EXAMINING COLLEGE SCIENCE TEACHERS' BELIEF SYSTEMS ABOUT INQUIRY-BASED TEACHING IN THE CONTEXT OF A PROFESSIONAL DEVELOPMENT PROGRAM

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by

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The undersigned, appointed by the Dean of the Graduate School, have examined the dissertation entitled

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Dedicated to my son, Blake, who continues to be an endless source of joy in my life.

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ABSTRACT

The purpose of this study was to examine how college science teachers' belief systems about inquiry-based teaching changed through their learning experience in a faculty development program. The program was designed to support college science teachers in learning about inquiry and incorporating an inquiry-based approach to teaching laboratories in their courses.

The theoretical framework included two perspectives: the Sociocultural Embedded Belief Systems Model (Jones & Carter, 2007) and inquiry in science education. Using a constructivist approach, I used a case study method for data analysis and constructed individual profiles for the five science faculty participants. My primary data sources were semi-structured interviews with the participants conducted prior to the program's summer institute, prior to implementing the inquiry-based instructional approach, and following their implementation. My secondary data sources included field observations during the summer institute and in the participants' classrooms during implementation, interviews conducted after the summer institute with SCTIL staff members, artifacts, and a researcher's journal.

Based on the cross-case analysis of the five profiles, I made the following assertions: 1) In the SCTIL program, participants developed more reform-oriented beliefs and knowledge about inquiry-based teaching and learning in which they placed

more value on student-directedness and classroom inquiry; 2) Participants' attitudes towards the inquiry article instructional format, attitudes towards implementing it, and motivations for participating in the program were the most influential components of their belief systems as they decided whether or not to incorporate the SCTIL inquiry article format into their future instructional practice; 3) Student responses to the participants' implementation of the SCTIL approach influenced their attitude towards the inquiry article instructional format and their plans for incorporating the instructional approach into their future practice; and 4) Participants gained knowledge about the inquiry article format during the summer institute; however, implementation within their own context led to a change in their beliefs about inquiry-based teaching.

This study demonstrates how college science teachers' belief systems influence their learning experience in faculty development. The findings from this study have implications for faculty development design as well as graduate education policies for future science faculty members.

CHAPTER ONE: INTRODUCTION

The quality of science teaching in higher education has become increasingly important for today's society. Scientific literacy refers to "the science-related knowledge, practices, and values that we hope students will acquire as they learn science" (Anderson, 2007). The goal of science education is to prepare scientifically literate students who possess knowledge of STEM (science, technology, engineering, and mathematics) in a way that is useful to their daily lives and future careers. For non-STEM majors in higher education, the need for scientific literacy is critical in any career they choose. *Science for All Americans* (AAAS, 1989) calls for science education to "equip [students] to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital…The nation and the world depends largely on the wisdom with which humans use science and technology" (p. 12). Unfortunately, we are not achieving this goal (DeBoer, 2000).

In the STEM fields, careers are highly competitive and require advanced knowledge as technological changes are drastically reshaping the way we work and live. For STEM majors in higher education, we need quality graduates to become researchers who can further our knowledge in the field. Companies in the United States are growing increasingly dependent on scientists and engineers from other countries. These individuals tend to receive their undergraduate degrees in their home countries and then enroll in doctorate programs in the United States. In 1999, one-third of science and engineering PhD graduates working in industry in the United States were born abroad (National Science Foundation (NSF), 2003). In 2003, about three-quarters of foreign recipients of United States science and engineering PhD degrees planned to remain in the

United States for postdoctoral study or employment (NSF, 2008). Between 1985 and 2005, the number of science and engineering PhD graduates that were temporary noncitizen residents rose from 4,200 to 10,800 (NSF, 2008).

The *Shaping the Future* report (NSF, 1996) called for an improvement in undergraduate STEM education in the United States. The report states that “while K-12 programming can expand the pool of those interested in pursuing careers in [STEM], it is at the undergraduate level where attrition and burnout can be most effectively prevented” (NSF, 1996). Currently, the situation for both STEM majors and non-majors is discouraging. Students are leaving the STEM pipeline during their college years, predominantly after taking introductory science courses (NSF, 1996; Tobias, 1990). Non-STEM majors are discouraged from taking further science courses after taking introductory courses (Sunal, Wright, & Day, 2004). STEM majors call introductory courses challenging “weed-out courses” and are changing to a different major (NSF, 1996). The most common complaint from STEM majors who switched to a different major was poor teaching by their instructors (Seymour & Hewitt, 1994). Students strongly believed that “faculty do not like to teach (especially lower division courses), they do not value teaching as a professional activity, and they lack incentive to improve” (NSF, 1996). With such a negative perception of faculty members’ beliefs about teaching, it is critical to examine graduate education in terms of preparation for teaching.

Teaching takes a significant amount of knowledge and skill, which tends to be undervalued in research-oriented doctoral programs (Serow, Van Dyk, McComb, & Harrold, 2002). For example, at the University of Missouri, which is a research university with very high research activity, doctoral science programs do not require their students to take education courses. Teaching opportunities tend to be limited to teaching assistantships in laboratory courses; however, the content, materials, and format of the courses are typically pre-determined. Doctoral students interested in going into academic careers must seek their own opportunities through campus-wide programs such as Preparing Future Faculty (PFF) or the College Teaching Minor program. On a national level, universities are not providing quality educational courses or internships for graduate students to learn about effective college teaching (Eisenhart & DeHaan, 2005). This lack of preparation contributes to their roles as college teachers who often enter into academia drawing only on their experience as students.

Therefore, there is a significant need for effective faculty development to support new and practicing college science teachers as they develop their knowledge and skill for teaching. Faculty development is a type of professional development that focuses on supporting the faculty member through "class organization, evaluation of students, in-class presentation skills, questioning, and all aspects of design and presentation" related to teaching (Professional and Organizational Development Network in Higher Education (POD Network), 2007). The need for quality faculty development designed specifically for college science faculty members is critical to support their learning about science-related pedagogy.

In *College Pathways to the Science Education Standards* (National Science Teachers Association (NSTA), 2001), the National Science Education Standards (NSES) professional development standards encourage a focus on how to: "(1) teach essential science content through inquiry, (2) integrate knowledge about science with knowledge about learning, pedagogy, and students, and (3) develop an ability for lifelong learning"

(NSTA, 2001, p. 25). For professional development to effectively impact teachers' practice and knowledge, it must focus on teacher beliefs. Researchers have shown that teacher beliefs play a prominent role in their teaching practice (Jones & Carter, 2007; Nespor, 1987; Pajares, 1992; van Driel, Verloop, & de Vos, 1998). Science teachers' beliefs about science teaching and learning influence every aspect of their teaching, including lesson planning, assessment, interaction with peers and students, as well as professional development and the ways teachers implement reform-oriented teaching practices (Jones & Carter, 2007). Studies have shown that beliefs about teaching are well established by the time a student enters college (Buchmann, 1987; Wilson, 1990), suggesting that college teachers, therefore, come into academia with established conceptions of effective teaching. Routines of teachers' practice are developed within the first few years (Veenmen, 1984), resulting in little change as their teaching experience grows. These set beliefs and practices may spiral into continued generations of ineffective college science teaching, which will result in declining numbers of STEM majors and continued failure to meet the goal of science literacy for all students. Based on these points and the limited literature base on college faculty development, there is a gap in the research on college science teachers' beliefs about teaching and learning. This knowledge will move the field of college science faculty development forward in supporting better undergraduate science education.

Rationale for the Study

The rationale for this research is twofold. First, our understanding of how teachers learn is limited to research on K-12 teachers with a weak literature base on college teacher learning. Loucks-Horsley, Hewson, Love, and Stiles (2003) present a model for designing effective professional development programs for science teachers, citing the importance of knowing how the "students," or in this case, the teachers, learn best. Professional developers need to know how college science teachers learn in order to design effective programs that will impact college teachers' belief systems and their practice.

Second, the shortage of STEM majors and the fact that students are leaving the pipeline of science-related fields indicates the need for a different approach to traditional faculty development programs. Typically, these programs tend to be one-session events that address a common issue teachers might deal with, but lack focus on the contextual needs of the attendees and their students. For science faculty, these general sessions fail to help them connect their students with authentic, inquiry-based learning experiences.

Professional developers at the University of Missouri responded to this need by developing a year-long program for college science teachers (faculty members and graduate students) titled SCTIL: *Science College Teachers using Inquiry-based Labs.* This program is specifically designed to support the teachers' learning about an inquiry-based teaching approach for the laboratory setting and support the faculty as they implement this new approach in their own classrooms. This study, therefore, takes advantage of the specific context of the SCTIL program to investigate how college science faculty members learn through faculty development by focusing on the changes in their belief systems about teaching.

Research Questions

Using the constructivist tradition (Lincoln & Guba, 1992; Patton, 2002) to guide the design of this study, the overarching research question is: *In what ways, if any, do* *college science teachers' belief systems about inquiry-based teaching change within the context of the SCTIL professional development program?* To fully address this question, I focus on the following four sub-research questions:

1. In what ways, if any, do participants' beliefs and knowledge about inquiry-based teaching and learning change during the SCTIL program?
2. What components of participants' belief systems have the greatest impact on their decision of whether or not to incorporate the SCTIL inquiry article format into their future instructional practice?
3. How do environmental responses to participants' SCTIL lab implementation influence change in their belief systems about inquiry-based teaching and their future plans for incorporating the instructional approach into their practice, if at all?
4. What components of the SCTIL program were the most supportive for changing the participants' beliefs and knowledge about inquiry-based teaching?

Theoretical Framework

My lens that informs this study includes two prominent frameworks: the first is the Sociocultural Model of Embedded Belief Systems (Jones & Carter, 2007), and the second is inquiry in science education. I begin by discussing the belief systems model, defining its components within the context of this study, and explaining its relevance in the design and implementation of this study. In the second section, I define inquiry as used in this study, and discuss the importance of teachers' understanding of classroom inquiry as they incorporate it into their teaching practice.

Sociocultural Model of Embedded Belief Systems

The Sociocultural Model of Embedded Belief Systems (see Figure 1) was developed "as a tool for understanding the construction and development of beliefs and attitudes" of teachers (Jones & Carter, 2007, p. 1074), and was based on a review of the literature on secondary science teacher attitudes and beliefs as well as social psychology theoretical models. In the following section, I first describe this model using Jones and Carter's definitions. I then discuss the major components of the model (attitudes, beliefs, and knowledge), as well as how I applied the components of the model to the context of my study. I conclude the section by discussing how this model was used as a conceptual framework for this study.

Jones and Carter (2007) designed the belief systems model to highlight the interactive nature of the components (see Figure 1). They noted, "Although the two-dimensional restrictions on illustrating the model may imply linearity of the components, this is not the intention; we acknowledge multiple reciprocal interactions" (Jones & Carter, 2007, p. 1074). This interactive nature is a critical feature of this model. Rokeach (1968) first introduced belief systems in the 1960s, defining them as a framework for helping individuals understand the world and themselves (Abelson, 1979; Nespor, 1987; Pajares, 1992; Rokeach, 1968). He believed they were useful as a psychological framework, but not a logical framework. They were not intended to be sequential in nature.

Jones and Carter (2007) developed the model with the teacher's sociocultural context serving as the teacher's environment, including peers, students, and culture, which binds the model together. Within this context are the teacher's belief systems that

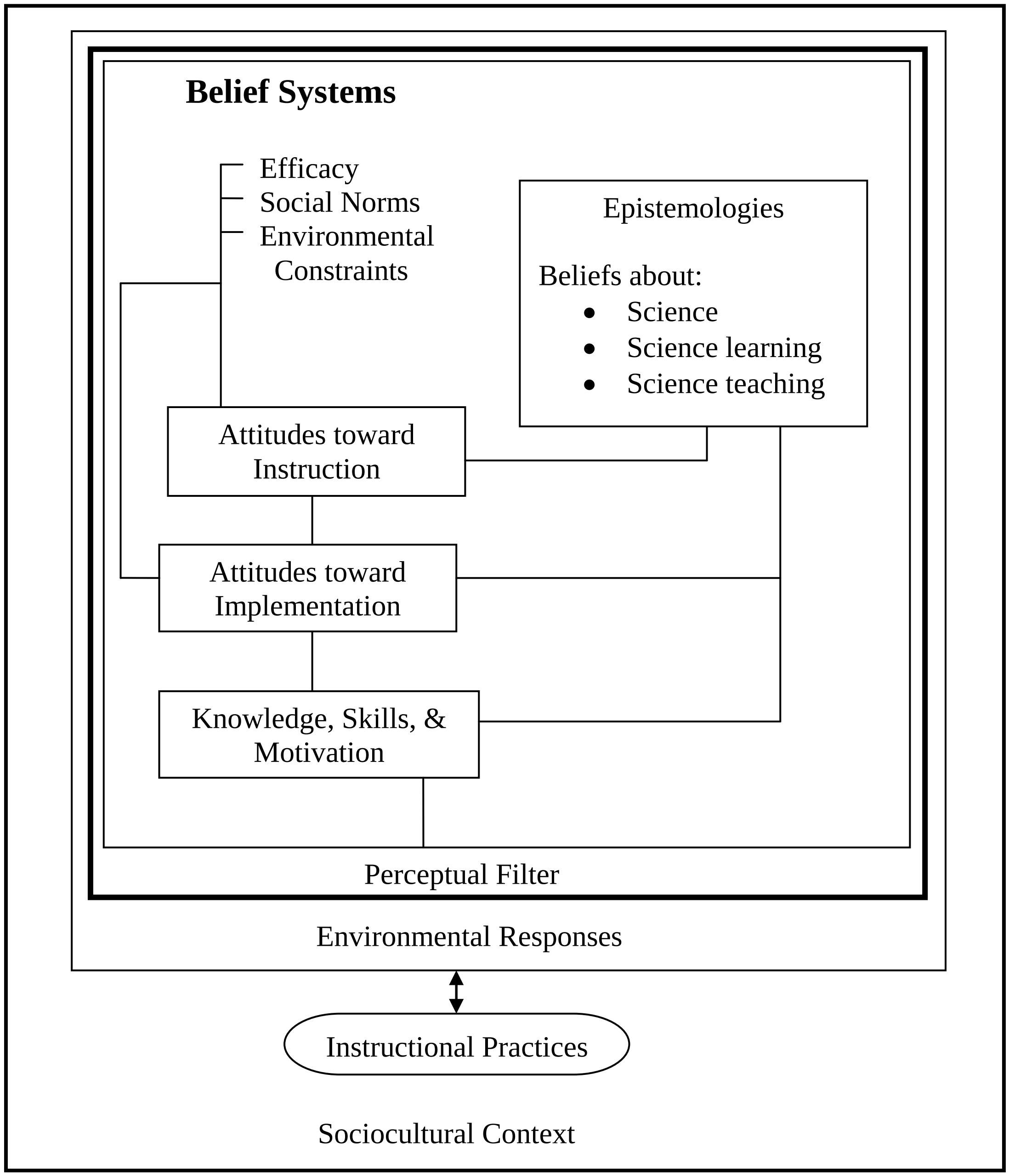


Figure 1. Sociocultural Model of Embedded Belief Systems (Jones & Carter, 2007, p. 1074)

serve as a filter as they engage in a particular instructional practice. Responses to their practice from students, administrators, etc., play a role in influencing their belief systems.

Within belief systems are multiple components influencing each other through various links. The belief systems model presents efficacy, social norms, and environmental constraints as one group of components. Jones and Carter described self-efficacy as "beliefs about one's ability to successfully implement an instructional strategy" (2007, p. 1075). They referred to social norms as teachers' perceived view of what others expect regarding their teaching. Environmental constraints are barriers to successful implementation of an instructional practice, such as a lack of time or resources. A separate group of components are labeled as epistemologies, or beliefs about the construction of knowledge. For science teachers, these are represented as beliefs about how knowledge is constructed in science, in science learning, and in science teaching. Jones and Carter compare beliefs to belief systems in the following excerpt:

> Beliefs are integral to larger belief systems that include self-efficacy, epistemologies, attitudes, and expectations. These are all intertwined and embedded in the sociocultural context. For example, a teacher's beliefs about using cooperative learning in the science classroom cannot be separated from her beliefs about science, science teaching, science learning, her motivation, her self-efficacy, her knowledge of constraints, her knowledge of cooperative learning, her skills using cooperative learning, prior experiences, the class and school context, as well as the larger cultural contexts (p. 1070).

The complete picture of the belief system connects epistemological beliefs to three separate components: attitudes towards instruction, attitudes towards implementation, and knowledge, skills, and motivation. They describe attitudes as being either positive or negative perspectives towards a practice or implementing that practice. For example, a teacher can have a positive attitude towards the practice of using PowerPoint in the classroom yet a negative attitude towards actually implementing PowerPoint in their classroom. The last group of components presented in the model includes knowledge, skills, and motivation. These refer to developing knowledge about a particular instructional practice, skills in using the practice, and motivation for implementing the new practice.

Jones and Carter (2007) agree that the critical components of the model are attitudes and beliefs. In the literature on teacher beliefs, knowledge is also an important component. Researchers conducting studies on beliefs, attitudes, and knowledge, have been debating the definitions and distinctions among these three constructs for decades. Although Jones and Carter do not take a clear position on this issue, my stance is that beliefs and knowledge are separate constructs. Beliefs are understandings that are strong-held, resistant to change, and constructed by the individual (Jones & Carter, 2007; Nespor, 1987; Pajares, 1992; Richardson, 1996). Rokeach (1968) noted that it is difficult for individuals to accurately represent their beliefs, making them unobservable and immeasurable. They must be inferred from what people say, intend, and do (Pajares, 1992). Thus, the design of this study will take this into consideration in understanding teachers' beliefs. Jones and Carter focus on epistemological beliefs, which they define as "sets of beliefs about knowing and learning that play a mediating role in the processing of new information" (p. 1077). In contrast, knowledge is an understanding that is continually changing and socially constructed (Jones & Carter, 2007; Pajares, 1992). Knowledge is agreed upon by a community of people (Richardson, 1996). Attitudes are predispositions that consistently affect actions (Richardson, 1996). They are "a mental concept that depicts favorable or unfavorable feelings toward an object" (Zacharia, 2003).

To illustrate how I distinguish among these three constructs (beliefs, knowledge, and attitudes), I will provide an example. When John Smith was a high school science student, he studied for exams by reviewing his notes from class and reading the textbook. Using this approach always resulted in high scores for him. Therefore, he believed the best way to study was to read the materials. During college, John began tutoring other science students. He taught them to use his study approach, believing that this would be beneficial to anyone. When his students received low scores on their exams, he believed it was due to inadequate reading of the materials on their part. Upon graduating from college, he went on to graduate school and eventually became a college professor. During the orientation for new college faculty members, John learned about student learning research and that students have different learning styles. He gained an understanding, or new knowledge, about the need for different teaching approaches to meet these different learning styles. John entered into his teaching practice with a positive attitude towards teaching now that he understood that his approach to studying in high school was not the only way for people to learn.

In the following section, I describe the components of the belief systems model in light of this study and explain how I applied its design to my context. The sociocultural context was the SCTIL professional development program, which included the 3-day summer workshop, follow-up support, and implementation of a specific inquiry-based teaching practice, the SCTIL inquiry article lab format, into their teaching context (described in detail in Chapter Three). Within the context of this program, the participants' belief systems about inquiry-based teaching were studied as they attempted to implement an inquiry-based instructional practice in their labs and considered using this approach in their future instructional practice.

In regards to this study, I begin on the left side of the belief systems model (see Figure 1). Participants' self-efficacy about inquiry-based teaching, the social norms within their departments and schools, and the environmental constraints of implementation may influence their attitudes towards both the SCTIL inquiry-based teaching approach and their implementation of the inquiry articles in their classrooms. Moving to the right side of the model, the epistemological beliefs about science, science learning, and science teaching are narrowed to beliefs about science as inquiry, science learning, and inquiry-based teaching for the purpose of this study. Based on the design of the belief systems model, the belief components may influence teachers' attitudes as well as their knowledge, skills, and motivation for changing their instructional practice. In this study, knowledge refers to the participants' knowledge about the SCTIL inquiry-based model and motivation represented their internal or external drive to participate in the SCTIL program. While the skills element was included in the Jones and Carter model, I chose to omit this component because there were no identified standards for skills required in teaching with the inquiry article format.

According to the belief systems model, the teacher's collective belief system would then serve as his/her perceptual filter as the teacher engaged in his/her new instructional practice. In the context of this study, participants' belief systems were considered as a filter as they attempted to implement inquiry article labs in their courses. Following their implementation, their environmental responses (i.e., responses from students, colleagues, and/or administrators) feed back into their belief systems. This reciprocal nature of the model allows continual change to belief systems as instruction is implemented and feedback is received. This model offers insight into the complex decision-making process teachers go through as they consider whether or not to change their teaching practice.

I used the belief systems model as a framework to inform the development of my interview questions for the participants. I also drew from my observations of their implementation of the inquiry articles to develop additional interview questions. In addition, my data analysis was designed around the components of the belief systems model and served as a guide in describing the individual participants' belief systems, as shown in Chapter 4. In the following section, I describe the second conceptual framework used for this study—inquiry in science education.

Inquiry in Science Education

In the late 1950s, increased value was placed on science education following the launch of the former Soviet Union's earth-orbiting satellite, *Sputnik*. The United States government began to encourage more research for improving our school science programs by funding the National Science Foundation and their efforts to understand how improvements could be made (DeBoer, 1991). Joseph Schwab became a leader in this period of science education reform by presenting the idea of scientific inquiry in the classroom. He stated, "The constitutive components of scientific knowledge –principles, data, interpretations – as well as the constituted conclusions, must become the materials regularly taught and learned in science courses (Schwab, 1962, p. 65). Over the past few decades, the focus on inquiry-based teaching and learning has served as the foundation for reform in science education.

