and dis-assembling cultural products. It re-positions teacher and student as co-directors and co-editors of their social world. (p. 263)
In McWilliam’s (2008) vision of a 21st century classroom, a teacher and student act in concert to contribute to socially-constructed knowledge creation. This is a similar classroom to the one that teachers and students in Fleith’s study (2000) have agreed helps to support creativity. The teachers and students she studied explained that a classroom that nurtures creativity: gives students choices, embraces divergent ideas, stimulates self-confidence, and tends to give assignments that are tailored to students' strengths and interests. They also concurred that in an environment that stifles creativity: student ideas are disregarded, teachers try to manage the environment too much, and class time is excessively structured. Franske (2009) found that problem finding scenarios (where students pinpoint the engineering problem and try to find ways to solve it) had a great effect in increasing student creativity. According to Franske, 21st century teachers might consider increasing problem finding scenarios in their engineering and science classes. In this study, it was found to be the case that the more the teachers used problem-based learning scenarios successfully in their classrooms (i.e., those teachers with the highest CAT scores, like Ginny, Bill, and Rob), the more they engaged their students in the science content.

Arguably, the 21st century small ‘c’ creativity classrooms that creativity scholars are interested in constructing are in line with the kind of classroom the study’s analytical framework promotes. This is a classroom where teachers accept students divergent thinking, offer alternatives to assignments, promote collaboration in small groups, provide student choice, and increase learning and self-confidence. This study adds to this body of research surrounding small ‘c’ creativity, because it exposes the need for more studies that reveal connections between school context and creativity. It also provides a
way to improve practice through a set of practical recommendations. In the following section, practical recommendations that emerge from this framework are described. These could be used in teacher training programs or incorporated into future studies that tease out the role of school context and culture in fostering creativity.

5.6 Recommendations for Practice

Table 9 describes a list of recommendations for practice that have emerged as a result of this study.

Table 9

Recommendations for Practice

| 1) Support divergent thinking that is grounded in the lesson's activities or concepts | 1. Get to know students' interests |
| 2) Accept learning artifacts that are novel and relevant to the lesson | 2. Offer alternatives for assignments (especially ones that cross disciplinary boundaries or are transdisciplinary) |
| 3) Nurture collaboration among small group members in which individual kinds of creativity within the group are supported | 3. Encourage collaboration through student time ownership and by constructing small groups to play up creative strengths |
| 4) Provide choices on what is an acceptable response (learning artifact or discussion point) to a lesson | 4. Expect creativity |
| 5) Include lesson guidelines that enhance, rather than restrict, learning and self-confidence | 5. Allow students to discover creativity at their own pace |
1. Get to know students' interests: Teachers who were successful at fostering small 'c' creativity in their classrooms mentioned that it is helpful to know their students' interests. This allowed them to find entry points into class content and provide opportunities for using their creative strengths to guide their learning.

1. Offer alternatives for assignments (especially ones that cross disciplinary boundaries or are transdisciplinary): Teachers who were successful at cultivating small 'c' creativity offered several assignments that crossed disciplinary boundaries. Some of these assignments could even be considered transdisciplinary. Creating disciplinary crossing or transdisciplinary assignments in science classrooms can help nurture students’ creativity and aid in the mastery of course content.

2. Encourage collaboration through student time ownership and by constructing small groups to play up creative strengths: Science teachers can benefit from encouraging collaboration in small groups where each student can take a role that utilizes his or her own creative strengths. This may mean assigning group members or letting the groups form naturally. The important recommendation is to be conscious of group formation, in order to ensure that members bring different strengths and can use these effectively towards group assignments and products.
3. **Expect creativity:** Students can benefit when teachers create assignments with language that does not restrict their novel thinking. This often happens when teachers actually use the word *creativity* and/or show how they value student creativity through their assessment rubrics. Classrooms where students exhibit small ‘c’ creativity are classrooms where the teacher stresses to students in various ways that he or she feels that everyone can be creative.

4. **Allow students to discover creativity at their own pace:** Teachers might aim to nurture new learning leaps in all students, no matter the students' age or background. Even when teachers know from their own background that certain techniques or advances in science have been applied before by others (i.e., they are not higher level thinking), it is important not to discourage any new thought in students. If a student uses an idea, for example, that a teacher finds to be not radical or even basic in a class assignment, she or he should encourage some shift in their thinking, if necessary, but should also try not to discourage the student from building upon the idea or suggest that they have failed.

### 5.7 Chapter Summary

This chapter outlined an interpretation of the results of the study, including CAT and framework scores and individual and global trends across the cases, in the context of the research goals. These individual and global case trends included the relationship between CAT and framework scores, as well as the importance of teachers’ student knowledge, transdisciplinarity, school and classroom culture, time ownership, and small
group formation. It also provided a set of practical recommendations that corresponded to the study's analytical framework. The chapter demonstrated that this dissertation offers the field of creativity research an understanding of how teachers' beliefs influence practice and how small 'c' creativity is fostered in students through various styles of teacher practice.
6. CONCLUSIONS

6.1 Summary of Study

Through the application of a Small ‘c’ Creativity Framework that gives suggestions for fostering small ‘c’ creativity, this study sought to fill a gap in the literature in teacher practice surrounding creativity in K-12 settings in the United States. Because creativity has a long history of being studied in the field of psychology and has been looked at as important to learning within the fields of arts and business, it was particularly key to consider how science teachers felt about the importance of nurturing creativity in their classrooms and how these beliefs interacted with their practice. Complex systems theory aided the development of the framework and the ways in which creativity was thought of as an emergent phenomena that can be nurtured in classrooms versus a trait that is inherent in particular types of students.

The study examined five case studies of high school science teachers as they participated in a large-scale, NSF-funded project premised on the idea that training teachers in 21st century pedagogies, (for example, problem-based learning), helps teachers create classrooms that increase science competencies in students. Using participant observation, interview data with teachers and students, and analysis of student work generated in teachers’ classrooms, I investigated how teachers’ curricular choices and their beliefs affect the amount of student creativity produced in their classrooms. Analysis included determining Consensual Assessment Technique (CAT) scores for student products and framework scores, alongside case study narratives, in order to give a robust picture of real teacher practices.
Using the study framework as an analytical lens, relationships were determined to exist between CAT scores, Small 'c' Creativity Framework scores, and school context. In addition, teachers’ student knowledge, teachers’ openness to allow for students to cross disciplinary boundaries in their assignments, allotment of time and organization of small groups, and belief in the importance of cultivating creativity in the science classroom all related to the amount of creativity fostered in classrooms. A set of practical recommendations arose from the data and these conclusions. In sum, the study provided considerable evidence that individual teacher beliefs and training only can have so much impact in sustaining creative thinking in students. The culture of schools influences teachers’ participation in activities that help to build creative classrooms, as much as their beliefs in the importance of creativity in the science classroom do. This information could affect pre-service education and professional development programs for teachers, which will be discussed further in the following section, along with some future research pathways.

6.2 Study Limitations

Methodologically, several limitations can be identified. Although the amount of cases was sufficient to make conclusions for the study, the relatively small amount of teacher participants, who have been trained in problem-based learning pedagogy likely yielded the ability of the teachers to foster small ‘c’ creativity better than other groups. There were missing framework scores in the set of profiles. For example, none of the teachers scored low on the Support Divergent Thinking Framework Component, low on the Accept All Artifacts Framework Component, high or low-medium on the Nurture
Collaboration Framework Component, high or low-medium on the Provide Choices Framework Component, or low-medium on the Enhance Self-Confidence Framework Component Framework. Doing additional case studies with teachers in other professional development and school contexts could aid the understanding of the study framework as a helpful tool. Likewise, two of the teachers taught in a school that uses problem-based pedagogy regularly, so these teachers potentially created a skewed perspective on the study outcomes. Additionally, this study addresses the importance of increasing creativity in science classrooms to potentially combat the STEM crisis by fostering creativity in individual students. The study is concerned with preparing more individual students to be scientists through fostering creativity, yet it employs a framework that is influenced by complex systems theory and looks at how small groups of students, versus individual students, produced creative products. This disconnect between creativity in individuals versus small, collaborative groups may have misaligned the study’s conclusions from its research questions.

Although the amount of time in each classroom (approximately 17 hours) was adequate to collect data for the study, more time could have given more robust pictures of teacher practice. As a researcher, I used CAT for the first time in this study and there are potentially ways that I did not use it as effectively as I could have done. For example, I might have asked expert scientists versus expert science educators to be my raters. I might have included more practice sessions to ensure they felt comfortable scoring. Future studies could build on my skill using this technique to better understand the amount of creativity produced in classrooms. Furthermore, the analytical lens of the Small ‘c’ Creativity framework was based heavily on the definitions presented in its
categorization manual. This study was exploratory and the manual was developed explicitly for the study. It was being used for the first time. Its definitions helped to shape portraits of teacher practice and score the data, but it is likely that these need to be revised and refined for future studies. Also, as a result of this study, school context emerged as an important factor in considering small ‘c’ creativity in classrooms.

6.3 Future Studies

Conclusions from this study suggest future studies that could be completed. A series of future studies might consider the context of school more closely to see if school context is always a factor. The outcomes of these future studies could be foundational for additional studies that look at pre-service and professional development programs for teachers, resulting in curricular intervention programs. Transdisciplinary activities were hypothesized to be successful in helping students engage with science content. Future studies and curricular interventions could probe this idea further. Also, the Small ‘c’ Creativity Framework that was used to frame and analyze this study is domain general versus domain specific; however, it was used in domain specific classrooms (i.e., science). Future studies could look at how the framework might be applied to other disciplines, in order to see if parts of the framework were more or less helpful in studying science classrooms, in particular. Lastly, this study looked at the amount of student creativity produced in the teachers’ classrooms, but it did not consider the process that students went through individually and in groups to construct their learning artifacts. Future studies might analyze students’ creative processes and relate these processes back to teacher practice and beliefs.
Appendices

Appendix A

Teacher interview protocol

Hello! I am going to ask you 11 questions regarding your beliefs about creativity. I will be recording your answers to these questions. If at any time, you would like to stop this interview, please let me know and we will stop immediately. The interview should take about 30-40 minutes.