In 1996, the National Science Education Standards (NSES) were published by the National Research Council to set a vision for science education by recommending principles and practices for K-12 grades that would "make scientific literacy for all a reality in the 21st century" (NRC, 1996). In the Teaching Standards of the NSES, teachers were encouraged to plan an inquiry-based science program for their students (NRC, 1996). In the Content Standards, the NRC claimed that students should engage in inquiry to develop the following: "(1) abilities necessary to do scientific inquiry; and (2) understanding about scientific inquiry" (NRC, 1996, p. 105). They defined inquiry as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (NRC, 1996, p. 23). This effort in incorporating scientific inquiry into the classroom was a challenge for teachers, resulting in the follow-up publication of a practical guide to help teachers, administrators, and professional developers learn about what inquiry would look like in the classroom (NRC, 2000a). This translation identified five essential features of classroom inquiry:

1. Learner engages in scientifically oriented questions.
2. Learner gives priority to evidence in responding to questions.
3. Learner formulates explanations from evidence.
4. Learner connects explanations to scientific knowledge.
5. Learner communicates and justifies explanations. (NRC, 2000a, p. 29)

Each of the features varies from teacher-guided (guided inquiry) to student-directed (open inquiry). For example, a teacher could pose scientific questions for the students to answer in their investigations (guided inquiry), or students could pose their own questions to investigate (open inquiry). These terms represent ends of a continuum presented by the NRC to help teachers understand classroom inquiry (see Table 1). This continuum identifies different variations for ownership of learning, whether it be teacher-directed, student-directed, or both.

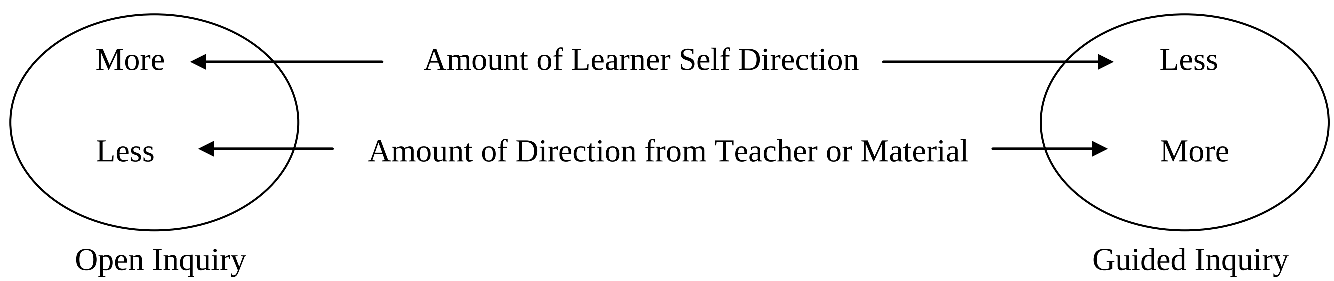
Inquiry is further defined on a second continuum ranging in degree of inquiry from full to none (see Figure 2; Brown, Abell, Demir, & Schmidt, 2006). If all 5 of the essential features presented in Table 1 are present within an investigation, it is defined as full inquiry. If any of the features are missing, it is defined as partial inquiry. Thus, classroom inquiry could be labeled as full and open if all 5 essential features are present and students design the investigations from start to finish (point E on Figure 2). An inquiry would be labeled as partial and guided if students engage in only a few of the inquiry features and the teacher primarily designs and structures the experiment carried out by the students (point C on Figure 2).

In *College Pathways to the Science Education Standards* (NSTA, 2001), which applies the NSES standards to the college level, the authors further emphasized the importance of students developing abilities and understanding about scientific inquiry. "Students should learn in the way that science is done" (NSTA, 2001, p. 97). While large lecture classrooms at the college level tend to be a barrier in implementing more inquiry-based teaching, the laboratory and field-based experiences in college science classrooms provide an excellent environment to foster an inquiry-based approach to teaching and learning (NSTA, 2001). In this study, inquiry is used as a conceptual framework as I looked at college science teachers' beliefs about inquiry and investigated change in their

Table 1

Essential Features of Classroom Inquiry and Their Variations (NRC, 2000a, p. 29)

Essential Features	Variations			
Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other sources	Learner engages in question provided by teacher, materials, or other source
Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to sharpen communication	Learner given steps and procedures for communication



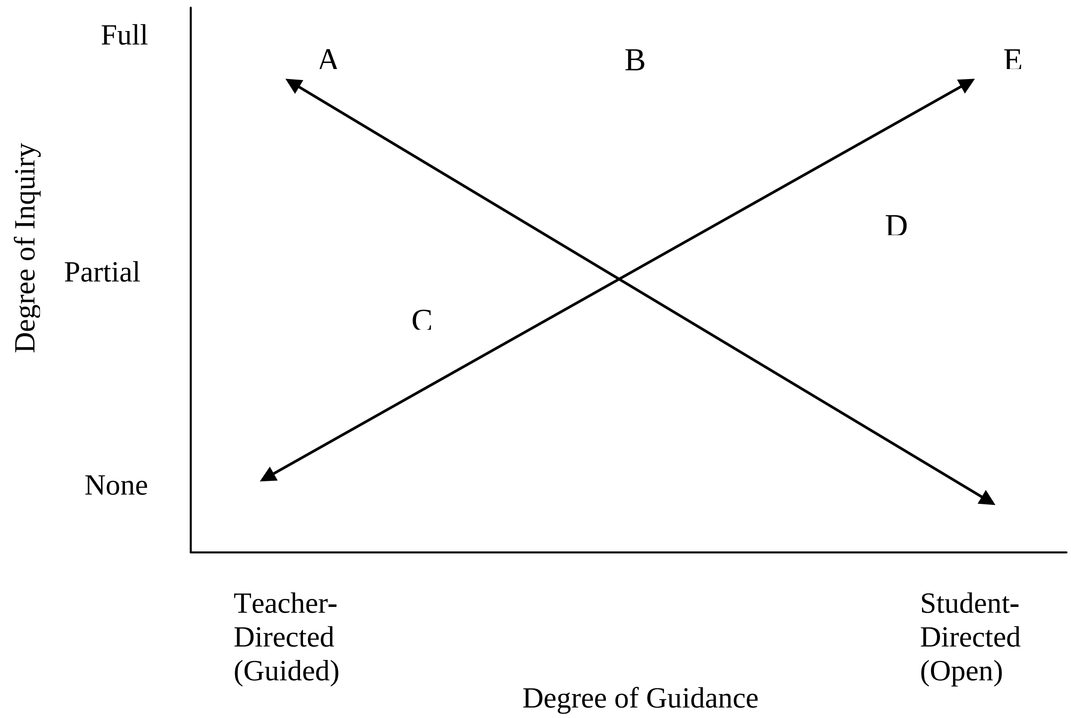


Figure 2. The Inquiry Continuum (Brown, Abell, Demir, & Schmidt, 2006, p. 799)

belief systems as they designed and implemented an inquiry-based approach in their labs.

Significance of the Study

This study aims to contribute to two bodies of literature—inquiry in college science teaching and college science teacher learning through faculty development. First, an underlying theme presented in the science education standards is the use of inquiry (NRC, 1996; NRC, 2000a). "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (NRC, 1996, p. 31). While the research base on inquiry-based teaching at the college level is limited, most of these publications are descriptions of college teachers' efforts to implement inquiry in the classroom rather than empirically based research studies (i.e, Crandall, 1997; Glasson & McKenzie, 1997/1998; Harker, 1999; Tolman, 2001). This study aims to contribute to our understanding of how college science teachers' beliefs about inquiry-based teaching and learning change through faculty development and how they choose to incorporate inquiry into their teaching practice, if at all.

The second body of literature to which this study contributes is faculty development, specifically college science faculty learning within a professional development context. Currently, the literature base for college faculty development focuses on design strategies and barriers for change (e.g., Sorcinelli, Austin, Eddy, & Beach, 2006; Sunal et al., 2001). Few studies investigate faculty development experiences in science disciplines (Glynn, Koballa, Coleman, & Brickman, 2006; Sunal, et al., 2001). Teacher learning literature indicates that learning is the result of change, and a change in practice often precedes a change in beliefs (Bolster, 1983; Guskey, 1986). Simply contributing to teachers' knowledge, therefore, may not be enough to create change in their beliefs and practice (Simmons et al., 1999). Thus the role of faculty development is to create opportunities for change. Research in this field is sparse in regard to investigating how this change takes place for college science faculty within a faculty development context (Sunal et al., 2001). Understanding college science faculty members' belief systems and how different components change and influence practice will inform the design of more effective faculty development programs.

Organization of the Dissertation

This study is divided into six chapters. Chapter One provides an overview of the study including the rationale, research questions, theoretical framework, and significance. The theoretical framework includes sections on the Sociocultural Belief Systems Model and inquiry in science education. Chapter Two focuses on a review of the literature in three areas: teacher learning in faculty development, models of faculty development, and college teachers' views of inquiry. Chapter Three describes the qualitative approaches used in this study. This includes a description of the research tradition, research methodology, and the design of the study. I included details of the context of the study including the design of the SCTIL program and the participants. I also describe data collection strategies and data analysis methods. The chapter concludes with a description of the trustworthiness of the design and implementation of the study. Chapter Four describes the findings of the study in the form of five case profiles of the participants of the study. The purpose of Chapter Four is to provide details for the assertions made in Chapter Five. In Chapter Five I provide a cross-case analysis and assertions that emerged from the data. Throughout this chapter I refer to the profiles presented in Chapter Four. Chapter Six is the final chapter and includes a summary of the findings in relation to the research questions and a discussion of the findings relative to the research literature. The chapter concludes with implications and recommendations for future research.

CHAPTER TWO: REVIEW OF LITERATURE

My review of the literature focuses on three areas that provide necessary background information for understanding the significance of my research questions and the context of my study. The first area focuses on teacher learning in faculty development, which draws from the adult learning literature. The second area focuses on faculty development programs for college faculty members, specifically the variety of strategies used and the barriers and support systems for implementation as identified in the literature. I conclude this chapter by reviewing the literature on college teachers' beliefs about inquiry.

Teacher Learning in Faculty Development

The field of research on teacher learning is relatively young, predominantly spanning the past 20 years (Borko, 2004). What we know about the field is "puzzling," in part due to the nature of teachers' learning being so varied (Wilson & Berne, 1999). Teachers learn through formal or informal faculty development, through educational programs as doctoral students or in-service teachers, in the field, in the classroom, etc. Adult learning research, however, began over 40 years ago (Knowles, 1968). In this section, I will look at key features of the adult learning literature base, drawing from the related literature in the field of teacher learning within the context of faculty development.

Adult Learning

Patricia Cranton (2006) defined adult learners as:

> …mature, socially responsible individuals who participate in sustained informal or formal activities that lead them to acquire new knowledge, skills, or values; elaborate on existing knowledge, skills, or values; revise their basic beliefs and

> assumptions; or change the way they see some aspect of themselves or the world around them. (p. 2).

While this definition encompasses a broad range of possibilities, the underlying theme is that change happens as a result of learning.

Malcolm Knowles (1968) first identified distinct differences between how children learn and how adults learn. He presented his idea of andragogy, which means "the art and science of helping adults learn," in contrast to pedagogy (the art and science of helping children learn) (Knowles, 1980, p. 43). In 1980, he published his list of assumptions that fit this idea, adding to the list in a 1984 publication. These are arguably the most referenced set of assumptions in adult learning literature:

1. As a person matures, his or her self-concept moves from that of a dependent personality towards one of a self-directing human being.
2. An adult accumulates a growing reservoir of experience, which is a rich resource for learning.
3. The readiness of an adult to learn is closely related to the developmental tasks of his or her social role.
4. There is a change in time perspective as people mature—from future application of knowledge to immediacy of application. Thus, an adult is more problem-centered than subject-centered in learning. (Knowles, 1980, pp. 44-45)
5. The most potent motivations are internal rather than external.
6. Adults need to know why they need to learn something. (Knowles, 1984, p. 101).

Knowles viewed these assumptions as foundational when designing learning programs for adults. He believed that the environment for adult learning should be one of "adultness," allowing adults to feel "accepted, respected, and supported," and emphasized that there should exist "a spirit of mutuality between teachers and students as joint inquirers" (Knowles, 1980, p. 47). His list of assumptions were characteristics that defined what a good adult learner would look like, which brought controversy as to whether this could be classified as a theory of adult learning. Hartree (1984) challenged these assumptions as merely descriptions and wanted them to be empirically tested. Each assumption was scrutinized and many researchers claimed that the assumptions were problematic. Brookfield (1986) argued that three of the six assumptions were difficult to consider when applying them to practice. For example, Brookfield felt that being self-directed was more of a desired outcome than a given condition, and immediate application led to a reductionist view of learning. Merriam, Caffarella, and Baumgartner (2007) argued that the assumption on motivation was situational. They stated, "Although adults may be more internally than externally motivated to learn, in much of workplace learning and continuing professional education…participation is required" (Merriam et al., 2007, p. 86-87). Therefore, some development programs that require participation may have adults with varied motivations for learning. It would be difficult to assume that all adults are internally motivated to learn through development programs, especially when they may have no choice in the matter. Merriam et al. also reflected on Knowles's sixth assumption concerning adults needing to know why they need to learn something. Merriam et al. noted that while this may be true on occasion, some research has shown that adults also learn because they simply enjoy learning.

While Knowles is considered the father of adult learning theories due to his andragogy model, researchers have labeled several different categories of learning. For the purpose of this study, I will narrow my focus to teacher learning and review categories within this field that are most appropriate for this research.

Teacher Learning

Teacher learning relates to a change in a teacher's thinking about teaching. Fishman, Marx, Best, and Tal (2003) defined teacher learning as "changes in the knowledge, beliefs, and attitudes of teachers that lead to the acquisition of new skills, new concepts, and new processes related to the work of teaching" (p. 645). Faculty development is an area specifically designed to support teacher learning and may be directed at developing areas in skill development, knowledge acquisition, a change in implementation, or any number of different related teaching areas. It is therefore appropriate to consider how teachers learn most effectively within the context of faculty development, which provides a window to study teacher learning. Research on teacher learning typically focuses on what teachers learn and how factors influence their learning in faculty development, while a smaller number of studies has been done on HOW teachers learn (e.g., Borko, 2004; Cranton & Carusetta, 2002; Darling-Hammond & Sykes, 1999; Deggs, 2005; Drago-Severson, 2007; Fishman et al., 2003; Garet, Porter, Desimone, Birman, & Yoon, 2001; Kazemi & Hubbard, 2008; Little, 2003; Wilson & Berne, 1999; Yerrick, Parke, & Nugent; 1997). In considering faculty development through the lens of adult learning literature, it is important to remember that instructors need to "create a climate of respect, encourage active participation, build on experience, employ collaborative inquiry, learn for action, and empower the participants" (Lawler &

King, 2000, p. 21-22). Teacher development programs should be designed as “attempts to bring about change—change in the classroom practice of teachers, change in their beliefs and attitudes, and change in the learning outcomes of students” (Guskey, 1986, p. 5). This literature review focuses on two aspects of understanding how teachers learn. First, I review three categories of learning in the adult learning literature: transformational learning, self-directed versus facilitated learning, and situated cognition. In teacher learning, transformational learning refers to a shift in a teacher’s view about something which is arguably the purpose of faculty development (e.g., Cranton, 1996). Self-directed and facilitated learning are approaches to learning with different participants taking ownership of the process, which is reflective of guided versus open inquiry with student learning in science (NRC, 2000a). The last category discussed in this review is situated cognition, which refers to the perspective that learning is contextual. The SCTIL program emphasizes the importance of implementation, which provides a situative context for teachers to apply their inquiry-based instruction.

The second focus of this review is to understand what the literature shows about the influence of affective domains on teacher learning, in particular attitudes and motivations. I selected these domains due to their relevance to the conceptual framework for this research. Focusing on how teachers learn and how affective domains affect their experience in faculty development lays the foundation for investigating changing teacher belief systems in this study.

Transformational Learning

One category within the teacher learning literature is transformative learning

(Mezirow, 1991; 2000). This is a complex category that is argued to describe learning in general. Cranton explains it in the following excerpt:

> When something unexpected happens, when a person encounters something that does not fit in with his or her expectations of how things should be, based on past experience, the choices are to reject the unexpected or to question the expectation. When people critically examine their habitual expectations, revise them, and act on the revised point of view, transformative learning occurs. (2006, p. 19)

Transformative learning is seen as voluntary and a way to make meaning out of an experience (Cranton, 2006; Mezirow, 2000). Similar to constructivism, transformative learning includes the assumption that meaning exists within ourselves and is acquired/validated through interaction and communication with others (Mezirow, 2000). While the original view of transformative learning was one of a linear process, more recent studies have indicated that it is more "individualistic, fluid, and recursive" than originally assumed (Taylor, 2000).

Some research suggests that transformative learning for teachers can occur through faculty development (i.e., Cranton, 1996; Thompson & Zeuli, 1999). Traditionally, faculty development programs tend to focus on "adding new skills and knowledge without helping teachers rethink and discard or transform thinking and beliefs" (Loucks-Horsley et al., 2003, p. 46). This approach of introducing new things can be overwhelming for teachers. Transformative learning takes into consideration current knowledge and beliefs and allows teachers to shift their ideas. This may take place during faculty development, during implementation and interaction with their students, or afterwards during reflection.

An example of a teacher's transformative learning experience would be the case of Charles, a veteran physics teacher (Donaldson, 2008). Rather than being a participant in a faculty development program for teachers, Charles was one of the instructors; however, he entered into his faculty development teaching experience with a didactic, traditional approach to teaching. Through the summer program, Charles watched and listened as the lead instructor, a physics educator, modeled a constructivist teaching approach. After seeing and hearing how this constructivist approach worked, Charles gradually began to believe in this approach, whereas in the beginning he thought it was a waste of time. Donaldson described Charles in the following way, “The first year of his participation he questioned many facets of the [constructivist] pedagogy…I was challenging his traditional nature and he was very unsure about this ‘crazy’ new way of teaching physics” (2008, p. 9). By the end of the fourth year of the summer program, Donaldson knew Charles had experienced a transformation in his own beliefs about this teaching approach when he disagreed with another traditional teacher’s recommendation to switch back to direct instruction to save time. Charles responded, “No—we have to model the constructivist pedagogy; the teachers will not learn if we try to pour content” (Donaldson, 2008, p. 9). Charles experienced a change in his own beliefs about constructivist teaching and acted on them by incorporating the new approach into his own instruction and defending it to his peers. Thus transformative learning experiences are critical to changing teachers’ strongly-held beliefs. In this study, I examine how teachers’ beliefs change through the context of a faculty development program. Based on the literature, my participants need to experience transformative learning for change to occur in their beliefs about teaching and learning.

Self-Directed vs. Facilitated Learning

Self-directed learning, also called self-regulated learning, refers to the processes that maintain the cognition, motivation, and behavior necessary to achieve intentional goals (Cross, 1981; Zimmerman, 2000). Facilitated learning tends to be seen as an organized type of instruction generally led by an instructor (Cross, 1981). While the literature base on self-directed learning is rich, facilitated learning is more of a description that lacks a literature base. Most faculty development programs are facilitative in nature. In the following sections, I present a review on self-directed learning and a contrasting description of facilitated learning in order to shed light on teachers' nature of learning in faculty development.

To be an effective self-directed learner, one must set goals, use effective learning strategies, evaluate his/her progress, and reflect on outcomes (Bembenutty, 2007). Alan Tough (1967) called this type of learning self-teaching. Knowles (1980) first assumption of andragogy presented adult learning as a mature, self-directed process. As the field grew, researchers began to see this type of learning as more of a product than a process (Brockett & Hiemstra, 1991; Brookfield, 1985). The aim of converting teachers into self-directed individuals is to make them "a continuing inner-directed, self-operating learner" (Brookfield, 1985, p. 18). In 1991, Philip Candy published a review of the self-directed learning literature, categorizing research into four views of self-direction: (a) a personal attribute (personal autonomy); (b) the willingness and capacity to conduct one's own education (self management); (c) a mode of organizing instruction in formal settings (learner control); and (d) the individual, non-institutional pursuit of learning opportunities in the natural social setting (autodidaxy) (Candy, 1991). Since the early 1980s, the research field has consistently advocated that "the goal of education ought to be the creation of independent, autonomous learners who assume responsibility for their own learning" (Weimer, 2002, p. 15). Based on these descriptions, self-directed teachers are those that are internally motivated to learn. Related literature on student learning indicates that self-directed learning is related to motivation (Pintrich, 1995). In applying this to teacher learning in the context of faculty development, those who are motivated to participate for their own reasons would tend to be self-directed in nature while those who participate due to external motivations would tend to be less self-directed in nature. Weimer (2002) emphasizes that a self-directed learner is self-motivated and independent, and assumes responsibility for their learning during a learning experience.

Self-directed learning could also be thought of as learner-centered in relation to faculty development, with the learners being the teachers (NRC, 2000b). Many faculty development experiences that are not program-oriented but rather designed for the individual to learn informally on their own time would be classified as a self-directed learning experience (Caffarella & Zinn, 1999). One example is the use of individualized learning plans or contracts to allow teachers to design their own learning experience from learning goals to self-evaluation (Caffarella 1993). Teachers are able to use these personalized experiences as needed to develop their understanding about a selected area.

In contrast to self-directed learning, facilitated learning in faculty development is often seen in workshops, courses, institutes, and seminars led by instructors or leaders. The instructors and leaders tend to be experts in the topic who facilitate a learning experience for teachers. While facilitation of learning cannot guarantee that transformative learning has occurred, this approach is a convenient way to guide teachers in reaching their faculty development goals. The SCTIL summer institute is designed as a facilitated learning experience led by experienced leaders in the field.

Situated Cognition

The majority of research on teacher learning uses a situative perspective, meaning that what an individual learns is specific to the situation in which is it learned (Anderson, Reder, & Simon, 1996; Lave & Wenger, 1991; Putnam & Borko, 2000). Using this perspective, Adler (2000) stated that teacher learning "is usefully understood as a process of increasing participation in the practice of teaching, and through this participation, a process of becoming knowledgeable in and about teaching" (p. 37).

Putnam and Borko (2000) reviewed current literature on teacher learning and identified three conceptual themes central to the situative perspective—cognition is situated, social, and distributed. The situated nature of cognition refers to the physical and social contexts. "Whereas most traditional cognitive perspectives focus on the individual as the basic unit of analysis, situative perspectives focus on interactive systems that include individuals as participants, interacting with each other as well as materials and representational systems" (Putnam & Borko, 2000, p. 4). Thus the act of learning in a situative nature includes interaction with your surroundings, including colleagues, materials, and lessons. In the classroom, this suggests that authentic activities are an important part of learning. In the context of this study, the SCTIL staff members designed the summer workshop so that participants learn how to develop, revise, and give feedback on their inquiry article lessons. This authentic activity has the potential to support their learning in a way that will encourage continued success in being able to modify future labs for their teaching practice.

The second theme, cognition as social, is critical for both teacher and student learning. Research has shown that learning is strongly influenced by social interactions

(NRC, 2000b). These interactions are important for what is learned as well as how learning takes place (Putnam & Borko, 2000). As participants in the SCTIL program engage in small group discussions and work together, the discourse among the community will support their learning and provide them with the experience and understanding of creating this type of supportive community in their own laboratory sections.

Putnam and Borko’s (2000) third theme is that cognition is distributed, referring to each community members having different knowledge to contribute to the social learning environment. It is important for teachers to understand that students come to the classroom with their own ideas and understandings about concepts in the field; likewise, teachers come into professional development environments with their own understandings about teaching. Working in groups allows them to share their specialized knowledge and experiences with others, making a contribution to others’ learning experience as well.

Resnick explains the importance of the situative perspective: “As long as school focuses mainly on individual forms of competence, on tool-free performance, and on decontextualized skills, educating people to be good learners in school settings alone may not be sufficient to help them become strong out-of-school learners” (1987, p. 18). In alignment with the professional development standards of developing lifelong learners (NRC, 1996), the SCTIL professional development program used a situative perspective.

Affective Domains of Teacher Learning

Adult learning is influenced by the cognitive domain as well as by their emotions and feelings (Ferro, 1993). After reviewing common categories of learning, it is important to understand a more personal side of their learning experience. Affective domains of instructional objectives emphasize a “feeling, tone, an emotion, or a degree of acceptance or rejection” (Krathwohl, Bloom, & Masia, 1964, p.7). Why do college teachers choose to participate in faculty development, and how does the learning experience affect their attitude towards teaching? A literature search revealed no studies on college faculty members’ attitudes related to faculty development. However, we can look at research from the adult learning literature and K-12 teachers’ motivations and attitudes towards teacher learning.

In adult education, motives for participating in learning programs have been studied since the 1970s (Boshier, 1971; Morstain & Smart, 1974). Adult learners have identified influential factors such as expectations of others, professional advancement, and cognitive interest (Caffarella & Merriam, 2000). Some individuals engage in lifelong learning because they “have an itch to learn” or because “a specific reward for the learning effort is clear to them” (Cross, 1981, p. 96). These represent different types of motivation classified as internal and external. Internal motivation comes from the individual while external motivation is brought on by an external source. Instructors in adult learning have considered participants’ motives for participation when they design education programs (Davis, 1993; Wlodkowski, 1998). This information allows instructors to think about incentives as well as how to retain participants in the programs. Similarly, faculty developers need to consider participants’ motives when designing learning programs related to teaching. While professional development for teachers at the K-12 level tends to be a requirement, development opportunities for college teachers tend to be voluntary. The research is sparse on college teachers’ motivations for participating in faculty development; however, the limited findings suggest that college teachers' motivations tend to be primarily internal (i.e., MacKinnon, 2003). A study of pharmacy faculty members' motivations for participating in faculty development reported three primary motivations: to improve their teaching skills, their quality of work, and their research skills (MacKinnon, 2003). At research universities, new faculty members are often motivated to improve in these areas as they work toward tenure, which serves as an external motivation to meet university standards. Researchers need to investigate both internal and external motivational factors for college teachers' participation in faculty development programs.

The level of a teacher's motivation for learning is influenced by his/her attitude toward the content (Jones & Carter, 2007). Simpson, Koballa, Oliver, and Crawley defined an attitude as "a predisposition to respond positively or negatively to things, people, places, events, or ideas" (1994, p. 212). More specifically, in faculty development an attitude can be thought of as how "favorable or unfavorable a [teacher] feels about performing a behavior" (Jaccard, Litardo, & Wan, 1999, p. 103). Faculty members can have a positive or negative attitude towards the learning experience and towards the instructional approach. The design of this study includes affective components (including attitudes and motivations), as described in the conceptual framework of the belief systems model (Jones & Carter, 2007). Jones and Carter reviewed the literature on K-12 science teachers' attitudes towards learning to teach a new instructional strategy. This literature base began in the 1970s during the reform of science education following the launch of *Sputnik*. Research indicated that teachers' personal characteristics, such as being open-minded to learn or preferring indirect or inductive thinking, were linked to positive attitudes towards learning and implementing more non-traditional instructional strategies (i.e., Blankenship, 1965; Strawitz, 1977; Symington & Fensham, 1976). Researchers studied ways of altering teachers' attitudes by introducing different strategies and collecting data on their attitudes before and afterwards. For example, when teachers were taught process skills, their attitudes towards using a process approach to teaching science improved (Butts & Raun, 1969; Kennedy, 1973). Modeling reform-oriented practices contributed to teachers' positive attitudes towards the practices being modeled (Bratt, 1977). By the end of the 1970s, research on attitudes declined and did not become prominent until the 1990s when a shift was seen in moving from behavior research to an individualized understanding of teachers' attitudes in relation to their beliefs and practice (Jones & Carter, 2007).

In the past few decades, researchers have developed assessment strategies to investigate teachers' attitudes using both quantitative and qualitative approaches. Quantitative approaches included Likert 5-point scales in which science teachers would indicate their level of agreement towards something (i.e., Aikenhead & Otsuji, 2000; Bratt, 1977; Thompson & Shrigley, 1986). Similarly, another use of a scale-oriented assessment was the application of semantic differentials in response to a statement. Teachers would represent their attitude toward a statement by marking a point on a continuum with two antonyms on either side, such as happy/sad, interesting/dull, or harmful/helpful (Butts & Raun, 1969; Sunal, 1980). In considering various qualitative assessment methodologies, the interview became the most prominent assessment tool in understanding teachers' attitudes. More recent research has moved from identifying attitudes to understanding the complexity of attitudes in relation to teacher beliefs (Richardson, 1996).

The affective domains of motivations and attitudes in teacher learning are important components that interact with teachers' beliefs and belief systems, as represented in the design of the belief systems model (Jones & Carter, 2007). For the purpose of this study, it is important to understand the value of affective domains and their influence on the participants' learning experience through the SCTIL faculty development program.

Summary

The umbrella of adult learning includes many perspectives. Over the past 3 decades, new learning theories have been proposed to categorize processes of learning. Within the context of teacher learning, we have reviewed three prominent categories: transformative learning, self-directed learning versus facilitated learning, and situated cognition. The theme across these categories of learning is that learning is the result of change, whether it is within an individual's beliefs, assumptions, actions, or context. While the literature base on how teachers learn within the context of faculty development is limited, we can conclude that their learning is dependent upon their self-directedness entering into the experience, their openness to experience change and act on that in their own lives, and experiencing/practicing change within an authentic environment. Considering the affective domains of motivations and attitudes is also important in teacher learning as influential factors in their faculty development experience. This study contributes to the literature by expanding our understanding of how teachers learn through faculty development and what components of their belief systems play critical roles in this change process.

Faculty Development Models

Higher education institutions strive to improve institutional quality for their students. This effort tends to be the driving force in providing faculty development opportunities for their teachers (Sorcinelli, Austin, Eddy, & Beach, 2006). Colleges and universities offer a variety of faculty development models to facilitate teacher learning. The purpose of this review section is to focus on current models of faculty development in higher education to understand their strategies and content focus.

Depending on the size of the institution, colleges and universities often provide a multitude of resources and support for faculty using strategies such as consultations, workshops, seminars, mentorship programs, and orientation programs. The design of these strategies varies greatly depending on the context, the funding source, and the professional developers' learning goals (Loucks-Horsley et al., 2003). Depending on their goals, the developers may choose to combine one or more of these strategies, such as a semester-long workshop series along with bi-weekly focus group meetings or a one-week summer session along with a follow-up mentorship program during the year. Regardless of the strategies used, it is critical that the planning and implementation process includes principles of effective professional development. Loucks-Horsley et al. presented seven key principles of effective professional development specific to science and mathematics teachers. Effective professional development:

1. Is driven by a well-defined image of effective classroom learning and teaching.

2. Provides opportunities for teachers to build their content and pedagogical content knowledge [teachers' specialized knowledge about teaching the content] and examine practice.
3. Is research based and engages teachers as adult learners in the learning approaches they will use with their students.
4. Provides opportunities for teachers to collaborate with colleagues and other experts to improve their practice.
5. Supports teachers to serve in leadership roles.
6. Links with other parts of the education system.
7. Has a design based on student learning data and is continuously evaluated and improved. (Loucks-Horsley et al., 2003, p. 44)

In addition, Guskey (1986) describes effective development as having ongoing follow-up support for teachers after their initial learning experience. The most difficult part of learning and implementing a new instructional strategy is the implementation phase when teachers tend to face anxiety and failures to their efforts (Cogan, 1975; Fullan, 1982). Teachers view an instructional strategy as successful if they see "evidence of improvement in the learning outcomes of the students" in their own classrooms (Guskey, 1986, p. 7). Therefore, effective professional development should provide support as teachers adapt what they learn in professional development to their own classrooms.

In the following three sections, I present a review of current faculty development models which I have categorized into three groups based on their common foci: Teaching and Learning Effectiveness, Technology and Curriculum Design, and Building/Supporting Community. These categories emerged from my review of the literature. Next, I discuss barriers and support systems related to faculty development, followed by a reflection on the emerging themes across the models. Finally, I will discuss Loucks-Horsley et al.'s (2003) key principles of effective faculty development that were addressed by these models.

The first category, Teaching and Learning Effectiveness, is based on the various models' foci to improve teaching practice and student learning (see Table 2). The second category, Technology and Curriculum Design, consists of models designed to either guide faculty in designing or redesigning curriculum, increase their use of technology, or a combination of the two (see Table 3). In the third category, Building/Supporting Community, the models guided faculty to some extent in the development of relationships between new and seasoned faculty, faculty from different departments across campus, and faculty from different institutions (see Table 4).

Teaching and Learning Effectiveness

Current research on improving effective teaching practice indicates the importance of using a team approach in the learning process of faculty development (see Table 2; Abell, 2005; Cook, Wright, & O'Neal, 2007; Koch, et al., 2002; Pittas, 2000; Potthoff, Dinsmore, & Moore, 2001; Stevenson, Duran, Barrett, & Colarulli, 2005). The make-up of these teams varies depending on the goals of the program. Some models use partners in the form of mentorships or co-researchers while others use group support which allows multiple participants to offer their different experiences in teaching to other group members. This collaborative environment allows for faculty members to learn from their peers who also might encounter the same difficulties in their teaching practice. A model presented by Koch et al. (2002) was based on an established Teacher Scholars

Program with eight faculty members from different departments on campus. The approach of the program was to have participants develop, implement, and evaluate a teaching project within their own classrooms. The faculty members met as a team each week during an academic year to discuss and reflect on their teaching projects, offering each other ideas and tips in a formative sense throughout the course. The reflection was a crucial component to their learning process, which led to the writing of a publication on this model and their experience. One teacher stated:

> In developing and initiating our learning plans, we benefited from both our successes and failures…Perhaps the most important lesson we learned was that implementing new strategies did not automatically result in positive changes, even if the strategies were well planned and researched" (Koch et al., 2002, p. 88).

The purpose of the teams' and the team members' roles also varied. Action research, which was first used with K-12 teachers, is slowly becoming more prominent in the higher education field as a form of faculty development (Abell, 2005; Cook, Wright, & O'Neal, 2007; Kember & Gow, 1992). Faculty members conduct research within their own contexts to improve their teaching effectiveness and ultimately improve their students' learning. This feedback process is part of four steps in action research: planning, implementing, reflecting, and evaluating (Kember & Gow, 1992). Abell (2005) presents three different action research studies in college science education as examples of varied research designs. The individuals making up the research teams in each study, along with the teacher conducting the study, included different collaborations of science faculty members, science education faculty members, graduate students, and undergraduate students. The individual questions that came about from their planning phase and the findings from each of the three studies are presented below:

1. How do students' experiences and expectations compare with the instructor's? Student and faculty perceptions of journal writing differed.
2. How do the professor, TA, and students perceive inquiry-based instruction? Tensions in teaching and learning through inquiry were experienced by all stakeholders.
3. How do we teach nature of science in our course and how do students learn it? Some components of the nature of science were emphasized and learned well; others were not. (Abell, 2005, p. 284)

Action research is primarily a self-directed approach to faculty development that uses educational research to support teacher learning. These personalized forms of faculty development provide a specific context for teacher learning.

The importance of contextual faculty development is also demonstrated through a model of a faculty training program focusing on faculty who teach Freshman Interest Groups, or FIGs (Pittas, 2000). Multiple workshops were developed and implemented for faculty members throughout the school year focusing on topics such as collaborative teaching, achieving learning outcomes, and assessment and evaluation. Based on what they learned in these workshops, faculty developed modifications to their courses for FIGs that crossed over areas with other courses taught by program faculty members. This collaborative effort allowed the students in the FIGs to see connections between their course content and encouraged faculty to think differently about their own context of curriculum.

Overall, the faculty development models reviewed on teaching and learning effectiveness stretched beyond the typical program approach with workshops or seminars

Table 2

Teaching and Learning Effectiveness

Model	Source	Target Audience	Nature of model	Purpose	Participants/ Departments	Length of project	Use of Technology
Teaching projects as part of a Teacher Scholars Program	Koch, et. al (2002)	Junior Faculty	Collaborative; peers/mentor teacher support	To enhance student learning; improve instruction; develop community	Eight college faculty members; various departments represented	One year	Not emphasized
Senior Symposium teaching preparation program	Pittas (2000)	All faculty	Collaborative; developed in response to faculty interest; once faculty complete program, on call to teach	To train practicing teachers in best practices teaching to present at senior symposia via preparation workshops; training for course redesign	Voluntary—changes each year	Four days of pre-service workshops; follow-up peer support for the year	Emphasized (technology lesson included in workshop)
FIG and collaborative teaching training program	Stevenson, Duran, Barrett, & Colarulli (2005)	FIG faculty leaders	Collaborative; multiple major goals to achieve in one year; community-building	To develop collaborative teaching and learning in the FIGs program	About 20 faculty members from various departments	One year (of a three-year intiative)	Emphasized (one workshop)
Action research	Abell (2005)	Science and science education faculty	Collaborative; reflective; research results as feedback for change	To inform faculty members about their students' learning and therefore their own teaching efficacy	Three projects discussed with 3 participants each (various combos of science faculty, science ed. faculty, and grad/undergrad students)	One semester	Not emphasized
Action research	Cook, Wright, & O'Neal (2007)	Science TAs and their trainers	Collaborative; reflective; research results as feedback for change	To improve TA teaching; to improve TA training programs and student retention in the sciences	About 3600 undergrad students in "gateway" science courses	One semester	Not emphasized

to reach faculty in their own contexts and provide various types of support as they implemented change in their teaching practice. This approach to teacher learning assumes teachers have a self-directed nature in their learning by desiring to see change in their practice and seeking out faculty development strategies for improvement. The design of the SCTIL program was a combination of collaborative and individualized approaches to faculty development. It began with a 3-day collaborative summer workshop. During the following school year, SCTIL staff members provided support and encouragement to participants as they designed and implemented inquiry article labs for their specific course context.

Technology and Curriculum Design

Technology in college teaching has become a critical issue with the accelerated growth in society's use of technology (see Table 3; Leh, 2005). Faculty members are being encouraged to incorporate more technology into their courses, which has in turn created a need for more faculty development on course design. Tarr and McDaniel (2005) presented a model of an intense, 4-day summer workshop for faculty members designing or redesigning an online course. Following the workshop in which the faculty developed their goals and one module of their course, faculty members were teamed up with a consultant to complete the design process for the remainder of their course. While teachers could have sought out support from the university's Teaching and Learning Center, this program provided a structured framework for faculty members to learn through the design process. A similar model by Leh (2005) used an approach called reverse mentoring, which involved faculty being trained by instructional technology graduate students in areas of need identified by the faculty members. Through the faculty development program, the graduate students served as mentors providing expertise in an area of technology (such as PowerPoint, digital video, Inspiration, or creating a web page) while also learning how to work collaboratively with a faculty member outside of the classroom. Through the researchers' evaluation of the program, they learned that teachers' appreciated the individualized support and felt that they benefited from participating in the program (Leh, 2005).

A second use of technology in faculty development is the online resource outlet. Models presented by Stover (2005) and Nellis, Hosman, King, & Armstead (2002) revealed the use of technology for faculty teaching online courses (via seminars or tech support) or faculty wanting to supplement their learning with easy-to-access online faculty development courses. Nellis et al. (2002) used online time-revealed scenarios in their program for community college faculty members. The scenarios provided real-world situations which faculty members might face (such as dealing with the needs of students or balancing family and work), and encouraged online discussions among participants. The program included assignments and assessments so faculty members were motivated to contribute to the online discussions. While some faculty members were not pleased with the web-based approach, others appreciated it due to the flexible hours.

Redesigning course curriculum is a challenging professional development task. While a one-time workshop or seminar on a new teaching approach is a common method used for teacher learning, Sunal et al. (2001) investigated a long-term faculty development program designed to study reform as college science teachers designed or redesigned course curriculum. Their strategy was to provide multiple learning

Table 3

Technology and Curriculum Design

Model	Source	Target Audience	Nature of model	Purpose	Participants/ Departments	Length of project	Use of Technology
Summer course design program with follow-up	Tarr & McDaniel (2005)	New faculty	Collaborative; ongoing design support	To guide the development and teaching of online courses	Ten college faculty members; various departments represented	4 days in summer; follow up support throughout the year	Strongly emphasized (Online course development)
Reverse mentoring and service learning	Leh (2005)	Education faculty	Partially collaborative; group or one-on-one training available; training based on needs survey;	To use and integrate more technology in instruction with mentoring from IT graduate students; to meet a grant objective	Thirty-five education faculty members in language arts, math and science, and educational psych.	One year; meetings based on group needs	Strongly emphasized (products included CDs, websites, etc.)
Online seminars and mentoring	Stover (2005)	All faculty	Collaborative; ongoing technical support and online seminars for teaching online courses	To provide instructional support via online means to meet the needs of a large university context	All campus faculty	Continuous seminar support and faculty mentoring program	Strongly emphasized (through delivery method and content)
Online time-revealed scenarios	Nellis, Hosman, King & Armstead (2002)	All faculty	Online faculty development course with facilitator; self-discovery approach; peer support; reflective	To provide real world scenarios on work/life for reflection on reactions to modify teaching practice	Thirty-two community college faculty members	One semester to one year	Strongly emphasized (only face-to-face contact is at orientation)
Course design/re-design programs	Sunal et. al (2001)	Science faculty (secondary: ed. faculty and admin.)	Collaborative (university teams required); systemic;	To provide multiple strategies within the program that support change	About 75 participants 30 universities	One year with potential to extend up to 3 or more years	Emphasized (addressed in workshops)

environments (workshops, seminars, mentorships, etc.) over the course of one to three years, depending on the university. Teachers experienced both pre-determined topic sessions as well as personalized attention for their particular issues. The authors reflected on the reasoning for this design, based on the understanding that change in teachers' beliefs does not typically occur through a one-event activity. Sunal et al. (2001) stated, "It is a systemic, long-term professional development and mentoring support system for faculty members wishing to implement new courses or change existing courses" (p. 250). Results from their study showed that faculty members with higher self-efficacy were more likely to change their courses. The college science teachers felt that the collaborative and long-term nature of their program contributed to their success in re-designing their courses.

The faculty development models related to technology and curriculum design focus on individualized support with some collaborative components. Teachers developing online courses needed to learn how to use the appropriate technology for its implementation. These programs tend to be focused on skill development. Faculty development programs are also taking advantage of the internet by providing informative resources that are quick to find and can be individualized as needed. For example, if a teacher wanted to learn more about using an online grading system, such as Blackboard, he/she could find an informative article through their university's Teaching and Learning Center website to explain how to use it. Teachers tend to appreciate this type of support as it can be searched when needed. The drawback to online faculty development resources is that it is an informal, non-program approach in which teachers are generally not working collaboratively with their peers, which is an important learning component of effective faculty development (Loucks-Horsley et al., 2003). Both technology and traditional approaches to faculty development have been used to address course design or redesign. The models presented show that a collaborative, personalized learning experience for teachers provides the best support for their learning. The SCTIL program emphasized curriculum redesign by having college science teachers bring previously implemented labs to modify into the inquiry article format. This was reflective of Sunal et al.'s (2001) long-term, collaborative approach to support change in teachers' beliefs about teaching. The SCTIL program did not emphasize the use of technology; however, they provided individualized support through e-mail availability and the use of their program website.

Building/Supporting Community

A sense of community among faculty members is crucial both within and between departments at an institution (see Table 4). The teacher learning literature supports these collaborative efforts as an effective approach to learning. Models in the current literature indicate that community has become an important aspect of faculty development (Cowan & Westwood, 2006; Glynn, Koballa, Coleman, & Brickman, 2006; Pierce, 1998; Potthoff, Dinsmore, & Moore, 2001; Savage, Karp, & Logue, 2004; Sherer, Shea, & Kristensen, 2003; Sorcinelli, 1994; Stevenson, Duran, Barrett, & Colarulli, 2005; Trowler & Knight, 2000; Williams & Pennington, 2002). A common reason for building a community among faculty is to support new and junior faculty members (Pierce, 1998; Savage, Karp, & Logue, 2004; Sorcinelli, 1994). At Clarion University of Pennsylvania, mentoring programs begin with the premise that it must be "faculty driven and administratively supported" (Savage, Karp, & Logue, 2004, p. 23). Thus multiple forms of support are needed for their mentorships to be effective. The university's purpose is to introduce new faculty to senior faculty from different departments, to provide new faculty with resources on campus, and to promote discussion and community among colleagues across departments. The reason for their focus on cross-disciplinary mentorship is to prevent any judgment opportunity within departments in the case that the senior faculty member plays a role in the tenure process for new faculty (Savage, Karp, & Logue, 2004). Faculty members who have gone through these mentorships report that the goals of the program met their needs, particularly in the areas of academic advising and online resources (i.e., e-mail support and instructional technology support). The authors did not report on the teachers' responses to the cross-disciplinary aspect of the mentorship design.

Another approach to mentoring and supporting new faculty into the community is demonstrated by a model that requires new tenure-track faculty members to participate in a year-long program (i.e., Pierce, 1998). In Pierce's example of this model, the program consisted of weekly cohort meetings, as well as additional one-on-one meetings with a mentor faculty member. The weekly cohort meetings involved discussion about critical issues on campus such as diversity, student-centered learning, and student advisement. The meetings also allowed university officials/administrators to speak about different aspects of the university. This model continually sought feedback from the participants to modify the program during the year as needed. Each year the model was adjusted to fit the needs of the new college faculty. For example, if incoming faculty have a wide range of experience in teaching, some teachers may move into the role of a peer advisor for the less experienced teachers. Pierce (1998) reports great success with this model and attributes its success to its ongoing evaluation and subsequent revision.