1. What is creativity? [Prompt that there is no one right answer.]
2. How does it look? How would you know that something or someone has been creative? [Prompt for occurrences in a classroom.]
3. Do you consider yourself creative? If so, how does this creativity manifest? Take me through what it is like for you to be creative. [Prompt for an example in a classroom and outside of one.]
4. How is creativity important in science? [Prompt for curricular issues.]
5. Do you think creativity has a place in the science classroom? Why or why not?
6. Are there lessons that I have observed that you think promote creativity? [Prompt for the ways in which they were taught to teach science.]
7. Can you think of the most creative student you’ve ever had? What class was he or she in (grade level and subject)? What did that student exhibit? [Prompt for them to think of additional ones, if possible.]
8. Do you think creativity is an important skill to develop in students today? [Prompt for what other skills they might find important.]
9. Are there any students that stand out for you as being particularly creative in the class I have been observing? [Keep asking for more than one, until they cannot think of any more.]
10. If so, can you describe something you saw them do that makes you think they are creative? [Prompt for why this made the student stand out. Try to get them to connect it to something they did in class to make the creativity occur, if possible.]
11. What do you do when you suspect a student is creative? [Prompt for concrete things that they might do.]
Appendix B

ITEST –Nano Project 2008 Interview Cover Sheet (general)

Name of Event(s):  (If you observe students fill in post-survey, please make a few notes about their attitudes and affect during the post-survey)

Site:

Date:

Researcher:

Other ITEST staff:

Challenges/supports evident during this event?

Additional Materials:

Reflections/ What stands out?/Questions?/Ideas for follow-up?:

1. First we will talk about the ITEST framework. (Review the 5 elements)

   1. Which one of these components do you feel was the most important for your class? (probe this area)
   2. Were there any components that were especially challenging for you to implement? (probe these components)
   3. Then ask about any other components that weren’t already mentioned.

In each area: What have you done in this area? Anything you wanted to do that you didn’t get to? What were successes, challenges and according modification (compared to the constructed units)?

   A. Real world science and engineering applications
      a. Current nanotechnology research
      b. Scientific issue that is relevant and important in current society (e.g., cancer, environmental applications)
      c. Ethical considerations (e.g., affordances and constraints to multiple constituencies, decision-making and considerations of complex variables)

   B. Educational Technology (simulations)
      a. Computer simulations (e.g., NetLogo)
b. Scientific imaging

C. IT for communications
   a. Web 2.0 tools (e.g., Google Groups and Docs, wikis, blogs)
   b. Multimedia applications (e.g., podcasts, online videos)
   c. Web investigation
      Are there any technology initiatives in your school that are relevant
to your work with ITEST-Nano? How did this impact how you
used IT for your unit?

D. STEM career investigations
   a. Guest speakers from industry partners
   b. Highlighting relevant careers in the PBL units
   c. Industry field trips
   d. Industry internships

E. Cognitively rich pedagogy
   a. Students work in collaborative teams to solve problems
   b. Peer evaluated product
   c. Open-ended, problem-based problem-solving with multiple
      possible solutions
   d. Evaluating information, creating and using evidence
   e. Scientific skill development (e.g., graphing, experimenting)
   f. Did this unit fit well with the your curriculum and the standards
      that you need to cover? Why or why not? What do you think your
      students learned from this unit? How can you tell that they learned
      this?

II. Future Use and Use with Other Classes
1. Will you use the nano unit again with this class? Why? What would you
do differently?

2. Will you use pieces of the nano framework later in the year? Why? Why
not?

3. [PROBE WHETHER THE TEACHER USED ANY OF THE PIECES OF
THE FRAMEWORK WITH OTHER CLASSES THAT YOU DID NOT
OBSERVE.] What worked? Why? If they didn’t use it with other classes,
do they think they will in the future? Why or why not?

III. PD. Now I have a few questions about the summer PD. This will help the
management team make improvements for the next summer.

1. Was the summer PD helpful? Why?
2. What was helpful for developing the unit? Anything else the project should do differently next summer to help with curriculum development?

3. Compared to the unit you constructed in the summer, what major changes did you make to fulfill the implementation? Why do you think such changes are necessary?

IV. Networks. Now I am going to ask some questions to find out if this project is creating greater interest in nanotechnology.

1. First, could you tell me what kind of communication you have had with people from the summer PD? How often? About what? How did this communication help you implement your unit and grow professionally?

2. Have you talked to other people in your school about nano, technology, or other aspects of the project? (if not mentioned earlier, probe – computer Staff? Colleagues? Principal?) What do you talk to them about in relation to the project? How often?