The use of professional development cases is another example of a model for developing community among the faculty (Glynn, Koballa, Coleman, & Brickman, 2006). The authors present this as an example in the sciences, but its design can be applied to any department due to the nature of the pedagogical approach. The authors define a professional development case as “a narrative about a significant event that leads to a dilemma and may involve instructors, students, and administrators. Cases may be open-ended, describing an event that leads to an unresolved dilemma, or closed, describing an event and how the dilemma was resolved” (Glynn et al., 2006, p. 10). Similar to case studies often used in college teaching (Herreid, 2005), these case studies are adapted to pedagogical situations, such as dealing with student motivation, evaluation, curriculum design, etc. They are used in faculty development to spark conversation about the case among small groups of 4-10 faculty members. While research has not been conducted on the success of case-based faculty development, Glynn et al. reported their view of the benefits of using this approach. They felt that this type of faculty development resulted in the development of communities among small groups of faculty members and prepared them for unexpected scenarios they might encounter in their teaching practice.

In considering the design of community-building through faculty development in this study, the SCTIL program used a collaborative approach to draw science faculty members from different institutions and departments together to support networking. As

Table 4

Building/Supporting Community

Model	Source	Target Audience	Nature of model	Purpose	Participants/ Departments	Length of project	Use of Technology
Faculty Learning Communities	Sherer, Shea, & Kristensen (2003)	All faculty	Collaborative; groups can be cohort-focused or issue-focused, formal or informal, solely in person or also supported by online technology	To develop community of practice among faculty members	Cohorts of about 6 faculty members from the same or various departments	One year	Strongly emphasized (supporting FLCs with listserves, chat rooms, and webcasts)
Collaborative PD between Comm. College and Univ. (Tools for Teaching program; 2-yr College instruction Cert. program; Training workshops)	Williams & Pennington (2002)	Adjunct faculty	Collaborative; cross-institutional; started with administrators	University offers programs to better prepare adjunct faculty for more student-centered teaching; to develop relationships between university and Comm. Colleges	One major university and 12 local community colleges collaborating	Continous development	Not emphasized
Diversity cohort training program	Potthoff, Dinsmore, & Moore (2001)	All faculty	Collaborative; community-building; reflective	To more effectively prepare future and practicing teachers to work with diverse groups of students	Forty-nine participants (education faculty, arts and sciences faculty, and K-12 teachers)	One semester (as part of the a three semester program)	Not emphasized
Mentoring program	Savage, Karp, & Logue (2004)	New/senior faculty	Collaborative; Cross-departmental pairing; non-heirarchical	To develop cross-disciplinary community; resource-sharing; promote collegiality	University-wide program; # of participants not specified	1 year	Not emphasized
Weekly cohort meetings and mentoring program	Pierce (1998)	New faculty	Collaborative; required; continuous feedback and modification	Exposure to university culture; promote collegiality; foster best practices; support careers	All new, tenure-track faculty members with 2-year contracts	One year	Not emphasized

Table 4

Building/Supporting Community (continued)

Model	Source	Target Audience	Nature of model	Purpose	Participants/ Departments	Length of project	Use of Technology
New faculty orientation programs; mentoring programs; development of teaching and research	Sorcinelli (1994)	New/junior faculty	Generally collaborative; some required, some voluntary; various forms and degrees of support	For new faculty development; to improve the environment for new and junior faculty	Varied depending on program (10 programs discussed)	From 75 minutes to 1 year	Not emphasized
Professional development case studies	Glynn, Koballa, Coleman, & Brickman (2006)	Science faculty	Collaborative; cooperative learning; faculty-led, not by an expert; discussion-oriented; cases can be open-ended or closed	To develop sense of community; provide a means for talking about faculty development in science	Small groups of 4-10 participants, including sicence faculty and administrators	Can be conducted in one discussion session	Emphasized (as alternative delivery approaches--interactive software or video)
Reflective journaling	Cowan & Westwood (2006)	Experienced faculty	Collaborative; peer feedback; reflective	For faculty to journal for themselves on pedagogy, students, time management, etc, and to receive formative feedback from a designated facilitator	Seven experienced faculty members from various departments	Five journal entries over individually-selected time periods	Strongly emphasized (all journal entries were submitted via e-mail and feedback was received via e-mail)
Long-term PD program based on critical thinking	Elder (2005)	All faculty	Systemic; organizational development beginning with faculty workshops on critical thinking	To foster critical thinking within and across the curriculum; begin to develop leaders who can take over teaching workshops	All campus faculty	Continuous; at least 5 years of training before systemic change, depending on the size of university	Not emphasized

seen in this study, participants benefited from this collegial environment and discussed it as a motivation for participating in SCTIL.

Barriers Related to Faculty Development

There are multiple barriers reported in the literature pertaining to the design and implementation of faculty development. In mentorship programs between new faculty and senior faculty members, the nature of hierarchy between the two individuals presents a power relationship that may be a hindrance to its purpose (Savage, Karp, & Logue, 2004; Sorcinelli, 1994). There also may be tension in the mentorship if the new faculty member will be judged for tenure by the senior faculty member. The new member might feel as though he/she they needed to demonstrate competence and not ask questions rather than benefit from the design. Developers often have difficulty in recruiting senior mentors for this type of program to match them with an incoming faculty member (Sherer, Shea, & Kristensen, 2003). Another barrier discussed in the literature on reverse mentorship is the lack of pedagogical support and knowledge when students serve as mentors to faculty members (Leh, 2003). At research institutions, faculty members divide their time between research, teaching, and service, often resulting in a lack of time to focus on faculty development opportunities (Caffarella & Zinn, 1999). Zinn (1997) focuses on the ongoing changes in faculty needs and in students' interests. These changes require modifications to faculty development design and content. Technology also changes continuously requiring faculty developers to gain new knowledge and experience in using the technology in the classroom in order to educate faculty members about it. A lack of knowledge and skill present an additional barrier in faculty development design and implementation.

These barriers are important to consider in this study when thinking about the faculty members' experience in the SCTIL program. They are learning from faculty developers who are also faculty members themselves. Some may be from the same institutions and play a hierarchical role in their tenure process. Several participants were from research universities where their responsibilities as a faculty member are divided between teaching, research, and service. The SCTIL program focused solely on teaching, which may have created a tension for faculty members in regard to spending time on their SCTIL labs, taking away from their research time.

Support Systems Related to Faculty Development

Ongoing faculty development requires support for the faculty member in multiple forms. This section presents examples of the types of support the literature identified as effective. The first is administrative support or presence (Sorcinelli, 1994; Sunal et al., 2001). Having administrators who encourage teachers through their learning is important to their participation. Collaboration with colleagues has been a significant form of support for teachers' learning (i.e., Caffarella & Zinn, 1999; Pittas, 2000; Sunal et al., 2001; Tarr & McDaniel, 2005). In addition, financial support in the form of stipends or grants is key to attracting teachers to faculty development opportunities in order to fund their teaching release time if needed, support the hiring of a graduate assistant, or often the need to purchase new technology (Sunal et al., 2001). Another example of how faculty development programs can support teachers is through the use of assessment and evaluation (Sunal et al., 2001). In guiding teachers through learning and developing new course curriculum, formative assessment provides feedback to the teacher during this development process rather than waiting until implementation occurs. In addition, evaluation of faculty development programs provides feedback for future designs to benefit faculty members in the next implementation of a program.

The design of the SCTIL program included each of these support systems. Most of the participants' department chairs or deans were supportive of their participation in the SCTIL program, as reported in the findings section. The funding source of the SCTIL program was the National Science Foundation, which provided stipends for the faculty member participants. The program also hired an external evaluator to conduct an evaluation during the summer institute and provide feedback (formative feedback), as well as summative feedback through the program evaluation at the end of the year. Finally, the design of the SCTIL program was collaborative in nature, encouraging science faculty members to work in small groups in the summer institute as they developed their SCTIL labs and stayed connected with their peers through the year as they had questions/concerns about their implementation. They also held a separate meeting in the spring in which participants could reflect on their implementation and talked about their successes and problems.

Summary

In reviewing the current literature on effective faculty development models in higher education, three prominent themes emerged. The first is collaboration. A common thread among effective models of faculty development is a collaborative component to the design, whether it be working with a mentor/peer, having discussion group meetings, or encouraging the development of relationships among cross-departmental faculty members, the collaborative nature is present. The SCTIL program emphasized collaboration among their participants through the design phase. During the summer institute, participants worked in interactive small groups as they developed their first inquiry article.

Second, technology use in faculty development is growing along with the continual expansion of its use in society. While faculty development seems to be encouraging its use through course design and online faculty communication, it contradicts the collaborative nature if not used appropriately. Online faculty development courses encourage an individual environment in which support for faculty members is strictly electronic; however, if used as a supplement along with other strategies, its use could be effective in terms of faculty time and extensive online resources. In the context of this study, the use of technology in the SCTIL program is limited; however, it is coupled with other strategies such as the use of an online program website with examples of inquiry articles as well as e-mail to support the teachers' learning.

The third prominent theme is the importance of situating the faculty development in a specific teaching context. Traditional forms of faculty development involve 1-hour workshops or seminars (Savage et al., 2003), while this review indicates a strong move towards applying best practices to specific classroom contexts (action research, course design, teacher scholars projects, etc.). As indicated in the review on teacher learning, situated cognition is an important aspect of contextual learning that is reflected in these approaches to faculty development. The importance of context is demonstrated in the design of the SCTIL program, which supports teachers through their implementation of the inquiry article labs within their own classrooms.

The research on faculty development in the sciences is limited. In my review of the literature, few publications were found that were in a science field context (e.g., Abell, 2005; Glynn et al., 2006; Sunal et al., 2001). These articles presented models of faculty development for science faculty members through the use of action research, case-based programs, and course design support. Our understanding of how college science teachers learn is limited and needs to be studied further. Though my findings in this study, I will address this gap in the literature.

In reviewing the current literature on professional development models, one sees progress toward alignment with Loucks-Horsley et al.'s (2003) key principles of effective professional development. Represented among the models presented are a collaborative nature, research-based designs, administrative support, and continuous feedback for improvement. However, there was limited representation in building pedagogical content knowledge and content knowledge, as well as the development of instructional leaders. Based on these findings, there is a need to improve faculty development by making the design more contextual, situated in an environment supportive for teacher learning with authentic activities. This change would result in strong communities of teachers willing and motivated to further enhance their teaching practice through faculty development.

To support science faculty in authentic activities related to scientific inquiry, we not only need to understand how to support their learning within their science learning context, but also understand their views of inquiry. The following section reviews the literature in this area.

College Science Teachers' Beliefs about Inquiry

The literature base on college science teachers' beliefs about inquiry is limited. In this section, I focus on the inquiry articles in this area, then draw from the closest field where research is more extensive on beliefs and practices related to inquiry: the high school level.

Following the publication of *Inquiry and the National Science Education Standards* (NRC, 2000a), Harwood, Reiff, and Phillipson (2002) conducted a study of college science teachers to understand their beliefs about the nature of scientific inquiry. They interviewed 52 science faculty members in their investigation. The authors organized their interview data into three categories: the investigator (how a scientist would teach scientific inquiry), the investigation (characteristics of a good scientific investigation), and characteristics of scientific inquiry. Faculty members focused mainly on the characteristic of making connections when discussing investigators, stressing the importance of being able to make sense of the data while also seeing the implications of an investigation. When discussing qualities of a good scientific investigation, interviewees agreed that it must be literature-based, exploring a question with an unknown answer. Finally, the researchers' analyses of the data identified what interviewees saw as common characteristics of scientific inquiry:

1. Fueled by questions, which drive the investigation.
2. A process which focuses on the investigation and not the end result.
3. An approach used in problem solving.
4. A natural way of thinking.
5. Involving skills children possess.

6. The bridge that connects the known to the unknown (Harwood et al., 2002, p. 26).

Harwood et al. reported that college teachers viewed scientific inquiry as authentic scientific investigations. In addition, these teachers felt that inquiry was process-oriented and required basic problem-solving skills. The six characteristics identified by the interviewees align with the National Science Education Standards:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; communicating the results. Inquiry requires a clarification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (NRC, 1996, p. 23)

While the Standards were developed for the K-12 audience, they clearly align with data from this college-level study of teachers' beliefs about inquiry.

To build on Harwood et al.'s study on teachers' beliefs about scientific inquiry, Brown et al. (2006) investigated college science teachers' beliefs about classroom inquiry. The researchers interviewed 19 college science teachers about their beliefs and practices in laboratory instruction, including their experiences with and understandings about inquiry. All participants were currently teaching undergraduate introductory science courses at the time of the study. Based on analysis of these interviews, the authors reported four cross-case assertions about the college teachers' beliefs and practices:

1. Inquiry instruction involves students in generating authentic questions and carrying out independent research.

2. Student factors (motivation, science knowledge, math ability, and lab skills) and logistical factors (time, class size, physical facilities) serve as constraints to implementing inquiry-based instruction at the college level.
3. Inquiry-based instruction is more appropriate for upper level science majors than for introductory majors and non-science majors.
4. College students benefit from inquiry-based instruction.

These assertions reflect beliefs that inquiry-based teaching is student-directed, holds many constraints, and is too difficult for students in introductory science courses. They also suggest a full and open view of inquiry in the classroom in which all five essential features (NRC, 2000a) would be present with classroom inquiry being represented as an independent research project led by students (see Table 1). The barriers presented in the assertions above often cause college science teachers to view inquiry-based teaching as unattainable. With the desire to broaden this limited view, Brown et al. proposed an inquiry continuum for classroom inquiry (see Figure 2) that included a different perspective on the dimension of guidance (teacher-directed vs. student-directed) and a second dimension they labeled as "degree of inquiry." This included a range for how many of the essential features were included: no inquiry (zero features), partial inquiry (some features), and full inquiry (all five features). This continuum allowed the authors to represent college science teachers' view of inquiry as full and open, as well as represent other possible views of classroom inquiry (see Figure 2). For the purpose of this study, the inquiry continuum was a useful tool in understanding the participants' views about classroom inquiry. As explained in Chapter Three, I used this tool during the interview process to help participants identify their inquiry-based SCTIL labs on the continuum.

The majority of the literature on beliefs about inquiry focuses on pre-service or in-service teachers at the secondary level (Brown & Melear, 2006; Crawford, 2007; Eick & Reed, 2002; Harwood, Hansen, & Lotter, 2006; Lotter, Harwood, & Bonner, 2007; Luft, Roehrig, & Patterson, 2003; Wee, Shapardson, Fast, & Harbor, 2007). Most of these studies focused on whether or not teachers' beliefs about classroom inquiry changed through the experience of a professional development program. For example, Crawford (2007) reported that her study of five prospective secondary science teachers' beliefs about inquiry-based teaching fell on a wide spectrum from traditional, non-inquiry to open and full inquiry approaches following their experience in a professional development program. Even with professional development support throughout their one-year practice teaching experience and feedback from mentors, some participants experienced little change in their beliefs.

Lotter et al. (2007) studied secondary science teachers' beliefs about inquiry before and after a professional development program designed to increase the use of inquiry in the classroom. The program consisted of a two-week research institute in the summer and three follow-up workshops in the following school year. The goal of the program was to support student learning through the use of inquiry-based instruction. Four core beliefs emerged as influential factors for the teachers' use of inquiry: their view of science, their view of the purpose of education as life preparation, their view of students as learners, and their view of effective teaching (Lotter et al., 2007). While teachers implemented inquiry-based instruction in their classrooms, some teachers' core beliefs constrained their use of inquiry. Lotter et al. felt that more long-term professional development programs are needed that "focus on evaluating how the science they do in their classroom portrays the nature of science to students" (2007, p. 1341).

Wee et al. (2007) investigated secondary science teachers' beliefs about inquiry before and after participating in a professional development program designed to teach science content, classroom inquiry approaches as identified in the National Standards (NRC, 2000a), and inquiry-based pedagogy. The program design included a 4-week summer institute, site visits during implementation, and pre/post institute workshops. Instructors modeled three approaches to inquiry teaching: field studies, investigative labs and models, and topic-related research. Following the program, teachers returned to their classrooms and attempted to implement inquiry-based pedagogy. The researchers found that while teachers learned about inquiry and how to develop inquiry-based teaching methods for their science topic, this did not translate into their practice or change the teachers' beliefs about inquiry teaching.

Therefore, these studies suggest that while teachers gain knowledge about inquiry and inquiry-based teaching, their beliefs and practice do not change in response to a one-year professional development program which included a summer institute and follow-up reflection workshops. The SCTIL program design was similar in format to the programs described in the previous teacher beliefs studies. SCTIL included a 3-day summer institute and a follow-up reflection workshop with the intention of supporting teachers through their implementation of an inquiry-based teaching approach. While some studies have suggested that teacher learning and implementation support through inquiry-based professional development does not change secondary science teachers' beliefs about inquiry, this study aims to understand if college science teachers' beliefs change during a faculty development program.

While the literature related to college science teachers' beliefs about inquiry is limited, it indicates that teachers tend to view classroom inquiry as conducting an independent scientific investigation. This is problematic because teachers see the constraints of implementing this type of approach within their contexts. Research has not investigated college teachers' attempts to learn about an inquiry-based approach and implement it in their classrooms; therefore, we do not understand how to help college teachers overcome their perceived constraints. From the secondary level literature, we learn that professional development programs with the goal of developing inquiry-based pedagogy tend to succeed in educating teachers about inquiry but lack success in making an impact on teachers' practice.

Gaps in the Literature

This review reveals several gaps in the literature. First, we have a limited understanding of how college science teachers learn. Faculty development programs are most successful when they are collaborative in nature, long-term, contextual for the teacher, and use multiple strategies to support teacher learning. The SCTIL program included all of these characteristics, making this study ideal for understanding effective faculty development environments for science teacher learning. Second, while the literature on college science teachers reveals the nature of their beliefs about inquiry, we still do not understand how inquiry-based faculty development can influence these beliefs. In order to improve undergraduate science education by making it more inquiry-based, we must first understand how to overcome the constraints associated with college science teachers' beliefs about classroom inquiry and provide a learning experience in which they can practice what they learn in their own classrooms. This study aims to understand college science teachers' beliefs about inquiry, inquiry-based teaching, and inquiry-based learning through a faculty development program designed to address misconceptions related to classroom inquiry and support change in teaching practice through authentic activities. Qualitative research studies like this one are needed to support faculty developers in designing effective faculty development focused on inquiry for college science teachers. Studies are also needed to support researchers in understanding the shifts that take place in the belief systems of college science teachers. This could be done by testing the belief systems model proposed by Jones and Carter (2007). Research on this model would then inform the design of effective faculty development programs.

CHAPTER THREE: THE RESEARCH PROCESS

Research Tradition

This research is guided by the research tradition of constructivism. Lincoln and Guba (1990) define constructivism as having an underlying principle that the human world is different from the physical world, and thus the two must be studied differently. “Because human beings have evolved the capacity to interpret and construct reality, the world of human perception is not real in an absolute sense, as the sun is real, but is ‘made up’ and shaped by cultural and linguistic constructs” (Patton, 2002, p. 96). Reality is not constructed; rather, knowledge is constructed about reality. I did not expect to uncover a specific answer to an established hypothesis—I expected to understand how the participants in the study constructed their own reality and viewed truth within their own context as an individual human being. Patton (2002) describes the central questions to a constructivist study as asking, “How have the people in this setting constructed reality? What are their reported perceptions, ‘truths,’ explanations, beliefs, and worldviews? What are the consequences of their constructions for their behavior and for those with whom they interact?” (p. 132). I used Patton’s questions for a constructivist study as a lens to develop my research questions. I focused on the participants’ constructed reality and their reported perceptions of their belief systems, as seen in the questions below. My tradition of constructivism, aligned research questions, and design of the study were centered on this lens of understanding the participants’ reality.

Research Questions

My interest in professional development and college science teaching contributed to the development of a research question around a specific program. The overarching research question was: In what ways, if any, do college science faculty members' belief systems about inquiry-based teaching change within the context of the SCTIL professional development program? To fully address this question, I focused on the following sub-questions:

5. In what ways, if any, do participants' beliefs and knowledge about inquiry-based teaching and learning change during the SCTIL program?
6. What components of participants' belief systems have the greatest impact on their decision of whether or not to incorporate the SCTIL inquiry article format into their future instructional practice?
7. How do environmental responses to participants' SCTIL lab implementation influence change in their belief systems about inquiry-based teaching and their future plans for incorporating the instructional approach into their practice, if at all?
8. What components of the SCTIL program were the most supportive for changing the participants' beliefs and knowledge about inquiry-based teaching?

Context of the Study

Professional Development Program

Background/Design of the Program

The context for this study occurs in the National Science Foundation (NSF)-funded professional development program *Science College Teachers using Inquiry-based Labs* (SCTIL). SCTIL was developed by science and science education faculty members for science faculty members and graduate students. According to the SCTIL staff members, the idea for this program began several years prior to the study when the primary investigator, Professor Turner, was part of a team that developed an inquiry-based approach towards teaching science laboratories. The inquiry approach is termed "inquiry article," and is based on the essential features of classroom inquiry (NRC, 2000a). (Inquiry articles are described in detail in the section below titled "The SCTIL Inquiry Article Format"). After using these inquiry articles in his graduate-level classroom for several years, Professor Turner began to work with colleagues in the Honors Program on campus to develop this approach for undergraduate science laboratory courses (Witzig et al., in press). Professor Turner and his colleagues were interested in teaching students how to write the equivalent of a scientific paper, and therefore designed the labs around the format of scientific paper. The outcome included two inquiry-based science lab courses (Warm Little Pond and Warm Little Planet) using inquiry articles with non-science majors (Park Rogers & Abell, 2008).

Encouraged by his colleagues, Professor Turner applied for funding from the National Science Foundation to incorporate this approach into a professional development program for college science teachers. According to the grant proposal, Professor Turner listed five objectives of the program:

1. To develop a full complement of SCTIL laboratories in a variety of science disciplines for use in various institutional types.
2. To prepare faculty and future faculty to design, adapt and implement SCTIL-like inquiry-based laboratory materials.
3. To assess how these materials work in different higher education settings with diverse groups of students.
4. To research teaching and learning in undergraduate science courses in a variety of institutional settings.
5. To ensure sustained development, use, and distribution of the inquiry-based laboratory materials.

The proposal was granted funding for two years. Professor Turner recruited three fellow professors to serve as investigators on the grant. Among the four lead staff members, three were science faculty members and one was a science education faculty member. They also hired a postdoctoral scholar and research undergraduate assistants to carry out supportive roles for the program. The postdoctoral scholar was a science doctoral graduate interested in advanced training in research on undergraduate science instruction. This scholar learned about inquiry-based teaching and learning, the inquiry article format, and science education research methods. The research undergraduate assistants were hired to work under the postdoctoral scholar to support his data collection and organization through the SCTIL program.

Within the first year of the program, the SCTIL staff members aimed to recruit their staff members and Year 1 participants; plan, implement, and evaluate a summer institute for participants, design and implement a third non-science majors course called Warm Little Cell, and plan the summer institute for Year 2 (see Table 5). Within the second year of the program, they would invite successful Year 1 participants back to help facilitate the summer institute for Year 2, implement and evaluate the summer institute, publish participants' inquiry articles on the SCTIL website, collect and analyze research data, and disseminate findings through conference presentations and publications (see Table 5).

Research previously published by SCTIL staff members reported that a limitation for using inquiry in college science classrooms is the instructors' views of inquiry (Brown et al., 2006). This professional development program was therefore designed to address this limitation by facilitating teachers' learning and implementation of classroom inquiry.

Table 5

SCTIL Program Timeline (from SCTIL grant proposal)

Year 1 (2006-2007)	Year 2 (2007-2008)
• Recruit Postdoctoral Scholars and Research Undergraduate Assistants • Scholars and Undergraduate Assistants undergo training in inquiry-based learning • Plan first Summer Institute • Implement first Summer Institute: participants create new labs • Formative Evaluation: Summer Institute site visit • Design *Warm Little Cell* labs • Scholars observe *Warm Little Pond* course • Participants implement labs • Scholars visit partner institutions • Scholars collect evaluation data • Plan Year 1 Follow-Up Meeting • Implement *Warm Little Cell* • Implement Year 1 Follow-Up Meeting • Formative Evaluation site visit • Postdocs enroll in *College Science Teaching* and educational research course • Create research agenda • Plan second Summer Institute based on evaluation data	• Implement second Summer Institute: participants create new labs • Evaluation: Summer Institute site visit • Design research studies • Publish Year 1 labs to website • Participants implement Year 2 labs • Scholars visit partner institutions • Scholars collect evaluation data • Scholars and Science Education students collect and analyze research data • Plan Year 2 Follow-Up Meeting • Implement Year 2 Follow-Up Meeting • Final evaluator site visit • Conference presentations • Publish balance of labs to website • Final report and manuscripts

I selected the SCTIL professional development program as the context of this study because of my interest in college science professional development. I have experience in designing, implementing, and researching in this field and plan to move into a career of professional development for science faculty members. Having previous studied college science faculty members' beliefs about teaching and learning (Hutchins & Friedrichsen, 2007), I was interested in understanding how the context of professional development might influence these beliefs. This research study was conducted during Year 2 of the SCTIL project and included the summer institute and participants' first implementation of their inquiry-based labs.

Summer Institute

In August 2007, the SCTIL staff hosted their first 3-day summer institute (see schedule in Table 6). The attendees were college science faculty members (n=11), science graduate students (n=6), SCTIL staff members (n=6), one external evaluator, and myself as a researcher. The institute was designed to educate SCTIL participants about inquiry, inquiry-based teaching, and inquiry-based labs through staff modeling inquiry-based instruction about inquiry and attendees experiencing inquiry-based labs as students. They learned about how inquiry can be used in introductory science lab courses as well as a range of possibilities in designing inquiry-based labs as seen on the inquiry continuum (see Figure 2). The staff then guided the participants through modifying two of their own labs to be more inquiry-based using the SCTIL model, inquiry articles. The faculty participants were expected to bring data from two labs they had previously taught to use in this modification process. After working on their revisions, they were given time to share their plans for each lab with colleagues and staff members and receive feedback before finalizing their plans.

Table 6

Summer Institute Schedule (from SCTIL grant proposal)

	Day 1	Day 2	Day 3
Morning	• Inquiry in Introductory Science • The Inquiry Continuum • Introduction to Inquiry article Format	• Sharing and critique of first lab • Revision of first lab • Assessing student learning	• Sharing and critique of second lab • Revision of second lab
Afternoon	• Creation of first inquiry article lab	• Creation of second inquiry article lab	• Finalizing strategies for networking during academic year

The SCTIL Inquiry Article Format

The SCTIL program focused on designing inquiry-based laboratory activities using an inquiry article format. Professor Turner and his colleagues developed the inquiry article format (see example in Appendix A) as a strategy to incorporate inquiry-based teaching into the laboratory classroom. Rather than students receiving a lab worksheet outlining a "cookbook" activity, or a step-by-step process that yields a right or wrong response, this inquiry-based approach involves giving the students a lab document in the form of a scientific paper. It includes background on the concept, a proposed hypothesis, an outline of the materials and methods for investigating the hypothesis, the presentation of actual data, data analysis, and a discussion that supports or refutes the hypothesis (Weaver & Schmidt, 2004). The paper concludes with emerging questions based on the findings. The students, working in small groups, are encouraged to take one of these questions or develop one on their own and carry out an investigation. They can use a similar approach to the one reported in the paper or develop their own. The students produce a research paper based on actual data from their investigation. This approach models the empirical nature of the scientific work in that it encourages critical thinking, team work, and creativity as students design and implement their investigation. The final format, a brief research paper, models the way in which scientists communicate their findings.

Research Participants

Selection Process

The 11 faculty members in the SCTIL program consisted of new and junior faculty, as well as more experienced faculty. Research in college professional development indicates that the target population with the highest need and motivation for change in teaching is new/junior faculty (Pierce, 1998; Savage, Karp, & Logue, 2004; Sorcinelli, 1994). For this reason, I selected for this target audience among the SCTIL participants. My criterion of the participant holding a PhD in a science content field was based on the knowledge that some SCTIL participants were in the field of science education. I wanted to focus on faculty members with similar training in scientific research-focused doctoral programs. This was also based on my assumption that science doctoral programs commonly focus less on pedagogy and more on scientific research. I specifically excluded graduate students because of my interest in working with science faculty members in my future career as a professional developer. Finally, the participants' willingness to participate was crucial to their consenting to be a part of this study. All research participants signed a consent form (see Appendix B) with the understanding that my data would be kept confidential, and that they could withdraw from the study at any time.

Following the case study design, I recruited a small number of participants in order to provide in-depth descriptions of their learning through the context of the professional development program (Merriam, 1998; Stake, 2005). I began recruiting participants 2 weeks prior to the summer institute, following approval of my dissertation proposal and IRB acceptance. I first discussed my intentions with the SCTIL staff members and requested a copy of their participant list, which included the participants' demographic information. Next, I used e-mail to contact potential participants and explained my purpose and methods for the study. I recruited in two phases, both within 2 weeks prior to the summer institute. My first recruitment phase resulted in 4 consenting participants; however, due to the possibility of participants withdrawing from the study in the following months, I decided to broaden my criteria in order to recruit more participants. My science content area of interest and past research experience is in the life sciences; therefore, I initially set a criterion that participants needed to be from a life science field to aid in my understanding of the content as I interviewed/observed the participants. In order to increase my sample size, I decided to expand my selection from life science professors to professors from any science field. This expansion resulted in one additional commitment from a physical science faculty member in the SCTIL program. My final criteria used in the second recruitment phase were:

1. Participation in the SCTIL professional development program,
2. New/junior faculty members (non-tenured),
3. A PhD degree in a science content field, and
4. Willingness to participate in this study.

Description of Participants

The participants in this study were five college science faculty members, identified in this study by the pseudonyms: Professors Brinkley, Garrett, Propes, Rogers, and Wilson (see Table 7). No two participants worked in the same science department at their institution. The participants' teaching experience as a faculty member ranged from one to three years; however, most had teaching experience as graduate students or post-docs. None of the participants were tenured at the time of this study. A more thorough description of each participant is included in their individual cases as part of the Results section.

Table 7

Participant Characteristics

Pseudonyms	Professor Brinkley	Professor Garrett	Professor Propes	Professor Rogers	Professor Wilson
Characteristics					
Science Area	Life Science	Life Science	Life Science	Physical Science	Life Science
Yrs as a Faculty Member*	3	2	2	1	2
Type of Institution	Community college	Liberal Arts college	Large research university	Large research university	Large research university
Primary Responsibility†	Teaching	Teaching	Research	Research	Research

*Completed number of years as of the beginning of the SCTIL program in summer 2007.
† As part of their faculty position, their primary responsibility is the area of their job (research, teaching, or service) that is valued most by their institution.

Design of the Study

In designing this constructivist study, I drew from my ontological, epistemological, and methodological assumptions. According to Denzin and Lincoln (2000), "The constructivist paradigm assumes a relativist ontology (there are multiple realities), a subjectivist epistemology (knower and respondent co-create understanding), and a naturalistic ([set] in the natural world) methodological procedures" (p. 21). From an ontological perspective, the multiple realities in this study were both the participants' perspective on their belief systems, as well as my perspective as the researcher interpreting their views. The subjectivist epistemological views of this study were aligned with its constructivist design, which allowed me to continually interpret my observations and impressions through interviews, while investigating the construction of their knowledge through multiple discussions throughout the study. This contributed to the generation of my understanding about the nature of the participants' belief systems.

Case Study Approach

Merriam (1998) differentiates case studies from other types of qualitative research by defining them as “intensive descriptions and analyses of a single unit or bounded system” (p. 19). Patton (2002) described case analysis in the following excerpt.

> Case analysis involves organizing the data by specific cases for in-depth study and comparison. Well constructed case studies are *holistic* and *context sensitive*, two of the primary strategic themes of qualitative inquiry…The case study approach to qualitative analysis constitutes a specific way of collecting, organizing and analyzing data; in that sense it represents an analysis *process*…The analysis process results in a *product*: a case study. (p. 447)

For this study, I chose the case study approach to guide my research design. I have set “boundaries” around each participant, studying them as individual cases within the context of the professional development program. I also conducted a cross-case analysis of the individual cases represented as my assertions. I did not evaluate the professional development program itself, but rather attempted to understand the participants’ construction/modification of their belief systems within the program.

Depth of individual cases is an important aspect of using the case study approach (Creswell, 1998). While investigating many individual participants would be ideal, researchers must decide how much data and how many cases are sufficient to answer the research question within the timeline of the study. The typical number of cases studied is small with the purpose of being able to focus on depth in each case (Creswell, 1998).

Role of the Researcher

In Hatch’s (2002) publication on qualitative research, he notes “the human capacities necessary to participate in social life are the same capacities that enable qualitative researchers to make sense of the actions, intentions, and understandings of those being studied” (p. 7). This interactive process played a large role in how I made sense of the data and interpreted the findings of the study. Patton (2002) states that participant observers “employ multiple and overlapping data collection strategies: being fully engaged in experiencing the setting (participation) while at the same time observing and talking with participants about whatever is happening" (p. 265-266). My role as a participant observer varied depending on the context. During the SCTIL summer institute, I participated in discussion with small groups, talked with my participants about their work, and took extensive observation notes of the context of the institute each day. During the implementation observations, however, my participation was limited to discussions with my participants in between student activities. We would discuss what activity the students were working on, and how they seemed to be responding to the assignment. I did not converse with students in this environment, but took extensive observation notes on the context of the classroom and instruction of the faculty member.

Institutional Review Board and Data Storage

The SCTIL program gained approval by the university's Institutional Review Board (IRB) to conduct research. I assisted in amending the IRB proposal to gain permission to observe the program and interview selected participants. Written consent was obtained from all of the interviewed research participants (see Appendix B). All consent forms, digital audiofiles, artifacts, and CDs with research data will be kept in a locked file cabinet for a minimum of three years following the final data collection of the study.

Data Collection

According to Yin (2002), there are three key principles in case study data collection: (a) use multiple data sources of evidence, (b) create a case study database, and (c) maintain a chain of evidence. The multiple data sources used in this study were interviews, observations, artifacts, and a researcher's journal. I organized all data sources within a database file using NVivo software (QSR International, 2006), and kept an audit trail to maintain a credible chain of evidence, as discussed in more detail in the Trustworthiness section.

Data were collected at multiple time points (see Figure 3). I collected the first set of data around the SCTIL summer institute. I interviewed the selected faculty participants within one week prior to the summer institute and took observation notes during the summer institute. I collected the second set of data around each participant's first

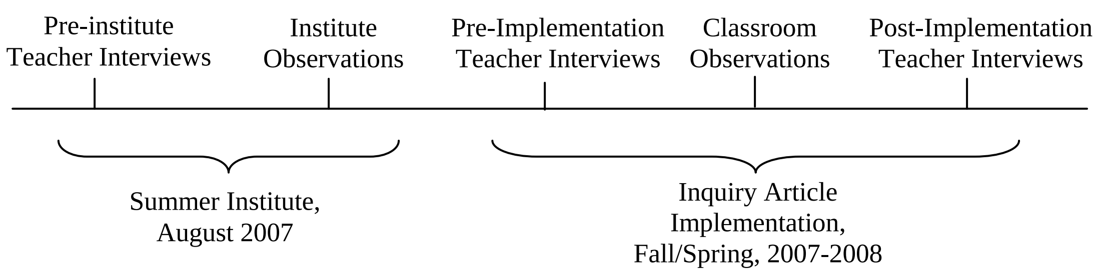


Figure 3. Data collection timeline

inquiry article implementation in their laboratory classrooms. I interviewed them within one week prior to the start of their inquiry article implementation, took observation notes during one or more classes of the inquiry article lab, then interviewed them within three days following their final implementation lab. The reason for scheduling the pre-implementation interview immediately prior to the implementation rather than immediately after the summer institute was to allow participants to get to know their students in their course and be able to discuss the classroom environment, as well as their expectations for how students would respond to this new teaching approach. The faculty interviews were the primary data sources for each research sub-question (see Table 8).

Interviews

Aligning with this case study design, the use of interviews is an essential data collection strategy. "Qualitative researchers take pride in discovering and portraying the multiple views of the case. The interview is the main road to multiple realities" (Stake, 1999, p. 64). In understanding each participant's belief system through their individual case, I used the interview as the primary source for obtaining descriptions and interpretations of their experience within the SCTIL context. According to Seidman (2006), it is critical to understanding the context of the research by engaging in multiple interviews rather than a "one-shot meeting" (p. 17). Drawing from Seidman's three-interview series, each interview was designed to be in-depth with a different focus at each of the three points in time (see Appendix C for interview protocols). The foci were based on the Sociocultural Model of Embedded Belief Systems (Jones & Carter, 2007). I designed questions to reflect the components of this model. The first interview addressed the participants' incoming belief systems about inquiry-based teaching. The second interview, conducted prior to participants' inquiry article implementation, addressed the participants' attitudes and concerns after designing the lesson and becoming familiar with their specific teaching context. The third and final interview was conducted immediately following the implementation of their lesson, focusing on components of the participants' belief systems about inquiry-based teaching after participating in the professional development program and implementing this new teaching approach in their classroom. The flow of this interview design, collecting data before they experienced the summer institute, then before and after they implemented their inquiry article, allowed for insight into the participants' belief systems at significant points in time within the context and

Table 8

Data Collection Matrix: Overarching Research Question: In what ways, if any, do college science faculty members' beliefs systems about inquiry-based teaching change within the context of the SCTIL professional development program?

	Teacher Interviews			Observations	
Sub-Questions	*Pre-Institute*	*Pre-Implementation*	*Post-Implementation*	*Institute*	*Implementation*
In what ways, if any, do participants' beliefs and knowledge about inquiry-based teaching and learning change during the SCTIL program?	P	P	P		
What components of participants' belief systems have the greatest impact on their decision of whether or not to incorporate the SCTIL inquiry article format into their future instructional practice?	P	P	P	S	S
How do environmental responses to participants' SCTIL lab implementation influence change in their belief systems about inquiry-based teaching and their future plans for incorporating the instructional approach into their practice, if at all?	P	P	P		S
What components of the SCTIL program were the most supportive for changing the participants' beliefs and knowledge about inquiry-based teaching?	P	P	P	S	S

P= Primary data sources used to answer the research questions; S=Secondary or supporting data source used to answer the research questions.

contributed to the construction of their individual case. Each interview was digitally audiotaped, and each digital document will be kept in a secure electronic file for a minimum of three years following the conclusion of data collection. The digital audiofiles were transcribed to allow for the analysis of the interviews.

Observations and Field Notes

The use of observations in qualitative research increases the researcher's understanding of the case by serving as a source of evidence (Stake, 2005; Yin 2002). I acted as a participant observer during both my summer institute observations and my implementation observations. My summer institute observations allowed me to gain an understanding of the participants' experience as well as take field notes on their comments, questions, and behaviors throughout the institute. During the implementation observations, my field notes and interpretations were used to develop interview questions for the post-implementation interview. Overall, the observations and field notes informed the context of this study and served as a catalyst for creating additional interview questions.

Artifacts

Throughout the SCTIL program, I collected artifacts to contribute to my understanding of the participants' belief systems (Yin, 2002). During the summer institute, I collected inquiry article examples, templates, and lecture notes from the staff members. Prior to the pre-implementation teacher interviews, I collected the participants' inquiry articles to use as a guide during the teacher interviews to discuss their purpose for their design and plans for instruction during implementation.

Researcher's Journal

Based on my subjectivist epistemological views, I kept a researcher's journal as a means to reflect on my own biases throughout the investigation, as well as to record methodological issues and potential insights into my interpretations (Lincoln and Guba, 1985).

Data Analysis

I used Glaser and Strauss's constant comparative method as an analytic approach (1999). This method is a well-established inductive framework for systematically organizing the data (Glaser & Strauss, 1999; Strauss & Corbin, 1998). I continuously coded interview transcripts and observation notes within and between cases using NVivo qualitative research analysis software for the coding process (QSR International, 2006). I began my coding process by using the components of my framework, the sociocultural belief systems model (see Figure 1), as my tentative categories, then inductively created sub-categories as they emerged from the data (Jones & Carter, 2007). I finalized the tentative categories during my analysis of their third interviews. An example of a tentative category that reflected the belief systems model was "Environmental Responses." By interview three, this general category included the following sub-categories: Responses from Students, Responses from Administrators, and Responses from Colleagues. The product of this analysis consisted of five individual cases consisting of common categorical headings. The sub-categories were not relevant for all cases, but were useful in the cross-case analysis. For example, not all participants discussed responses from their colleagues; therefore, this was not represented in each of the individual cases.

For each case, I created a profile for the individual based on the categories, relevant sub-headings, and the verbatim excerpts that were coded during my analysis phase. The multiple data sources used to develop each profile contributed to their thick descriptions. While developing each case, I continually referred back to the data sources (interview transcripts, observation and field notes, artifacts, and researchers' journal) to test claims.

Throughout the analysis process, I recorded researchers' notes about cross-case categories as tentative assertions for this study (Stake, 2005). Once the individual cases were complete, I tested the tentative assertions against all five cases and added additional cross-case assertions as they emerged. For example, one tentative assertion that developed early in my analysis stated, "Participants with departments/administrators who valued teaching tended to enter SCTIL with stronger beliefs about teaching and learning." I later rejected this assertion about the social context because it did not fit all five of the participants. Some participants entered the program with strong beliefs about teaching and learning; however, they did not provide enough information through their interviews for me to make this claim about what their administrators valued. Another tentative assertion was "Environmental constraints/responses were a significant filter point for faculty members to incorporate this model into their instructional practice." After reviewing my analysis of the five cases, I was able to make this claim based on evidence from my data sources. However, I modified the assertion to best represent the data. Environmental constraints were not instrumental for faculty members, and attitudes were shown to be an important part of their belief systems; therefore, the final assertion stated, "Environmental responses (i.e., student and/or colleague responses) to the participants' implementation of the SCTIL approach played a critical role in influencing their attitude towards inquiry-based instruction." I continually tested claims and revisited my data sources for evidence of the claims. I also presented my tentative assertions to a researcher on the SCTIL staff for additional feedback. This cross-case analysis allowed me to identify themes across the participants.

Limitations of the Study

The design of this study presents three evident limitations. First, the framework for the study, the Sociocultural Belief Systems Model (Jones & Carter, 2007), was developed based on research conducted on high school teachers. The participants in this study were college teachers, therefore, the model was applied to a different audience from its intention. A proposed outcome of this study is a modified version of the model adapted based on college teachers' belief systems.

A second limitation is the sacrifice of breadth for depth in using the case study approach. Creswell (1998) discusses the importance of depth in case study designs to gain thick descriptions within profiles and a deeper understanding of the picture presented. The researcher must decide how much data and how many cases are sufficient to gain this depth of understanding with an investigation. For this study, I designed a trustworthy study using five cases.

The last limitation of the study is the timeline. The design of the SCTIL program included the summer institute, two inquiry article implementations in the following school year, and a follow-up session in the spring. My study focused on the summer institute and the first inquiry article implementation, which allowed me to investigate how the participants' belief systems changed through one attempt at implementing this inquiry-based teaching approach.

Trustworthiness

As a qualitative researcher, it is my responsibility to ensure the trustworthiness, or rigor, of this study. There are four common criteria of trustworthiness in qualitative research: credibility, transferability, dependability, and conformability (Lincoln & Guba, 1985; Patton, 2002). These are known as the equivalents for the conventional terms of internal validity, external validity, reliability, and objectivity. By these standards, I have conducted a trustworthy study as elaborated below.

Credibility

I used triangulation by collecting and analyzing multiple data sources (interviews, observations, and researcher's journal), as well as conducting three separate interviews (Seidman, 2006). I also used the peer debriefing method with my advisor and colleagues, "a process of exposing oneself to a disinterested peer in a manner paralleling an analytic session and for the purpose of exploring aspects of the inquiry that might otherwise remain only implicit within the inquirer's mind" (Lincoln & Guba, 1985, p. 308). In this process, I was able to gain additional insight about the data and how to organize and interpret my findings.

Transferability

A transferable study is one that contains "thick descriptions" (Lincoln & Guba, 1985, p. 316). "The naturalist cannot specify the external validity of an inquiry; he or she can provide only the thick description necessary to enable someone interested in making a transfer to reach a conclusion about whether transfer can be contemplated as a possibility" (Lincoln & Guba, 1985, p. 316). A case study is an ideal representation of presenting thick descriptions, which are narratives of data in a manner interpretable for others. In studying the participants' belief systems, the data sources contributed to the basis of thick descriptions through individual cases.

Dependability

In an effort to make this study dependable, I used multiple data collection methods (interviews, card sort activity, and researcher's journal). In terms of the reliability of the transcriptions, each interview was audio recorded and transcribed.