3. What about other teachers in other schools? What do you talk to them about in relation to the project? How often?

V. Concluding Questions

1. Would you recommend this project to other teachers in Philadelphia? What would you tell someone else who is thinking about participating in it?

2. Is there anything else that you would like to share about the project?
Appendix C

Student interview protocol

Hello! I am going to ask you 10 questions regarding your beliefs about creativity. I will be recording your answers to these questions. If at any time, you would like to stop this interview, please let me know and we will stop immediately. The interview should take about 20 minutes.

1. Do you think you have ever been creative? [Prompt for whether this occurred outside or inside the classroom.]
2. If so, what was your experience like? Take me through the steps. [Try to get them to name the steps as clearly as possible.]
3. Do you think any of the lessons you are doing in [teacher’s name] classroom ask you to be creative? Why or why not?
4. Are there any lessons in another class that ask you to be creative? What subject are these lessons in and what are the lessons like? [Prompt for curriculum]
5. Have you thought about activities you did in your science classes with [teacher’s name] when you weren’t here? What did you think about? [Ask for them to name lessons until they cannot name anymore.]
6. Have you ever talked about your classes with [teacher’s name] with your parents or friends? If so, what did you say? [Prompt for curriculum.]
7. Do you like to think of new ideas? What kind of new ideas do you like to think of? [Prompt for ideas in science.]
8. Do you ever so caught up in any of the activities in science class that you forget where you are cause you are so absorbed in the task? If so, what are they? [Prompt for curriculum.]
9. Have you ever gotten so caught up in doing any other classroom lesson or activity? Tell me about the experience. [Ask them to think of examples until they cannot think of anymore.]
10. When you are learning in this class, do you like the activities in which you can work with other students? Explain. Have you ever had a new idea or made something you might consider creative when working with other students?
Appendix D

FRANKLIN LEARNING CENTER

Learning Activity Packet

Subject: Biology Course # 300
LAP #9 Title: Nanotechnology & Our Baby
Standards # 3.6.10 A, B; 3.8.10 A, B, C; 3.7.10 D, E;

A. Introduction – Well, you and your partner have just made a baby. Now, it must grow up in the 21st century. But, your child is not perfect, at least not yet. No doubt he or she will be exposed to many diseases throughout their life from the common cold, ear infections, the flu, an upset stomach, etc., so many problems. Or, maybe your little bundle of joy will have poor teeth, risk of diabetes, high blood pressure, or cancer…so many possibilities. Maybe your child is destined to have sickle cell disease, or carries a likelihood (genetic marker) of being an alcoholic or schizophrenic?

B. One of the possibilities to help your child cope with these issues lies in the field of nanotechnology. Yep, “nano” means small, but just how small? Nano is even smaller than the Orioles chances of winning the World Series this year! But, here is what your job as a responsible parent is;

1. You will propose a nanotechnology-based treatment for whatever condition your child may be susceptible to…AND…this is based on your actual family histories. For example, how can nanotechnology help someone who is a diabetic? Or, may suffer from high blood pressure, or has a strong chance of getting some type of cancer such as prostate or breast cancer, 2 of the more common forms. Many of us have diabetes and/or cancer in our family history. How can we deliver diabetes medication more effectively? Would nanosensors work? Maybe, your want to insert a new gene into every cell in your child’s body…Can nanobots do this task? Your proposal will be outlined in a two-three minute podcast for each group. In that podcast, you will include; 1) the condition you have to chosen to address in your child; 2) the nanotechnology idea that will be used to address that condition (by address, I mean sense a level, then deliver medicine, cure, whatever); 3) the desired result of your intervention.

2. The specific type of treatment you have selected for your child. This will also be outlined in the podcast. When I say specific, what chromosome might be targeted in each cell? How will you deliver the medicine...gold nanobullets or carbon nanotubes for example? You must be specific here.

3. You and your partner will construct a small poster (8 & ½” X 11” or larger) with some specific information about a career in nanotechnology. After all, if your child is to benefit from nanotechnology, wouldn’t it be great if their mom or dad worked in the field? But, tell me in this section a
job, the educational requirements, and what you might make based on today's estimates.

C. Your grade will be broken down like this...70% on the podcast...30% on the career information. Deadline for the work is Friday, June 4th. If you finish early, you may start LAP #10, Ecology.