Confirmability

Lincoln and Guba (1985) suggest that a confirmable study is one that has an audit trail. The audit trail for this study included the following:

1. Raw data (digital interview audio recordings, researcher's journal)
2. Data reduction and analysis products (research protocols)
3. Data reconstruction and synthesis products (coding scheme, final written product)
4. Process notes (notations in researcher's journal such as those concerning the methodology, trustworthiness, or the audit trail)
5. Materials relating to the use of the results (research proposal, reflections, publication of dissertation).

Therefore this study is trustworthy due to my actions of making it credible, transferable, dependable, and confirmable.

CHAPTER FOUR: FINDINGS

The findings from this study are organized by participant in individual cases. For each of the following five cases, I present a profile of the participant and their inquiry article lab, as well as a description of their belief system prior to and following their participation in the SCTIL program. The profiles are organized around the modified components of the sociocultural belief systems model (Jones & Carter, 2007).

Case #1: Professor Brinkley

The following case of Professor Brinkley is divided in four sections. First I will introduce him by describing his teaching experience, his faculty position, and his self-reported teaching practice prior to attending the SCTIL program. In the second section, I describe his belief system about inquiry-based teaching prior to participating in the SCTIL program. The third section focuses on his written inquiry article lab. I describe how this written document changed between its first draft written during the SCTIL summer institute and the final draft implemented during his course in the fall of 2007. In the final section, I describe the evidence-based changes in Professor Brinkley's belief system about inquiry-based teaching.

Context of Professor Brinkley

Professor Brinkley's teaching experience, current faculty position, and teaching practice played an important role in influencing his experience in the SCTIL program.

Faculty Position and Teaching Background

Professor Brinkley was an Assistant Professor in the Biology department of a community college. He received his doctorate in ecology and evolutionary biology in 2001. His teaching experience began as an undergraduate student in 1984, when he served as a tutoring instructor and review session leader for lower-level undergraduate courses. He first learned that students have different learning styles during this experience, as evident in the following statement:

> So a lot of them really trained me in how people learn because I realize they come from many different styles, many different challenges that they face, so you gotta be, so I learned to be very adaptable and look at those different issues. (Interview 1)

As a graduate student, Professor Brinkley spent a significant amount of time designing instruction and teaching courses. During his PhD degree program, he taught science laboratory courses and tutored students in the sciences. He also co-designed and taught a Biodiversity course with a strong field component drawing on his own research experience in the Sonora Desert. During the summers, he designed and implemented an NSF Young Scholars Program for 7^{th} grade students. This 8-week program was centered on studying lizard behavior. At the end of the program, students gave a mock scientific conference presentation of their data and the experiment.

Following these teaching experiences, Professor Brinkley chose to work in a community college where he could continue to focus on his teaching as well as have the flexibility to investigate different research areas. He stated:

> Keeping current cutting edge is very exciting and the students pick up on that, and the teaching and the research. That's why I chose to leave research universities, to have the freedom to synergistically look at all these different avenues and…bring them all together. I mean I couldn't do all of this and be at a research university I realized. (Interview 1)

At the time of this study, Professor Brinkley had been teaching at the community college for 3 years where he typically taught 20 credit hours per semester. His courses included Introductory Biology for non-science majors, Conservation and Ecology, Marine Biology, Nutrition, and Evolution. Each class had an average of 30 students. In addition to his community college position, Professor Brinkley taught one to two evening courses a year at a neighboring research university.

Self-reported Teaching Practice Prior to PD

As an Assistant Professor, Professor Brinkley had been a faculty member for 4 years; however, he had extensive prior teaching experience. On average, he reportedly spent 5 hours a day preparing for his courses outside of class time. When discussing his own teaching practice, he continually focused on making the content applicable and relevant to the students, as well as providing them with authentic learning experiences. At the beginning of each course, Professor Brinkley considered his students' background and experiences and what he needed to include in the design of his course to make it meaningful for them. He also tried to take as many students as possible to his field research site at a local nature reserve so they could have hands-on experience with data collection, something he noted that is not available for most community college students. He typically assessed his students' learning through exams, journal entries, and reports or presentations.

He described a typical Introductory Biology lecture class and laboratory in his courses. In a typical lecture class, he began by connecting the concepts back to the previous class, then sharing his learning objectives or "road map" for the day (Interview 1). The majority of the class consisted of lecture with discussion, student interactions, and questioning. He purposefully used multiple instructional strategies during class to change the pace. He ended class by summarizing the material and providing key points for how to prepare for the next class.

In a typical Introductory Biology laboratory class, Professor Brinkley began by having students take a pre-lab open-book quiz to "make sure they prepared for the lab" (Interview 1). Next, he discussed the quiz, and quickly got them into teams for the day's activities. He introduced the main concepts for the activity and had them go through what he called a "guided" approach to the task; however, he tried to let them be as independent as possible. In the following statement, he described the typical lab activity out of their lab manual and expressed his frustration with its limited use of inquiry:

> Now, it's kind of like an ecosystem. Here's the three different zones we're going to focus on. Here's the three different sampling methods. Here's the food chain of the overall system. Let's go out and collect some of these organisms and let's draw them, look at them under the microscope to the macroscope viewing scope to the naked eye. Key them out to their different zones where we collected them, and link them up in the overall biogeochemical cycle. So it's all very descriptive. The only inquiry is just what's out there . . . I mean it's useful but it can go so much further. (Interview 1)

Professor Brinkley's typical laboratory instruction could be described as primarily teacher-directed using active learning strategies.

Nature of Belief System about Inquiry-based Teaching Prior to PD

In the following sections, I describe Professor Brinkley's belief system about inquiry-based teaching prior to the SCTIL professional development program.

Beliefs

Student learning in science. Prior to participating in the SCTIL program, Professor Brinkley's beliefs about how students learn science were complex. He discussed four different components that he felt were important in science student learning: (a) different learning styles (i.e., kinesthetic, auditory, oral, and written); (b) personal relevance; (c) overcoming an aversion to science terminology through repetition; and (d) being metacognitive about their own learning experience. This is evident in his following statement:

> The best way that they learn is to activate kinesthetic, auditory, oral and verbal senses. . . . So that's one way to answer the question. The other way is well, they can do all that and SCTILl not care about it. It just doesn't sink in because it's uninteresting, unimportant, so then I challenge them to make it relevant and I reward that. . . . And then another thing that's important, a third answer to that question, science. Some people have this built in aversion or barrier, and so when I catch that, I go 'hola is Spanish and it means hello, right. You cool with that? Hola means hello, so I'm going to ask you that later. Hola! What's that mean? Hello.' And I'll do that a few times and they'll get really comfortable, hola means hello. And then I'll go, 'metabolism! Heredity, inheritance.' And they get the connection that oh, these are just weird terms that I just need to get comfortable with. And then you know some people need a lot of help in how to learn, from the level of metacognition to observe how they learn so that they can really add to it. So I give them handouts on this, learning styles, learning strategies, etc. (Interview 1)

Thus, built on a strong background in teaching and an interest in student learning, Professor Brinkley believed that students learn science best by being active and engaged in their learning experience and incorporates those beliefs into his teaching practice.

When discussing how students learn through inquiry, Professor Brinkley explained that he encouraged his students to "inquire" by asking them leading questions in class, presenting contrasting stories on topics, and modeling how inquiry is done (Interview 1). He stated, "I'm trying to model all the ways they can inquire, look at the material and think about it and connect it, discrimination, discernment, all those things that are learning" (Interview 1). He believed that inquiry primarily involved critically thinking about an issue in science and designed his instruction toward developing this skill in his students.

Science as inquiry. When asked to define inquiry, Professor Brinkley responded:

> Specifically in inquiry for science learning is to inquire as a scientist does, to utilize the senses and the equipment that we've developed, to observe the natural world . . . to come up with questions from those observations, attempt to answer those questions, hypotheses, and then come up with ways to try to falsify those explanations, and design tests to do so or to gather data to do so, and to analyze it and draw conclusions from it, possibly refine it . . . and of course anywhere along the way. (Interview 1)

He noted that he informs his students about his own role as a scientist. He stated:

> I tell them as a scientist I never stopped making those observations. And if those observations shed new light, new ways of SEEING things, then I would make revisions rather than lock stop and barrel staying with one particular avenue. (Interview 1)

Professor Brinkley viewed inquiry as an authentic approach to doing science and used his experience as a scientist to help his students understand the process.

Inquiry-based teaching. During Interview 1, Professor Brinkley gave an example of what inquiry looks like in his own laboratory teaching. When discussing enzymes in Introductory Biology, he began by passing around a test tube and had all of the students spit into the tube. He then asked questions like, "what is saliva? What does it do?" Next, he had them crush up crackers and put them in the tube. This example demonstrated his belief about inquiry-based teaching as being guided by scientific questions. Professor Brinkley viewed this approach to teaching as being an authentic strategy for doing science. He defined inquiry-based teaching in the following statement:

> So that's an inquiry activity, kind of prompting them and leading them through authentic . . . and I could've designed that into an experimental format on enzymes. So sometimes, wouldn't it be easier to define by defining what it's not? Inquiry is NOT simply shutting off their higher order cognitive explorations and just feeding it to them and thinking they'll get it by that method. But you could give somebody a shovel, a tool to use, and then say go out and do something with it in that plot of land there. It's very different than just throwing them out there and saying, 'do something.' (Interview 1)

Professor Brinkley distinguished inquiry in his lab from inquiry in his lecture classes, pointing out that “in class, that’s a different style of inquiry because it’s a different material, it’s a different approach. There I want them inquiring into connecting the material globally, which includes the individual all the way up” (Interview 1). He noted that he tries to acclimate to the culture of the classroom and connect with the students to find out “what really works for them.” He continually wanted to add in more inquiry, focusing on the importance of not only content and depth in his teaching, but process as well. Overall, he believed that inquiry-based teaching involved asking and investigating scientific questions, authentic learning experiences, and connecting science to society.

Social Norms

At Professor Brinkley’s community college, teaching is highly valued. The institution sets an expectation that faculty members spend over 60% of their time on teaching. They are primarily evaluated through yearly portfolios, which include student evaluations, dean evaluations, and self evaluations. They are required to present a professional development plan to the university each year, and funds are available for faculty members to attend professional development activities. Professor Brinkley stated that he “taps into that well as often as possible” (Interview 1).

As reported by Professor Brinkley, the typical teaching strategy in his Biology department and in his own practice is the lecture approach, or “sage on a stage.” In reflecting on this blanket characterization, he stated:

> The BELIEF that I’ve found below [referring to his impression of colleagues’ core beliefs] is that it’s not an aversion necessarily to any other technology or time constraint or anything, it’s a belief that that’s

> what the students need. They need to be led through the material. Now this is intro level. (Interview 1)

Professor Brinkley's Biology department is currently in a "flux" state. The Introductory Biology course has multiple sections, and therefore is taught by several faculty members. They are currently revising the laboratory manual, and Professor Brinkley is taking the lead on making these revisions. He explained the situation in the following statement:

> It's almost like we have the ability to start off pretty fresh, especially with anything inquiry-wise. So I'm taking the themes, like we have a pond ecology lab, but I'm making it more quantitative and more scientific processed. It's not really now. It's more, you know, observe. So it's all very descriptive. The inquiry is just what's out there, . . . it's useful but it can go so much further. And that's what I'm taking it to okay, well what if we're going to actually do RESEARCH on this pond, which . . . my training is as a research scientist, so if I was going to do a research project, I would want to understand the natural world or predict the future if we understand it enough. (Interview 1)

As he reflected on the change taking place in his department, he noted the reason for needing to change the labs. "I think what has been happening in this department is that, they had lowered things to the students' abilities TOO much. So I'm kind of doing the reverse trend" (Interview 1). He felt that the community college student population tended to be at a different level of learning than those at research institutions; however, he felt that modifying their instructional approach to meet their needs was more important that "dumbing down" the content (Interview 1).

Overall, Professor Brinkley felt he had a positive relationship with his administration. He noted, "I have a lot of interaction with the dean, he's very supportive." He explained that he attempted to recruit a colleague from the Biology department to join him in participating in the SCTIL program, but the colleague was unable to commit the time; therefore, Professor Brinkley was the only participant from his institution.

Environmental Constraints

In considering what environmental constraints might hinder the implementation of the SCTIL inquiry article format, Professor Brinkley discussed his students and their expectations for learning. The freshman class of his community college would have to make an adjustment to an inquiry-based approach, in which the answers are not given. He stated:

> The challenge here is a lot of the students are either coming from high school or coming from being out of school for a long time, so . . . I guess they're used to being led by the nose. And they're used to having one right answer, to search hunt and peck for it type of thing, so the inquiry labs are going to be an interesting challenge. (Interview 1)

Therefore, Professor Brinkley believed that his greatest environmental constraint would be his students' expectations of being given all the answers.

Self-Efficacy

Professor Brinkley's confidence level towards implementing an inquiry-based lab format was high prior to the first day of the SCTIL program. When asked if he felt like he was an expert in inquiry-based teaching, he responded, "Expert? I don't know, I would be more comfortable saying I'm a more of jack-of-all-trades, proficiency in many and expertise in scientific inquiry as a scientist, and a gift in being able to transmit that to teaching" (Interview 1). In terms of guiding students through their learning process and trying to give them more ownership, he felt that he was highly skilled in that instructional practice.

Attitude

Before the SCTIL workshop, Professor Brinkley's attitude towards learning and implementing the inquiry article format was very positive. He expressed an enthusiastic outlook on incorporating this approach into his laboratory courses. He noted, "When this SCTIL project came up, I was like, oh perfect!" (Interview 1). He was excited to learn a new inquiry-based teaching approach.

Knowledge and Motivation

Professor Brinkley entered the SCTIL program with extensive knowledge about scientific and classroom inquiry; however, his knowledge about the inquiry article format was limited to what he learned through the SCTIL program website. Once he learned about the program, he investigated its purpose and mission to understand how he would be spending his time. This knowledge helped him understand the program's expectations and allowed him to better prepare for his experience in the faculty development context.

Professor Brinkley discussed several motivational factors contributing to his participation in the SCTIL program. First, he entered into the PD program with knowledge about and experience in using inquiry-based teaching, and was therefore enthusiastic to learn a new approach to use in his classroom. He also saw the value in linking it with his own scientific research. He stated:

> I was already involved in inquiry labs and there are so many different ways to cut that onion, you know, I thought oh here's another way to look at inquiry and I really like this way, I like this mini journal format. And since I'm actually doing authentic research, I'm thinking of ways to tie that authentic research into these inquiry labs. (Interview 1)

A second motivator for him was the networking aspect of the program, meeting other science faculty members who would use this approach and be resources for exchanging feedback. Being the only participant from his institution, he was eager to connect with faculty members from other institutions and maintain communication throughout the program.

A third motivator for Professor Brinkley was his interest in conducting research that would result in publications. He stated:

> And THAT'S how I'm going at this SCTIL project, this is stuff that, with a little bit of tweaking, a little bit of expansion, you know, this could be an actual informative, beneficial research project. I'm looking for the opportunity to observe the students and then present at a conference. . . . At the end for me personally, I'll have at least four implemented labs, at least two conferences gone to, potentially publications, depending on what I want to look at. (Interview 1)

Overall, his motivations focused on connecting this teaching approach with his own research to result in publications, networking with other science faculty members, and expanding his use of inquiry in the laboratory.

SCTIL Inquiry Article

At the end of the first day of the SCTIL summer institute, participants were asked to use what they learned that morning about inquiry and the inquiry article format to begin to convert one of their labs into that design. On the second submission, they submitted this first draft to the SCTIL staff members and peers for feedback. In this section, I compare Professor Brinkley's first draft of his converted lab with the final version he implemented in his lab course. Between these two points in time, Professor Brinkley made several modifications based on feedback from SCTIL staff members and colleagues and his impression of his students once the semester began. I present how the design of the two versions of the inquiry article lab differed, as well as what modifications he made during his implementation of the lab.

First Version of Inquiry Article

Professor Brinkley chose to convert a lab he had previously used in his course on pond ecology. The original version of his lab was not a typical "cookbook" lab with step-by-step directions and an expected result. Professor Brinkley designed it as a guided lab in which students used a prepared lab worksheet to guide them through taking water samples to test for pH and temperature, as well as taking organism samples to identify the organisms present in different areas of the pond. After identifying the organisms, students drew them on the worksheet. After converting this lab into his first draft of an inquiry article format, he decided to narrow his focus to plant ecology in ponds, specifically looking at duckweed (see Appendix D for Inquiry Article version 1). His inquiry article investigation focused on examining duckweed populations in two separate ponds located on his community college campus. His goal in this study was "to assess the potential of duckweed to serve as a biological indicator of chemical contamination of freshwater aquatic ecosystems" (Inquiry Article version 1, Professor Brinkley). He tested population samples of duckweed in different areas of the pond that he assumed had different levels of contamination. In his closing Discussion section, he listed several possible follow-up student investigations, such as looking at the effects of different pollutant concentrations or the effects of water disturbance on growth.

Final Version of Inquiry Article

The design of Professor Brinkley's final version looked similar to his first version (see Appendix D for Inquiry Article version 2). The wording of the inquiry article was more clear and concise; he made the major aspects of his investigation more explicit, such as the objective, hypothesis, and prediction. Professor Brinkley decreased the number of formulas in his methods section, and shortened his discussion section, which had ideas for future investigations. He added the following supplemental materials to help guide his students through the assignment: a design set-up sheet, an outline for their final product, a peer review rubric, and his grading rubric. Professor Brinkley explained that after meeting his students, he believed they needed more guidance in preparing for this change in laboratory format. Prior to the actual lab, Professor Brinkley taught preparatory lessons on the scientific process and how to write a scientific paper. Next, he presented his students with his inquiry article. As homework, he asked them to grade his inquiry article using the rubric he created to grade their own products. After seeing his expectations for the inquiry article through this grading practice, they began designing their own projects within small groups of three or four students. After 2 weeks of designing and conducting their investigations, each student group presented their findings to the class. Professor Brinkley wrote the following guiding questions on the board for the students' presentations (Field Observation Notes, September 19th, 2007):

1. What ideas came to you from reading the report I wrote
2. What you decided to investigate and WHY
3. Your hypothesis and prediction or expected results—come up and graph on the board
4. Independent variable and dependent variable
5. Your experimental design
6. IF TIME:
   --Complete experiment (calculate means, graph data, draw conclusions)

Following this presentation session, Professor Brinkley reminded the students their abstracts were due in 2 weeks, which included their expected graph, their actual results graph, and their data table.

After meeting his students and understanding the context of their learning experience as freshman in community college, Professor Brinkley made minor modifications to his expectations for their final product. Rather than requiring that they submit a complete inquiry article with all the sections of scientific paper, he negotiated with them to require only an abstract as their product:

> Yeah, I told them that I'm most interested in their learning, and I don't want to have them do any work that is going to OVERWHELM them, because we're doing a lot that is new for them, I'm aware of that. I said, 'you all are first going to crawl, then you'll walk, then you're going to be running. I'm fully confident. And I'm going to help you along each step of the way.' So we negotiated just the abstract. (Interview 3)

In addition, he chose to offer the option of an honors project for those who were interested in completing the entire project from start to finish. He had three students who completed the requirements for honors credit.

Change in Belief System about Inquiry-oriented Teaching

In the following sections, I describe the changes, if any, in Professor Brinkley's belief system about inquiry-based teaching after implementing his first inquiry article lab.

Beliefs

Student learning in science. By the end of his first inquiry article implementation, Professor Brinkley's beliefs about how students learn science changed very little from the beginning of the PD program. Through this program, he was able to implement his beliefs about science teaching and learning using this inquiry article instructional approach. For example, he felt strongly that critical thinking and metacognition were major components of science learning. This belief was expressed prior to his experience in the SCTIL program as well as throughout the program. In reflecting on his students' experience with the inquiry article activity in his third interview, he stated:

> So I really try to give them enough to get started and to go forward with, and to leave as much of that intellectual grappling and decision-making up to them. . . . They're vocalizing and discussing things in a different way

> because, they're being challenged to think about what they're doing. So that's the biggest thing, so instead of pulling teeth to get things out of them, I don't have to do that because they KNOW that they are responsible. So they took ownership, and then the way that they're extending the ideas and making the connections, that's totally new! There's a lot of student reflection and thought that is required of this that is not in the way we have traditionally taught these labs. There is NO WAY that they can fill out my rubrics without thinking. They are designed to not be, there's nothing that they can copy to fill it in. (Interview 3)

After learning about the SCTIL inquiry-based teaching approach, Professor Brinkley was motivated to think more about the collaborative nature of learning in the laboratory environment. He wanted to bring in more collaborative laboratory activities for his students, encouraging them to work in teams and support peer group learning. He discussed his reading of research literature on student learning in the following statement: "That's one of my goals, is that since I've been working here is to get the students working in teams and collaborating, you know the evidence and research has shown that study groups support student learning, peer groups—so I personally have created my labs to follow that." (Interview 3) While he had used student group work in previous labs, the SCTIL program encouraged him to make this a more prominent component of his instructional design.

Understanding that his freshmen students were inadequately prepared for college work, Professor Brinkley felt that this was one of the most challenging contexts to implement an inquiry-based method; however, he felt his students were successful in their learning, becoming more vocal through the collaborative nature and taking more ownership of their own learning through the entire process. Overall, he believed that using the SCTIL inquiry-based approach improved his students' learning experience and taught him aspects of inquiry-based learning that he wanted to include more often in his teaching.

Science as inquiry. Professor Brinkley's beliefs about inquiry expanded from scientific inquiry to a deeper understanding of classroom inquiry. He noted that through his experience in the SCTIL program, his definition of classroom inquiry had become "more refined in implementation" (Interview 2). His discussion about inquiry in his second and third interviews focused on teaching with inquiry.

Inquiry-based teaching. After experiencing the SCTIL program, Professor Brinkley described his role in supporting student inquiry as allowing his students "more room to be creative, and to exercise higher-ordered critical thinking in terms of observing without someone else's bias" (Interview 2). While he provided them with a framework through his inquiry article, he believed that students need to have as much freedom as possible in this learning experience. "So I give them a starting point, but they're still given free-rein. The way I've created this paper, they're free to INQUIRE, almost in an unlimited series of scenarios." (Interview 2)

In his third interview, Professor Brinkley discussed his desire to integrate the "process component" into his labs, while still keeping an emphasis on the content component. Professor Brinkley's view of the instructor's role in an inquiry-based lab did not change, holding strong that the instructor is a guide for the students, leading them through the question-asking process and encouraging critical thinking throughout the lab. One new component of his beliefs about teaching the inquiry article involved critically evaluating the process of science in society, something he gained from a discussion on assessment during the SCTIL summer institute. As he completed his first inquiry article lab experience, he explained that he planned to end with an additional assignment, and considered how he might use this assignment differently in the future:

> I'm going to ask them to write a reflection on the process, and I'm looking forward to reading what they'll say. I'll do that as an anonymous assessment of learning, some kind of like extended minute paper, I'll let them go home and just reflect on it—what did they think about this whole experience, what do they think about science now, what did they think about it before, and I think in the future I'll do that before and after-'what do you think about science and the scientific process?' And then I might bring in some semi-controversial or controversial science news media reports, and hopefully look for some that have some components of the scientific method and have them critique those—what did they think about them? What I would be looking for is, can they apply the scientific process to evaluating or critiquing science news? (Interview 3)

During the 2nd interview in the fall of 2007, I asked Professor Brinkley to identify where he felt the different versions of the pond ecology inquiry article lab fit on the Inquiry Continuum (Brown et al., 2006), which was used in the SCTIL summer workshop (see Figure 4). As he marked on a printout of this figure, he explained why he felt his labs fit in those locations. He noted that the original lab was on the X and Y axis at point zero (see Figure 4, Point 1), indicating it was a teacher-directed lab with no features of inquiry. As described in the Social Norms section in his Belief Systems prior to the SCTIL program, he was working on revising the Introductory Biology laboratory manual, and therefore felt strongly that the previous versions of the labs were very teacher-directed with little inquiry. During the workshop, he made significant modifications to his first inquiry article lab. While identifying his lab on the Continuum during the 2nd interview (see Figure 4, Point 2), he explained the changes he made:

> I immediately designed it a little bit too far to the student-directed end, but I moved it up half way up the Y-axis and more than half way across the X axis DURING the workshop, and then after I met the students I moved it back a little bit to the left. (Interview 2)

Once Professor Brinkley entered the lab course and met his students, he decided to make changes to the lab design before handing out his inquiry article. When asked to identify his implemented lab on the Continuum (see Figure 4, Point 3), he responded:

> Well, because I [Pause] this was after I met with the students. I realized that, I had a mix of students that some of them were just going to get totally lost if I didn't give some remediation. That's the bottom line. And you never know at [his community college] what kind of class you're going to get, from semester to semester. Some of the sections that are notorious for getting the worst students are the ones that fill up last. And luckily I don't have any of those. So if I would've had THOSE students I would probably push much more teacher-directed just to accomplish the goals. With the honors students, my goal is to get it more and more student-directed. And of course with just one lab out of the blue for the first time, I just felt like I needed to get a little bit more teacher-directed in there. (Interview 2)

Through his instruction, Professor Brinkley was mindful of his students' needs.

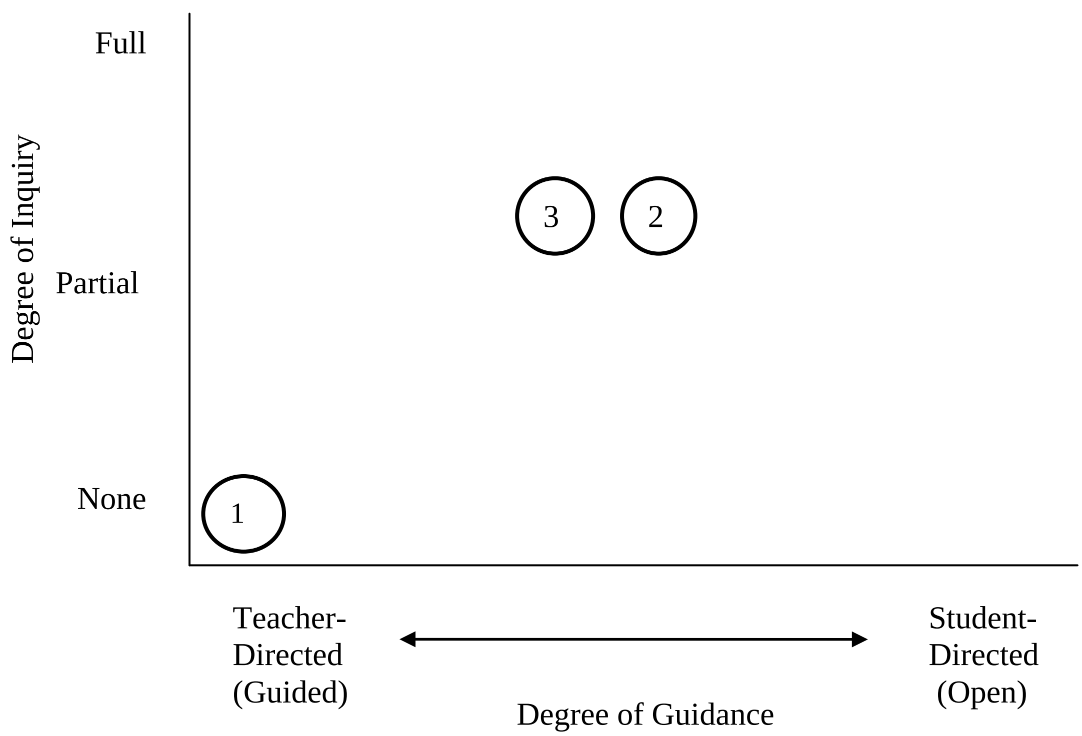


Figure 4. Professor Brinkley's Inquiry Continuum (modified from Brown et al., 2006)
1=Pre SCTIL program; 2=pre-implementation; 3=actual implementation.

Environmental Constraints

Prior to implementation, Professor Brinkley described both continuing and new types of environmental constraints that might hinder his implementation of the inquiry article lab. Continued constraints included his students' lack of learning experience with this approach. He explained:

> Just getting them out of their pre-conceived mode of learning, which is the cookbook, and 'somebody is going to give me the answers and I'm not really going to have to do much on my own,' THAT'S the biggest challenge for anything at [his community college]. (Interview 2)

He was also concerned with the students' skills in reading and writing, something he had seen to be significantly poor in his students. Two years ago the Biology department instituted a reading proficiency requirement for enrolling the Introductory Biology courses; however, he felt that the proficiency requirement was not effective as he still had many students with reading difficulties in his courses.

After his implementation, he identified new environmental constraints, the first being the lack of instructional support. Professor Brinkley did not have a teaching assistant to help with grading the inquiry article reports. While he wanted his students to complete the entire inquiry article as their products, he negotiated with them to write only the abstract, both to help the students and to limit the amount of grading. He stated, "I'd love to have them do the whole thing but I'd need to have a little more training from them in writing, and I'd need some assistance, I can't do it all on my own" (Interview 2).

Another new constraint Professor Brinkley identified was time. He stated:

> It was so different from what the students normally experience. So I think I would allow 2 weeks to integrate that adjustment. I think I tried to push them too hard this time. I personally felt pressed for time, that's why each

> week I kept having to try and come up with ways to maximize the time that I did have. (Interview 3)

Additionally, there were limited supplies available for the students to use in their investigations. Professor Brinkley responded to these requests by sharing a story with the students about how he adapted to this problem during his own research investigations:

> I've told them stories about how I needed buckets and didn't have any money, so I went to local groceries stores and asked them for their discarded icing buckets from their bakery. So after discussing how I scavenged items, when they were implementing their experiment they kept coming and asking me for equipment I said, 'Well look around the room, see what you can scavenge. This is the real world, we don't have funds for certain things so, but we do have resources all around.' (Interview 3)

Overall, Professor Brinkley's perceived constraints after implementing his inquiry article lab included time and supplies, however, he did not seem overwhelmed by these constraints. He focused on how he would address these constraints and modeled ways to adapt for his students.

Self-Efficacy

Professor Brinkley's efficacy towards teaching with this inquiry-based approach remained unchanged. Similar to his efficacy during his first interview, he again referenced the importance of his role as a scientist in contributing to his success in his instruction: "I've had decades of experience in the lab…I'm a scientist. I live and breathe science" (Interview 3). After his first implementation, he continued to feel highly confident in his teaching of the inquiry article lab.

Attitude

Professor Brinkley's attitude towards the SCTIL inquiry article format remained very positive following the institute and after implementation of the lab. "So the SCTIL format to me, I feel like I've assimilated it, and I like it, and it feels like it was a missing piece for me to be able to design inquiry-based labs" (Interview 3).

Following the workshop, but before implementing his lab, Professor Brinkley's attitude towards implementing the inquiry article was positive, yet somewhat hesitant. He was excited to see his students conduct scientific investigations, which he noted would probably be their first time doing that sort of activity; however, he also discussed his concern with the limitations of this group of students and how that would affect the success of the lab's implementation:

> A community college course of non-majors, typically freshman, straight out of high-school, and from a high school district that frankly does not retain teachers and does not have a high reputation. So we had to institute a reading proficiency a couple of years ago, and I still think they slip through the cracks. So I'm really concerned about the reading and writing aspect of it. (Interview 2)

Following his implementation of the lab, Professor Brinkley's previous concerns about the students' background and limitations were no longer present. He was comfortable and confident with how they responded to the activity, and was pleased with the outcome. "Well first off, I'm totally psyched after watching their performance . . . it was just beyond my expectations" (Interview 3). The students' responses to his implementation contributed to his ongoing positive attitude toward the inquiry article format.

Knowledge and Motivation

Following the summer institute, Professor Brinkley discussed what he learned about the SCTIL format. Learning about the essential features of inquiry and the importance of collaborative learning allowed him to rethink his approach to his own inquiry-based instruction. He also gained new knowledge about student-directed learning through the inquiry continuum. Professor Brinkley's motivation for participating in SCTIL remained strong in regard to producing publications as a product of his experience. Initially he was interested in general publications and conference presentations. After implementing the lab, Professor Brinkley articulated specific avenues of sharing what he learned through the SCTIL program:

> So, I am ALL about dissemination. And I have tremendous amounts of energy, so I'm looking at taking this to [the community college], to all [neighboring community colleges], to the larger community college nationwide eventually, and conferences, and actual publications and promotion of students in connections locally between universities and colleges, between [a local research university] and a few others, and then internationally. (Interview 3)

Part of his motivation for participating in SCTIL was to be able to publish his teaching ideas. After the workshop, this motivation only increased and he saw additional avenues for sharing his work. Not only was Professor Brinkley motivated to publish for his peers' benefit, but he also wanted to provide students with the experience of writing for publication as a way of modeling the process of science. He stated:

> So it's not only authentically-done science, it actually IS science, it's published. Can you imagine the pride on the students' parts, participating, and I can do that in such a way that we publish in a third-tiered journal, doing simple experiments like cafeteria experiments! (Interview 3)

Therefore, prior to the workshop, the possibility of publishing was a strong motivator. After the workshop, Professor Brinkley's interest became more directed to benefit both his students and his peers.

Environmental Responses

Overall, Professor Brinkley's perception of the students' response was positive. After implementing the duckweed lab, he discussed how much change he saw in his students through the inquiry article activity, as they moved away from the expectation that easy answers are given out. He anticipated that they would have difficulty in using this type of learning approach and explained how he responded to his students' needs:

> My response was rubrics, so that they would know exactly what was expected. And, I told them, the more they vocalize with me the more I can contextualize and modify it, but if they don't talk, I won't know to do that. So, they communicated, oh yeah they communicated [laughing sarcastically]. (Interview 3)

Once Professor Brinkley made clear his expectations and the students experienced this new type of learning approach, their response changed dramatically. He described their change in the following statement:

> They were at ease, and alert, and on task, and I didn't really have to DO a lot, they were pretty much doing it on their own. Which I had ENCOURAGED them from day one, and they have done beautifully. I wish you could have seen their growth. You know, from just FREAKED out, 'OH MY GOD, I'VE GOT TO DO WHAT? NO COOKBOOK?' And then to just go with it, and feel comfortable with it, and how they're handling the different data, I loved how they were discussing it with each other and coming up with ideas about how to deal with it. And then they learned that science is not clear cut answers all the time . . . but just WATCHING them over the last several weeks, and listening to their comments, especially overhearing their comments as they're talking without knowing I'm there [Pause] this seems more meaningful to them, because they're doing it. It seems more exciting to them. Because I'm sensing that they're seeing the broader picture.

Professor Brinkley also noted that his students' responses were reaching other faculty members on campus. This was encouraging to him because of the response from the faculty members as well. He noted:

> I think that [the students are] more comfortable with science in general. Especially, well they're obviously talking about it because I've had students NOT in this class coming and asking to do this experiment, as an honors project. The other faculty are referring students and they know about it, so the grapevine has spread. (Interview 3)

Environmental responses played an important role in Professor Brinkley's belief system, contributing to his positive attitude and encouraging him in his future plans for implementation, as discussed in the next section.

Change in Instructional Practice

Professor Brinkley's self-reported plans for changing his instructional practice within his laboratory courses were significant. His main focus at the end of the SCTIL program was to make a systemic change in how he organized his introductory biology course. "My GOAL is to have this implemented across the board in Intro" (Interview 2). While he described his first inquiry article implementation as "a pilot study, just to try it out and see what happens" (Interview 2), he saw its relevance to what he values about learning in the lab courses and also to his own research interests. "It's authentic, and I'm interested because I'm going to guide them into areas that I want to know" (Interview 2). In his self-reported teaching practice prior to the program, he expressed a deep belief that authenticity and applicability/relevance were most important to him in his teaching. The inquiry article provided him a strategy to build in these pieces within a context of his own research area, which was highly motivating to him.

One outcome of this experience was Professor Brinkley's plans for creating an honors course strictly organized by inquiry article labs:

> On my own, next year, I'm going to write an honors lab manual, all SCTIL format, essentially. And then, once that's conquered, and I have evidence that I can show the dean, and the chairman that that's successful, I'll design one to be implemented in the regular non-honors section . . . and this is all for non-majors. (Interview 3)

The honors course would be his first course-wide implementation of the inquiry article approach. During his teaching of the non-honors course, he plans to slowly work in more inquiry article labs, but not converting it entirely to the SCTIL format. For this group of students, he reiterated his goal of developing scientifically literate individuals participating in a collaborative learning environment:

> The major goal is, competently trained citizens that can discern and critique scientific news stories and possibly even scientific literature. You know I'm not holding on to, that these students are going to get all excited like I am about scientific literature, but if they can be more informed citizens in terms of what science is about and how it operates and how to interpret media news stories about science-related material, that is an auspicious goal. And then, of course, to get them familiar and comfortable and INTERESTED in science, with the content matter of each of the labs, cause that also occurs. And, those are equally important goals. I think without the first one though, you don't really retain the second. If you don't really understand or care about science, you're going to want to slip away. (Interview 2)

Professor Brinkley was eager to add more inquiry article labs in his non-honors Intro Biology course; however, he expressed a concern with covering the same material required for the course and also wanting his students to conduct an authentic investigation. This balance was something he struggled with in developing his first inquiry article lab. He explained the situation in the following statement:

> So I couldn't just scrap the whole thing and just do this, I had to [Pause] so they have to still get the cell, they have to look at cell models, animal and plant, and look at plant cells under the microscope. That is an entire lab. Well I've never needed the entire lab to do that. I wouldn't even have that as a lab. It's all covered in lecture, explicitly. So you know, I relegate that as the sideline, but I still cover it. And, so I'm going to mention, 'you need to look at this animal cell model and this plant cell model and I want you to know these organelles, just like they're mentioned in your textbook,' so I'm going to give 20 minutes to do that. And then they need to look under the microscopes themselves, so I give them about 10 minutes to do that. And then for the remaining time, they're going to recap their experiment to everybody on video, and they're going to do their final counts and calculations and interpretations, and give a final concluding comment on their conclusions. (Interview 2)

Therefore, he resolved to balance his previously designed labs with the new inquiry article approach by doing a little of both within his lab course. In thinking about his use of assessment, he noted:

> I WILL keep these things call pre-lab questions, and they're kind of like pre-tests, and the way I use them is as a pre-test and a post-test. So I might keep those, and that's the content type of thing. But I'm going to move it more into integrating the PROCESS component. And keep that content component. (Interview 3)

Overall, the changes Professor Brinkley discussed in terms of his instructional practice would impact multiple courses through his use of the inquiry article approach.

Summary of Change in Professor Brinkley's Belief System

Coming into the SCTIL program with strongly-held beliefs and a positive attitude towards inquiry-based instruction, Professor Brinkley experienced few changes to his belief system about inquiry-based teaching. After experiencing the program and implementing his lab, his students first responded with difficulties in basic reading/writing skills and an attitude that preferred cookbook learning; however, Professor Brinkley supported the students by modifying his instruction and expectations during the implementation of the inquiry article. By the end of their inquiry article experience, Professor Brinkley felt that the students enjoyed it and were successful. Their response fed back into his belief system resulting in no major change to his self-efficacy and strengthening his positive attitude. His beliefs about teaching and learning were expanded to include a deeper understanding of classroom inquiry. His motivations changed to include more widespread dissemination after seeing its success, and he developed plans to use this format more in his future instructional practice. Overall, Professor Brinkley's positive attitude and strong motivation towards learning and implementing the SCTIL inquiry article format contributed to changes to his instructional practice with plans for future implementations in multiple courses.

Case #2: Professor Garrett

Professor Garrett's case is presented in four sections. First, I introduce her by describing her current faculty position, her teaching experience, and her self-reported teaching practice. In the second section, I describe her belief system about inquiry-based teaching prior to participating in the SCTIL program. The third section focuses on Professor Garrett’s written inquiry article lab and her plans for implementation. I show how this written document and her plans for implementation changed between its first draft, written during the SCTIL summer institute, and the final draft, implemented during her course in the Spring of 2008. In the final section, I describe the evidence-based changes in Professor Garrett’s belief system about inquiry-based teaching.

Context of Professor Garrett

Professor Garrett’s teaching experience, current faculty position, and teaching practice played an important role in influencing her experience in the SCTIL program.

Faculty Position and Teaching Background

During the fall of 2007, Professor Garrett began her third year teaching science courses in the Biology department of a small liberal arts college. She typically taught five courses a semester (12 credit hours) which included both lecture and lab science courses. Professor Garrett’s background was quite different from the other participants in this study. After receiving her PhD in Reproductive Physiology/Endocrinology in 1981, Professor Garrett completed several post-doc positions before accepting a position as a director of a clinical fertility program. She described her primary role as administrative, “so things like consents, patient information, legal issues, ethical issues, IRB interface, fiscal management, personnel management, technical training, bring the science from again in sort of the [Pause] make the science to practice, as well as hands-on to the web" (Interview 1). In 2002, she changed careers and started a part-time position as a director of a research clinic at a large research university. During this time, she mentored graduate students in her laboratory on how to conduct scientific research. In 2004, she began teaching courses as an adjunct instructor and developed a passion for teaching. She decided to become a full-time college teacher in 2005, accepting her current faculty position as an Assistant Professor. She also continued to work part-time in the research clinic.

She entered her first faculty position with little classroom teaching experience. During her graduate program, she taught a small number of lecture/lab sessions every semester. She explained:

> In the lecture component it would often be either covering lectures when the instructor was out of town traveling, and then leading small group discussion, problem sets, things of that nature. For the lab we were pretty much responsible for, "Figure it out, set it up, execute it, do it, whatever." You may or may not have had the instructor at the labs. . . . Both of these classes tended to be moderate size classes, maybe 40 or 50 students, so pretty traditionally just chalkboard-style lecture—long before the days of PowerPoint. You know, I've led workshops, but I've never had formal training in teaching education. (Interview 1)

Therefore, in her current teaching position, she had little classroom teaching experience to draw from; however, she did use her many years of experience in an authentic, apprenticeship-style laboratory environment to develop and teach her science courses. During the 2007-2008 school year, she taught Cell Biology (lecture and lab), Molecular Technology (lecture and lab), and a Research Design course. She had taught all three courses once before, either as an adjunct or during her first 2 years as a faculty member.

Self-reported Teaching Practice Prior to PD

Professor Garrett designed her courses based on a master syllabus developed by her institution, which included a core scope of content for a given class. She also referred to professional organizations in her field for their perspective on core concepts for student learning. Once she established what concepts she wanted to teach in her course, she selected a corresponding textbook and considered the use of primary literature in the course readings. She explained this process in the following statement:

> I try to find a textbook that I think fits those objectives, that scope, and once I pick a textbook, depending on the class, I try to make sure, at a minimum, I follow sort of the sequence that the text presents. I may or may not cover all of the content, but I try to keep at least in that sequence, because I find that students really struggle if you're jumping around . . . even if I skip sections at least it's more or less in order. And depending on the level of the class, I try to bring primary literature in to supplement whatever it is we're talking about. So some units I may draw more heavily from the text, some I may draw more from literature. In advanced electives, we probably do both as we go through the book—incorporate literature for each and every section. (Interview 1)

In describing her typical lecture format, she noted that she "changes her teaching every semester," but focused on a biochemistry course she taught the previous semester as an example of her typical approach (Interview 1). The biochemistry lecture sessions were 50 minutes in length. She explained what she did within a 50-minute timeframe in the following statement:

> We might start off with very traditionally, "Okay this is what we were talking about last period, you know, anybody have questions about where we were at, anybody have questions about problems you were asked to work on?" Then depending on what kind of response that you get, you may spend zero time on that, and then you might spend a few minutes. And then I try to outline, here are the four or five main things we want to get through today, the concepts that we're covering. And I don't use in class clickers but I may talk for five or ten minutes and then we'll just throw up a question. "Okay so what do you think about this? How do you [Pause] what do you see going on here? How would you go about

> answering this question? What are the key things?" Even though it's lecture format, we try to incorporate at least some stop and think about it. Try to think about, how does this relate to what we were previously talking about, maybe how does it relate to some other class they might have had? Try to constantly get them to build connections. (Interview 1)

Professor Garrett also talked about her use of cases in her course, a strategy she used a few times during the semester to develop the students' problem-solving skills. She described how she guided the students through these activities:

> And maybe one out of every five or six classes in biochemistry we would do these little mini cases where they would have the case ahead of time to look at, so we would do an applied problem that may require them to work through a series of questions to get to the overall solution, if you will. And on those days we'll start real briefly as a whole class, "Okay so what's the major thrust of this case?" Then we might break up into small groups, and we might spend 15 minutes in one grouping working through a certain number of questions. We'll take a break and we'll just ask okay, does everybody kind of have those under their belt, so to speak. And meanwhile I float, so if everybody is stuck, then we'll stop and talk about, "Well what is it everybody's stuck with?" And then we'll switch groups around and work through the rest of the case. And we'll do that for about 30 minutes, maybe 35, and then we'll come back together as a class and talk through, just go around and ask different people, "So what did you guys come up with for this, what was your thinking, why did you say that," blah blah blah. If anybody has something different, we try to pull it together and then bring those through. So, I mean we have a lot of traditional lecture, but trying to mix it up a little bit. (Interview 1)

Thus, in Professor Garrett's typical lecture class, she primarily taught using a traditional lecture approach with cases inserted a few times throughout the semester. Within the case work, she guided them through problem-solving exercises, valued collaborative learning environments, and was sensitive to the students' pace of learning, willing to slow the pace of the class if needed.