B. Behavioral Objectives

- [Objective 1]
- [Objective 2]
- [Objective 3]
- [Objective 4]

C. Vocabulary – None

D. Activities / Projects

- Activity 1a, 1b etc (Meets Objective 1)
- Activity 2 (Meets Objective 2)
  - Must be completed with at least 2/3 other students
- Activity 3 (Meets Objective 3)
- Project 1 (Meets Objective 4)
  - Activity A
  - Activity B
  - Activity C

E. Resources

- Textbook 1 (could be used with all objectives)
- Computers
- These websites:

http://www.nanotechproject.org/
http://www.idb.hr/diabetologia/05no4-1.pdf
http://www.researchandmarkets.com/reports/c48929
http://www.physorg.com/nanotech-news/

Careers:
http://www.nnin.org/nnin_careers.html

F. Assessment
   • Activity 1 Assessment
   • Activity 2 Assessment
   • Activity 3 Assessment
   • Project Rubric

G. Instructional Accommodations / Alternative Assessments
FRANKLIN LEARNING CENTER

Learning Activity Packet

Subject: Biology
Course # 300
LAP #10
Title: Nanotechnology & the Environment
Standards # 4.6.10-A, B, C; 4.7.10-A; 4.8.10-C

D. Introduction – British Petroleum, a.k.a. “BP”, is currently experiencing a small problem in the Gulf of Mexico. Well, maybe it’s not quite so small. After all, about 40,000 barrels of crude oil leaking into the Gulf cannot be too good for the environment. Let’s take advantage of this disaster, and see if we cannot learn something from it.

1. Here is your assignment – How can Nanotechnology be used to help remediate this situation?
   - Remediate means to “clean-up” or generally improve the situation that is occurring in the Gulf.
   - Let us look at the history of this spill. It started April 20th, 2010. Google “BP Oil spill timeline” and look for the esri.com website which is pretty good. Others are available, but be careful as some of them slant or bias their story.
   - Think about the situation:
     i. We are over 1 month into the spill
     ii. Salt water
     iii. Depth is 5000 feet (almost 1 mile. That is incredible water pressure)
     iv. Cold underwater; dark (no light)
     v. Hurricane season starts June 1st
     vi. The Gulf is home to so many shellfish, fish, and crustaceans

E. How to go about it
   - Can work solo, 2, or 3 in a group. No more than that

F. Assessment is a Power Point.
   - The Power Point must contain slides to answer these questions
     1. What specific type of fish, shellfish and crustaceans are impacted by this spill? List no more than 5 species. Put this on one 1 slide
     2. What types of birds are affected? List at least 2 species. Put this on one 1 slide
     3. Finally, detail your proposal using nanotechnology how BP might attack this spill. If you Google “Nanotechnology and Oil remediation” you will find a number of hits. I’d think this will take at least 3-5 slides, and that is for one person. Figure 3-5 per person per group. So if 3 people are in a group, I expect a Powerpoint with NO LESS THAN 11 slides (1 for item #1, 1 for Item #2, and 3 per person as a minimum for item #3
4. Be creative and have some fun with this

G. By the way, it’s due by Thursday, June 10, 2010 if you would like credit #10 on your final credit report

H.

B. Behavioral Objectives

- [Objective 1]
- [Objective 2]
- [Objective 3]
- [Objective 4]

C. Vocabulary – None

D. Activities / Projects

- Activity 1a, 1b etc (Meets Objective 1)
- Activity 2 (Meets Objective 2)
  - Must be completed with at least 2/3 other students
- Activity 3 (Meets Objective 3)
- Project 1 (Meets Objective 4)
  - Activity A
  - Activity B
  - Activity C

E. Resources

- Textbook 1 (could be used with all objectives)
- Computers
- These websites:

F. Assessment

- Activity 1 Assessment
- Activity 2 Assessment
- Activity 3 Assessment
- Project Rubric

H. Instructional Accommodations / Alternative Assessments

Definitions of Crude Oil
- Petroleum in its natural state prior to any refining process. Main elements are hydrogen and carbon (= hydrocarbon)
- Crude oil is a naturally occurring, flammable liquid consisting of a complex mixture of hydrocarbons of various molecular weights, and other organic compounds that is found in rock formations beneath the earth's surface.
- A dark oil consisting mainly of hydrocarbons
- Unrefined liquid petroleum. It ranges in density from very light to very heavy and in color from yellow to black, and it may have a paraffin, asphalt, or mixed base.

Here is some information on how sea water pressure affects us

**Ocean Water: Pressure**

Even though we do not feel it, 14.7 pounds per square inch (psi), or 1kg per square cm, of pressure are pushing down on our bodies as we rest at sea level. Our body compensates for this weight by pushing out with the same force.

Since water is much heavier than air, this pressure increases as we venture into the water. For every 33 feet down we travel, one more atmosphere (14.7 psi) pushes down on us. For example, at 66 feet, the pressure equals 44.1 psi, and at 99 feet, the pressure equals 58.8 psi.

To travel into this high-pressure environment we have to make some adjustments. Humans can travel three or four atmospheres and be OK. To go farther, submarines are needed.

Animals that live in this watery environment undergo large pressure changes in short amounts of time. Sperm whales make hour-long dives 7,380 feet (2,250 meters) down. This is a pressure change of more than 223 atmospheres! By studying and understanding how these animals are able to withstand great pressure changes, scientists will be able to build better tools for humans to make such journeys.

**More about how salty the water is**

Most people come in contact with the ocean only near its surface, and usually near its edges. In the huge part of the ocean that remains hidden, sea water is salty, cold, dark, and deep. Average salt content in the ocean is 35 grams per kilogram of sea water, composed mostly of six constituents: sodium (Na⁺), chloride (Cl⁻), sulfate (SO₄²⁻), magnesium (Mg²⁺), calcium (Ca²⁺), and potassium (K⁺). *These are often referred to as conservative elements, because their ratios to each other remain constant throughout the ocean.
It is important to measure salinity of sea water accurately. The salinity and the temperature determine water density (which drives water movement), and concentrations of many elements can be indirectly determined from salinity.
Appendix E

PBL Scenario:

Lung Function Tied to Pollution Level

July 9, 2009

In the first long-term study of the effects of air pollution on children, researchers reported Wednesday that children and teenagers in Philadelphia communities with higher levels of air pollution were more likely to have diminished lung function.

In their study, published in The New England Journal of Medicine, James Freeman of the University of Penn and his colleagues followed 1,759 children ages 10 to 18 in a dozen Philadelphia communities. The pollutants they considered came primarily from car exhaust, they said.

The investigators found that 7.9 percent of the 18-year-olds in the highest pollution areas had lung capacities that were less than 80 percent of what they should have been. Among those subjected to the least-polluted air, 1.6 percent had underperforming lungs.

The investigators added that the lung effects were similar to those that occur when children live in the home of a mother who smokes.

"This is some of the most convincing evidence that air pollution has chronic effects," Dr. Freeman said. "We see the effects in all kids. And it's an unavoidable exposure. It's not like smoking, where you can advise people to stop."

In an accompanying editorial, Dr. C. Arden noted that the air quality in Philadelphia and elsewhere had improved considerably since the 1990's, when the study was done. There will be debate, Dr. C. Arden said, over the costs and benefits of making additional improvements, but "continued efforts to improve our air quality are likely to provide additional health benefits."

Guiding Questions:

1. What is your response after reading this article?
2. What do you already know about the problem of air pollution?
3. What additional information do you need to research in order to solve the problem?
4. Brainstorm possible solutions to the problem including using the emerging nano technology
5. The effects of nanomaterials on human health and on the environment are still unknown, do you think they should still be used?
Appendix F

You and your team are food scientists for Rita’s Water Ice, in charge of developing a new flavor. As you prepare your new flavor, you need to consider several things: 1) your flavor needs to taste good. 2) you are targeting the Philadelphia population, where many people come from low-income neighborhoods, so your new flavor has to be fairly cheap. 3) you need to look at different sweeteners (artificial and natural), and how we taste things differently. 4) you want to consider the health consequences of your flavor—does too much of your sweetener cause health problems? Is there a way that you could increase the health benefits of your new flavor? (If you want to propose a new application, or have an idea for future research, include it here!) Then, when you have developed your product, you need to market it to the public. Create a Powerpoint slide (or slides), and a podcast, explaining all of your research.
Product Testing
The Principal has Mandated that NO! teacher is to be seen wearing Jeans in the building. Although some teachers have ignored the directive routinely this poses a problem for laboratory instructors. Pants worn by lab instructors must be resistant to staining and mild acids you must experimental determine which of two similarly appearing fabrics would be suitable for wear in laboratory conditions

Show youtube clip of nanotex shirt repelling different liquids, discuss whether students believethe ad or not.

(http://www.youtube.com/watch?v=EuLCYQbDp9U)

“The next lab we are going to do is a product test between two materials that have different properties. One of the materials we are going to give you has been specially treated through a new nanotechnology method so that it is hydrophobic.(scared of water).

Why might this be useful? Marketers for this nanofabric claim that is stain resistant, wrinkle resistant. The other piece of material you will receive has not been treated at all. For this lab, you are going to test different staining agents, to see whether or not the nanofabric is everything it is advertised to be. For this lab, what are going to be our independent variables?, Dependent variables?. and Constants?”

Nanopants activity.

Purpose: To compare the ability of two materials to resist staining, based on their chemical
properties.

Materials:
Nanofabric pipets paper towels (for cleanup)

Untreated fabric ~6 different staining agents

<table>
<thead>
<tr>
<th>Staining Agent</th>
<th>Nano fabric did it stain</th>
<th>Untreated fabric did it stain</th>
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Post-Lab Questions:
1. What was one observation you made that surprised you?
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________

2. Do you think the stain-
free claim made companies who advertise products made with nanofabric is accurate? Is it ethical for them to advertise their product this way?

3. If you were to repeat this experiment, or to build off of it, what other variables you would like to test?

After completing the product test, discuss how the different properties of the pants are a result of their chemical properties.
Appendix G

Introduction to the Nanotechnology, Food, and Nutrition PBL Unit

You and your team are food scientists for Rita's Water Ice, in charge of developing a new flavor. As you prepare your new flavor, you need to consider several things: 1) your flavor needs to taste good. 2) you are targeting the Philadelphia population, where many people come from low-income neighborhoods, so your new flavor has to be fairly cheap. 3) you need to look at different sweeteners (artificial and natural), and how we taste things differently. 4) you want to consider the health consequences of your flavor - does too much of your sweetener cause health problems? Is there a way that you could increase the health benefits of your new flavor? If you want to propose a new application, or have an idea for future research, include it here! Then, when you have developed your product, you need to market it to the public. Create a PowerPoint slide (or slides), and a podcast, explaining all of your research.

Initial reaction and notes:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Now that you've met your group members, decide who is going to do which job.

________________________ 1- flavor expert- responsible for helping the group reach consensus on the water ice flavor and directing the investigation/really understanding the science of taste

________________________ 2- dietitian- responsible for directing the investigation into the health pros and cons of each sweetener, helps direct the group in ethical decision making

________________________ 3- chemist- responsible for directing the research, is in charge of lab investigations, has a good understanding of the chemistry aspect of your flavor

________________________ 4- marketing/public relations- in charge of the cost analysis and marketing your new flavor, also plays a key role in your ethical decision making
Appendix H

CAT Scoring Sheet

Hello! Thank you so much for helping me score my teachers’ products as to their creativity. I really appreciate your time. We are going to score the problem-based learning (PBL) products I have today and this session should take 1.5 hours. I know you both were involved in the ITEST-Nano project, so this helps in that you understand the context for the teachers’ lessons. I will likely have some additional products for you to score and will schedule another time to get your scores in the future. If at any time you feel uncomfortable during this process, please let me know and we can stop.

For the scoring we will be using Consensual Assessment Technique (CAT). CAT is a relatively new technique that asks experts from the field that the lesson is in to score the amount of creativity in products that were produced in classrooms being studied. In general, this scoring asks raters to act as experts and give a score 1.0 to 5.0 as to the amount of creativity (Baer, Kaufman, & Gentile, 2004) in products. Raters do not need to defend their scores, but simply act as experts in the field and score the products in relation to each other.

I am going to ask you to do this with a little guidance. Because I have multiple teachers and multiple classes, I will be showing you the lesson plans from each classroom. When you give scores, please score the products in relation to those within their own class and not those in other classes. Please also try to make sure your scores are distributive, so that there can be a comparison. For example, try to avoid giving products within one class all 4s if you can help it. Try to think of each class and the products within them as their own units. Also, please do not discuss scores with your fellow scorer while you are scoring. You should have an electronic version of this sheet. Please save a copy with you name at the end and email it back to me with your scores.

CAT does not necessitate that creativity be defined for the scorers. However, I will now provide a definition of creativity that ideally would be a frame for your scores. Kaufman and Sternberg (2007) define a creative idea, act, or object as something innovative or different than anything created before it, be of excellent quality (i.e., shows itself to be of high standards and conveys the work put into it to make it well-crafted), and relevant to the task or problem from which it was created. In addition, this dissertation is studying the distinction between small ‘c’ creativity and large ‘C’ creativity, which McWilliam and Dawson (2008) differentiate as the difference between the kind of creativity that advances a field and the kind of creativity we engage in everyday. Try to hold both of these definitions in your mind as you do the scoring.

Remember any score between 1.0 to 5.0 is acceptable. Please feel free to use any gradation you want within this number set, although try to avoid going past one decimal place (for example, 2.2 or 4.3).
Ginny products:
1.
2.
3.
4.
5.
6.
7.
8.

Bill products
1.
2.
3.
4.
5.
6.
7.
8.
9.

Rob products
1.
2.
3.
4.
5.
6.
7.
8.
9.

Anna products
1.
2.
3.
4.
5.
6.
Appendix I

Analysis of Case Study Scores Along Study 5-Part Small 'c' Creativity Framework: A Categorization Manual

For this dataset, I considered how teacher practice (seen through classroom observations), teacher beliefs regarding creativity (determined through interview responses), student products made in the teachers' classrooms, and students' attitudes towards the class (demonstrated through interview responses) could be scored along the study framework. The unit of analysis is the entire case study.

The study framework asserts that teachers who foster small 'c' creativity in their classrooms:

1) **Support divergent thinking that is grounded in the lesson's activities or concepts**
2) **Accept learning artifacts that are novel and relevant to the lesson**
3) **Nurture collaboration among small group members in which individual kinds of creativity within the group are supported**
4) **Provide choices on what is an acceptable response (learning artifact or discussion point) to a lesson**
5) **Include lesson guidelines that enhance, rather than restrict, learning and self-confidence**

Scores along the framework were given ranging from high to low. They were divided into five gradations of the range: high, medium-high, medium medium-low, and low. Rationales for giving each score along the framework are as follows:

1) **Support divergent thinking that is grounded in the lesson's activities or concepts**

   **High:** The teacher gave students open-ended assignments that required them to create a product completely on their own. In his or her interview, he or she expressed that he or she valued divergent thinking and gave clear examples of past and present students who exhibited creativity.

   **Medium-High:** Teachers provided loose guidelines and valued work that was created within a certain amount of constraint. In their interview, teachers referred to students either in past or present classes who exhibited creativity.

   **Medium:** Teachers provided guidelines that allowed for some divergent thinking, but the assignment necessitated a majority of conformity to the guidelines. Teachers could name a student in their present classes who exhibited creativity.

   **Low-Medium:** Teachers provided assignment guidelines that most of the time have one correct answer and/or did not ask students to think creatively. They might have an assignment, which allowed for students to have novel thinking or to create a novel product. Teachers could think of a student who exhibited creativity in their present class, although the description was unspecific.
Low: Assignments only had guidelines that were looking for one correct answer and/or did not ask students to think creatively. Teachers could not name a student who exhibited creativity.

2) Accept learning artifacts that are novel and relevant to the lesson

High: Teacher accepted all learning artifacts that were novel and relevant to the lesson. Relevancy went beyond disciplinary and/or assignment constraints.

Medium-High: Teacher accepted all learning artifacts that were novel and relevant to the lesson, as long as the learning artifacts produced kept within the assignment guidelines. Disciplinary boundaries could be crossed.

Medium: Teacher was moderately accepting of learning artifacts that were novel and relevant to the lesson. However, “relevant” was defined strictly as falling within the assignment guidelines and students may have been only moderately allowed to cross disciplinary boundaries.

Low-Medium: Assignments mostly only allowed space for one correct answer and did not ask for students to create novel and relevant learning artifacts. There might have been one assignment that asked for students to create a novel and relevant learning artifact in response to the assignment.

Low: Assignments only allowed space for one correct answer and did not ask for students to create novel and relevant learning artifacts.

3) Nurture collaboration among small group members in which individual kinds of creativity within the group are supported

High: Small groups were constructed consciously by the teacher to assemble students together with various creative strengths.

Medium-High: The teacher let small groups emerge within the class and gave ample time both in and out of class for students to self-organize and demonstrate their individual creative strengths within small group projects. The teacher might have done things in class to aid small groups to form, like arrange desk in small groups, assign small group projects, etc.

Medium: The teacher encouraged small groups to work together and supported their emergence, but did little to construct them (for example, assign groups with members exhibiting various creative strengths together) or to maintain them (for example, did not enforce groups working together on small group projects, even if they were assigned to do so).

Low-Medium: The teacher did not reprimand students working together in small groups, but did little to encourage, construct, or maintain small group work.

Low: The teacher discouraged small group work.

4) Provide choices on what is an acceptable response (learning artifact or discussion point) to a lesson

High: The assignments were open enough so that what is an acceptable response to a lesson could vary widely and go between format and/or disciplinary boundaries. Often, in the case of longer projects, what is acceptable may have
been negotiated between teacher and student, so as to meet the assignment’s learning goals.

**Medium-High:** The students were given a list of two or more acceptable assignment responses. The teacher was open to negotiating with the student for an alternative assignment.

**Medium:** Students had the freedom to respond to an assignment, as long as the outcome was a certain type of product. For example, students in a class were allowed to create any sort of response they wanted to in regards to an assignment, as long as it took a particular form. Students could complete a diagram of a certain concept, as long as it is a poster or powerpoint slide. The teacher’s definitions of these forms were clearly defined.

**Low-Medium:** In general, there was little student choice in terms of what was an acceptable response to a lesson. There may have been an assignment where a student had some freedom in terms of their response, but most of the time, students had to keep their learning artifacts in a particular form.

**Low:** There was no student choice in terms of what was an acceptable response to a lesson. Form and components of acceptable student products are clearly defined and students are reprimanded for even slight deviations.

5) **Include lesson guidelines that enhance, rather than restrict, learning and self-confidence**

**High:** The teacher created open-ended assignments that were grounded in core concepts. The teacher expressed and explained these concepts, but gave students the freedom to synthesize them into their learning artifacts however they wished. He/she gave students sufficient time (both in and out of class) to complete the assignment and scaffolded this time with check-ins to ensure student success. The teacher stressed the importance of being creative and may have defined what this means to him/her during class.

**Medium-High:** The teacher created open-ended assignments that were grounded in core concepts. The teacher expressed and explained these concepts, but gave students the freedom to synthesize them into their learning artifacts. He/she gave students ample time (both in and out of class) to complete the assignment; however, this time was largely unstructured. The teacher stressed the importance of being creative; however, what this meant may have been undefined by him/her.

**Medium:** The teacher created lesson guidelines that were meant to be followed closely; however there was some room for student creativity to be expressed. For example, the teacher might ask students to make a video podcast of a news broadcast that clearly demonstrated their knowledge of five key Nanotechnology concepts in the first two minutes and in a particular order, but also might give them license to develop their news characters and other relevant components to the podcast.

**Low-Medium:** There were a few and/or a large amount of lesson guidelines for class assignments. Most of the assignments required one correct answer and how students could get to this answer on their own was clearly defined.
Low: There were very little to no lesson guidelines and/or the guidelines were so restrictive that all expressions of individual learning leaps and self-confidence were reprimanded. For example, in a class like this, the majority of the classwork would be done as worksheets or tests.
7. REFERENCES