In discussing her typical laboratory course, Professor Garrett focused on the same biochemistry course. The lab portion of this course met twice a week for three hours each. She explained that her goals in lab were to “try to incorporate, in any given lab, certain core skills” (Interview 1). She elaborated in the following statement:

> These skills might be as simple as making reagents or making dilutions or working with a new piece of equipment or just, you know, building some of the technical hands-on, as well as maybe some of the concepts that we’ve talked about in class or some of the methodologies that might be germane in that discipline, with an emphasis on using data, interpreting data, and problem solving. (Interview 1)

She tended to use the lab manual to sequence her labs for the course, but stayed away from strictly worksheet exercises in which students write the correct answers. Her students were used to the fill-in-the-blank approach to completing lab reports. She noted, “I don’t like that—I actually want them to do things in class at the bench, which I’m discovering is not typical of their experience, so that’s been a learning process for me, to see where they’re at” (Interview 1). She taught her students a more authentic approach to conducting a lab experiment. Professor Garrett explained:

> What I’d like to see them do is be able to run their labs more in a manner analogous to how science gets done, obviously on a simplified scale, because you know, and I need to investigate this, but that they have more of an approach towards using the lab to not only understand the concepts but to develop broader skills--problem-solving skills, critical thinking skills, teamwork skills, use the computer, be able to interpret data, translate something that you read into what you do. To me that applies to a LOT of things no matter what you decide to do with your degree. (Interview 1)

Based on these beliefs, Professor Garrett organized her course lab sessions to build her students’ skills in these areas. She tried to guide her students as much as possible, requiring a book for the lab course called, *A Student Handbook for Writing in Biology* (Knisely, 2004), which included a checklist to ensure that students include all the sections of a scientific report—abstract, introduction, methods, results, discussion, and conclusions. She used this book as a basis for her course activities and referenced it for all science writing products in her courses.

In describing her use of assessment across both lecture and lab courses, she described a connection between these beliefs and her practice. She assessed her students through the use of cases, as well as essay exams and quizzes. In her case assessments, she would give students a couple of pre-case questions to answer and submit individually, then they would work in their small groups to go through the cases. Following class discussion of their work, they had a few days to respond individually to questions about the case and submit their responses. Professor Garrett used student pre-case and post-case responses to assess their integrated understanding of the topic. She noted:

> At the end of it, what I'm looking for is, were they able to integrate multiple points of the class that came up in their response. So they didn't have to, you know, necessarily just GET it from the get go. But when they heard it and it was discussed, could they then talk it back to me in some sort of integrated way. And so usually what I'm looking for is did they expand on what they brought in. (Interview 1)

Professor Garrett's self-reported teaching practices included an emphasis on lecture, teacher-guided cases, and using scientific writing as assessments.

Nature of Belief System about Inquiry-based Teaching Prior to PD

In the following sections, I describe Professor Garrett's belief system about inquiry-based teaching prior to the SCTIL professional development program.

Beliefs

Science as inquiry. Professor Garrett's view of inquiry was limited prior to her participation in the SCTIL program. She defined inquiry as "simply asking questions and developing strategies to answer questions" (Interview 1). When asked to elaborate, she stated, "I don't know that I've thought about it more critically than that" (Interview 1).

Student learning in science. Professor Garrett felt that students learned science best through problem-solving and applying their knowledge to a different context. She explained:

> It's a more active process, rather than "I told you this, you tell it back to me." Okay fine, but reality is that five years from now, the content of science may change. The content of science changes a lot. So you know, I think they're better off saying, "Well what's the question we're trying to answer . . . what do we KNOW that helps us look at that issue, where are the possible flaws in that. Okay what's sort of the current thinking, where's the gaps, connect the pieces." (Interview 1)

While she expressed the belief that students learn science by application and problem-solving, she also believed memorization was necessary to learn basic science vocabulary. She believed that understanding the basic level of knowledge in terminology and underlying concepts allowed students to build on that knowledge with more difficult concepts.

Professor Garrett described a tension that existed between her expectation for her students' learning and their desire to have more concrete expectations for the course content. She stated:

> I don't think you learn if all you do is, I tell you, you repeat it back. When we're learning metabolism, what I really want to see is what all the interrelations are, how things are connected. Yeah, we're going to talk about some details, but the big picture, I mean make sure you know the big picture before you get bogged down with details. And they're still struggling with this idea of "where's my study guide, tell me what I need to know." And I'm trying not to teach that way. (Interview 1)

This tension between her expectations and the students' expectations was a source of frustration in Professor Garrett's view of effective teaching and learning. She wanted to challenge her students by requiring an application level of understanding, yet be successful in her teaching practice and work collaboratively with her students to make their learning experience meaningful.

Inquiry-based teaching. Professor Garrett's belief that inquiry meant "asking questions" informed her description of inquiry-based teaching, which she felt involved looking for answers to those questions. She noted that most science lab courses involved the demonstration of a concept. For example, "Do this and you'll see what it looks like to transform stuff" (Interview 1). This was a frustration for her; she felt that labs should be much more than just demonstrating, but rather should focus on getting the students involved in making observations, interpretations, explanations, allowing the students to develop more ownership in the process. She explained, "In my view, inquiry is a little bit closer to how science gets done . . . it's very active . . . and most importantly you have to report what you find" (Interview 1). When she first began her faculty position, she asked her students to write a lab report, assuming they had written lab reports in other science courses. She responded to the students' first products in the following statement:

> I was flabbergasted! They turned in MOSTLY procedure, most of which I could have done without. Very little concept of what constituted the introduction, very little concept of how to organize themselves, many of them not comfortable with how to present data. They wanted to give me, traditionally, ALL of the raw data rather than what's the summary tool that presents the picture of the message that you're trying to get that day. They just hadn't done it! They hadn't experienced it, to have a clue. And for the most part, I found myself giving them all back and saying, "Okay let's start over. Let's talk about what we're trying to do here, why a lab report is very similar to how scientists communicate in terms of journal articles. What are the parallels?" (Interview 1)

Professor Garrett was adamant that her students understand the process of science and conduct investigations that reflect what happens in an authentic science laboratory. She had difficulty identifying what her role was in an inquiry-based teaching environment, noting that it was important for her to guide students in thinking about their next question. She also explained that this approach allowed her to evaluate her students' basic skill level and guide them in improving those skills. Overall, her value of scientific inquiry was reflected in her belief that inquiry-based teaching and learning required authentic investigations in which students took ownership of their learning.

Social Norms

Professor Garrett's biology department consisted of four professors who were relatively inexperienced teachers. Historically, her department experienced frequent turnover; however, she felt that the current faculty group would stay at this institution longer. She described her university as "a teaching institution, so teaching is a major commitment across the spectrum" (Interview 1). Her colleagues in the biology department often conducted peer reviews of each others' classroom teaching. The typical lab teaching approach included the use of cookbook labs. While she used the university's master syllabus to guide her course content, she was given leniency in how she designed and implemented her course.

Research was not a significant part of her department, although she wanted it to play a larger role in the students' college experience. Professors involved in research tended to collaborate with colleagues at a neighboring research university. She noted:

> I would like to see a bit more that is research-oriented, that we have the appropriate infrastructure to allow our STUDENTS to engage in independent research, especially for those students that want to go to grad school or professional school, and right now that's something that's not part of the environment. (Interview 1)

The social norms of Professor Garrett's department included a strong emphasis on teaching, a traditional approach to teaching labs using the cookbook approach, and little support for faculty and student research.

Environmental Constraints

In anticipating possible environmental constraints in implementing the SCTIL inquiry article lab approach, Professor Garrett focused on her lack of space in the laboratory classroom, her limited resources, and her students' negative attitude towards laboratory learning. In discussing the lack of space, she explained:

> I think in the lab environment, there are probably several issues. One is the facilities issue, which does not have a short-term solution. Space, how many students are in the lab, what's the right size lab for one person to work with small groups, you know, the ratio to make that effective. (Interview 1)

Having implemented small group work before, she expected that space would be a constraint. She also identified that the numbers of students in each small group would contribute to their success with the lab, fewer being better. Her typical lab course held about 20-30 students; however, the laboratory space was best suited for 10-15 students.

Professor Garrett also discussed the nature of her classroom environment and other limitations that might surface. She stated, "The nature of the equipment and the resources that you have limits the kinds of experiments you can do or the kinds of things you can do, so a lot of times students will come up with stuff that might be a great idea but YOU can't do it" (Interview 1). In discussing these limitations, Professor Garrett did not seem intimidated by them, but rather expectant of such issues based on prior experiences. She expressed a desire to have more resources available, yet a willingness to work with students based on the available resources.

Professor Garrett identified her biggest potential constraint as her students' views that laboratory work is not valuable for their future careers. She stated:

> Most of my students do not see themselves as pursuing careers that involve lab work. And so many times they'll say to me, "Why do we have to take this lab? I'm just not interested in lab work." So that is sometimes a barrier and trying to figure out how to shift their mindset. I think what they see from the lab is, "What do I have to do to get through this lab class, to get a decent grade? Tell me what I need to do and I'll do it." They don't see it as connected to where they're headed in terms of a career. They don't see the value in it. (Interview 1)

In summary, Professor Garrett identified space, resources, and her students' lack of interest in lab work as potential constraints; however, she was optimistic she could overcome these constraints.

Self-Efficacy

Professor Garrett's efficacy for implementing the SCTIL inquiry article format was at a moderate level. She expressed a negative feeling in identifying herself as an expert in inquiry-based teaching, or any kind of teaching. She felt she was continually trying to improve her teaching. She wanted to move away from the type of teaching she experienced as a student, and move toward a more effective teaching style based on her clinical mentorship experience. She explained:

> I grew up in a classroom that was intensively chalk talk driven. You recalled it. And then, if you go on, you go into graduate school and then you think, "Well wait a minute, that didn't help me at all, it's way more complicated than that." I think my traditional background has been focused on content, remembering content. On the other hand, I was fortunate enough that the exam formats were application and understanding, so when I took Biochemistry it wouldn't be uncommon to have oral exams. And I think I have the tendency to sort of go back to what you know, so I have a tendency to deliver a content-intensive instruction. So I'm working on that. . . . I'm trying to understand the diversity of my students, and try to make sure that I have a diverse enough approach to presenting information so each of them can find a way to grapple with it. So THAT'S what I'm struggling with, how to deliver a

> certain amount of content, how to use a diverse array of approaching that content so different students have access to that…and then how to pull something that's integrative into the curriculum so it's not just, "I read the book, I answered the questions, I passed the exams." (Interview 1)

She expressed a level of confidence in her teaching that she developed in the clinical research lab setting. During that experience, she trained individuals to "be able to perform things in an efficient and effective way, using many different teaching strategies to help different people learn--when its hands-on, you have a very immediate feedback on whether they get it or they don't get it" (Interview 1).

Overall, Professor Garrett's self-efficacy was at a moderate level, influenced by a lack of quality teaching models and her positive experience in mentoring students in her clinical research experience.

Attitude

Before the SCTIL workshop, Professor Garrett's attitude towards learning and implementing the inquiry article format was somewhat positive. She felt the inquiry article format would be invaluable for her students in learning how to be lifelong learners, and expressed her feeling in the following statement:

> [Inquiry-based learning] is more active, and it's more interactive. And I think the longer-term learning value comes when it's more active. And getting students off this passive thing, and engaging them in the material more. I think they will overall learn more, whether they can answer more multiple choice questions at a given time, I don't know, but to me that's not the value of learning. So, if you think about it as a lifelong activity, it's really something you'll have to do the rest of your life. So if you get comfortable with this process of inquiry, I think you better position your students to be lifelong learners. To learn how to learn, so that they can now learn independently and not rely on you to tell them what they're supposed to know. (Interview 1)

While she looked forward to the SCTIL program, she expressed apprehension about the workshop. She stated, "People who have been teaching for many years are participating--that's somewhat intimidating. And in this experience, we're really the students, kind of swapping roles and seeing the other side" (Interview 1).

Overall, Professor Garrett's positive attitude contributed to her belief that the SCTIL program would lead to a quality learning experience for her students.

Knowledge and Motivation

Coming in to the SCTIL program Professor Garrett had no knowledge of the inquiry article format. She knew the workshop would use an inquiry-based approach and she was interested in expanding her understanding of effective college science teaching. When asked why she decided to join the SCTIL program, Professor Garrett responded:

> Well, because I personally think the idea of an inquiry-based approach to labs is much more dynamic, interesting, hopefully gets students more excited and enthused about a lab experience, helps them learn better, and hopefully makes it more fun—I mean labs should be fun, even when you're trying not to, you've probably learned something. And since my background is not education, anything that you can learn about how to do a better job about teaching ought to be pursued. (Interview 1)

Professor Garrett chose to participate in the program to gain the pedagogical knowledge and skills needed to effectively implement an inquiry approach in her classes.

SCTIL Inquiry Article

At the end of the first day of the SCTIL summer institute, participants were asked to apply what they learned about inquiry and the inquiry article format to convert one of their labs into that format. They submitted this first draft to the SCTIL staff members for feedback. In this section, I compare Professor Garrett's first draft of her converted lab with the final version she implemented in her lab course. Between these points in time, Professor Garrett made several modifications based on feedback from SCTIL staff members and colleagues and her impression of her current students. I present how the design of the two versions of the inquiry article lab differed, as well as what modifications she made during implementation of the lab.

First Version of Inquiry Article

Professor Garrett entered the SCTIL program with an idea for a lab, rather than a previously implemented lab. She converted that idea for a lab into the inquiry article format. Her idea for her first SCTIL inquiry-based lab focused on the cell cycle and would be used in a Genetics course for science majors (predominantly forensic science majors) (See Appendix E for Inquiry Article version 1). The title of the lab was, "The Effect of Colchicine on the Cell Cycle." In the following excerpt from her first draft, she explained the purpose and hypothesis for the experiment, as well as how the data would be used in future research:

> The purpose of this experiment is to examine the effect of colchicine on the cell cycle of an Allium [onion] root. We hypothesize that colchicine will disrupt the cell cycle as previously observed in vertebrate cells. These data would then provide the basis for further development of a plant model system to characterize factors affecting the cell cycle. (Inquiry Article version 1, Professor Garrett)

The design of Professor Garrett's inquiry article included all of the components suggested by the SCTIL staff (abstract, introduction, methods, results, discussion, follow-up questions, and references). Her follow-up questions focused on assessing students' knowledge based on the investigation reported in the inquiry article and encouraging them to think further about possible influencing factors and rationales. The following excerpt provides examples of Professor Garrett's follow-up questions:

- Do the data presented support the conclusions drawn by these authors? Why or why not?
- Where in the cell cycle is disruption most likely occurring? How did you make this determination? What are the unique features of this stage of the cell cycle?

- Is it likely that colchicine impacts animal cells in a similar manner as seen with onion meristem? What elements of the cell cycle are similar or different between plant and animal cells? Do you think other plant tissue would respond in a similar manner? Why or why not?
- What other factors could have influenced the author's results?
- What is colchicine (structure/ class of compound)? What other common compounds are similar to colchicines?
- What additional information would you need to effectively repeat this experiment?

Prior to her participation in the SCTIL program, I asked Professor Garrett to verbalize her goals for using the modified inquiry-based lab. Her response included goals for her own instructional planning, as well as for her students' learning. She stated:

> So I'm hoping to maybe do fewer things with a greater emphasis on the connectivity, and asking questions that get them thinking about what we're doing, and incorporating that into the interpretations and conclusions and the next set of questions. Maybe get away from this idea that we have 15 weeks, and therefore we have 15 lab modules. And think about, okay are there are some core things you want to expose your students to, so you have to ground them in some basics and maybe you can do three sets of inquiry-based labs across seven, eight, or nine weeks and that's okay! Get away from the, how much do we do—lose the scope, increase the depth. So that's probably the MAJOR goal that I have. And then to see how that works with students, what kind of feedback I get from them, do they feel like, "Well we didn't cover enough and now I have to go take the MCAT and I don't know enough," or do they feel like they were better able to work with the material. (Interview 1)

In writing the learning goals in her first version of the inquiry article lab, Professor Garrett focused on content goals (i.e., distinguishing cell cycle stages, understanding the difference between animal and plant cells), skill development (i.e., use of a microscope, graphing in Excel), and general learning goals (i.e., integrating information across disciplines).

In summary, Professor Garrett focused her first version of her inquiry article lab on developing students' depth of knowledge in cell biology, teaching them basic skills in the lab, and creating a long-term approach for completing the lab over several weeks.

She did not focus on who would be taking ownership of the learning experience in her first draft or to what degree she would guide the students.

Final Version of Inquiry Article

Professor Garrett implemented her SCTIL inquiry article lab with 20 science majors in her Genetics course. The implemented version of her inquiry article was identical to her first draft, with the exception of one added follow-up question that encouraged students to think about applying the investigation to different chemicals: “Would this model be useful in studying other types of chemicals? Why or why not?” (See Appendix E, Inquiry Article version 2). She noted that after the summer workshop, she considered developing a different version of her inquiry article to implement in her class, saying that the one she developed during the workshop was “pretty straight forward and dry,” and she wanted to “make it more creative” (Interview 2). She was dissatisfied with its open-endedness, explaining that she felt it should have been more focused for the students, providing them with “more leading issues like maybe sample size is inadequate, or what statistics need to be more rigorous” (Interview 2). In assessing her first version of the inquiry article lab, she expressed a sense of relinquishing what she really wanted to accomplish for the sake of time. Due to her heavy teaching load, Professor Garrett did not think she would have the hours she would need to modify the inquiry article before teaching it.

As Professor Garrett discussed her plans for implementation during Interview 2, she thought the entire lab implementation would take three weeks (two lab session per week) to complete. In the following statement, she described her plan for how the implementation would begin:

> The concept that I have in mind is to first introduce the idea of understanding mitosis as a core knowledge, so that's a focus on the lab the first class, and then, they'll already be in groups by then because we'll have already had a lab the previous week, and I'll ask them to simply read this small paper, and I had crafted some questions that I'm either going to give it to them ahead of time or I'm going to wait until they've read it and then give it to them. I don't quite know, but that kind of will HOPEFULLY cause them to have some conversation amongst themselves, and allow them some time to do that. And then maybe stop the group and back up a little bit, and say, "Well, let's just see what kinds of things as a class we've come up with, and go BACK to some of these questions. Well, what did you think the purpose of this study was? Does anybody have some different ideas about that? How did you come to that conclusion? What is it in this paper that helped you deduce that that's the purpose?" And then some of the more straight-forward questions like, "HOW did the authors go about doing this? Do you think you could repeat this work? If so, why, if not, what else do you think you would need in order to be able to repeat what these people have done?" You know, just getting them to think about some of the taskier [*sic*] sides of executing something, just to see where they're at in their thinking. (Interview 2)

Next, Professor Garrett explained how she would guide the students in thinking about their own investigations after they read her inquiry article:

> Then talk about, "When you've read this paper what other questions came to mind? What other questions did YOU think of when you finished reading it?" Brainstorm and put those on the board, and then try to think, using this as a springboard. "I want you to think about designing an experiment to explore a question you're interested in" and really the main focus that I'm going to ask them to do is, it has to have something to do with mitosis. Beyond that, it's pretty wide open. We have limited things available to them, but I have different seed types, they can grow things in water or soil, and then I have a bunch of different chemicals that they might look at, so instead of working with just colchicine, I also have caffeine and other chemicals. (Interview 2)

She discussed her plans for implementing the lab, but stopped short of explaining her expected outcome. From that point, she stated, "We'll see where that goes in terms of actually implementing and carrying it out" (Interview 2).

Professor Garrett's actual implementation was similar to her initial plans with a few minor modifications. Her original plan of a 3-week implementation period was extended to four weeks to allow students more time to carry out their experiments. The students needed an extra week to "allow time for their treatments, exposure of their cells to whatever, harvest their roots, do their squashes, read their slides" (Interview 3). Professor Garrett also included a feedback component that she had not initially planned. After the students developed their ideas for an investigation, they submitted their proposed research questions to her for feedback and then met with their small groups for any necessary revisions prior to beginning their investigations. To guide the students in writing their individual lab reports, she used the Knisely (2004) book. The outline suggested in this book aligned with the components of a SCTIL inquiry article lab, allowing Professor Garrett to continue using the book as a supportive guide for students in writing their inquiry article papers.

As she reflected on her implementation of this cell cycle inquiry article lab, Professor Garrett noted that in future implementations she would take into consideration the amount of technical skill required to complete the lab, either better preparing the students or requiring more adequate training for students enrolled in the course.

Change in Belief System about Inquiry-based Teaching

In the following sections, I will describe the changes, if any, in Professor Garrett's belief system about inquiry-based teaching after implementing her first inquiry article lab.

Beliefs

Science as inquiry. After experiencing the SCTIL summer workshop, Professor Garrett maintained her belief that scientific inquiry was asking and answering questions; however, she developed a deeper understanding of what inquiry would look like in her classroom. She described her view in the following statement:

> So conceptually, what I'm trying to get them to do is see science as something active, and to get comfortable with this idea of how questions can be solved and answered and how we can use this process to go from a question to potential information that may help answer the question, and get them away from 'here's what to do, step 1 step 2 step 3 step 4,' because this is what they're used to. They will have step 1, 2, 3 and 4, it's there but they might not recognize it. And I have other resources that I can provide them with, but in some ways I want them to say, 'Well, gee I get this but I'm not quite sure how to DO it.' And I want to be able to say, 'Well what do you NEED to KNOW to be able to do it?' Try to get them to ask the question and think about how to find the answer to the question. Maybe that's what I mean by inquiry. That I haven't TOLD them how to solve the question, how to get the answer, I've allowed them to ask the question and get them to think about how to get to the answer of the question [laughing]. (Interview 2)

Following the summer institute, Professor Garrett expressed a belief that classroom inquiry included the possibility of a more student-directed approach rather than strictly teacher-directed. Following her implementation of her first SCTIL inquiry article, this view remained.

Student learning in science. After implementing her first inquiry article, Professor Garrett's beliefs about science learning changed. Her focus on learning through application and problem-solving was expanded by the end of her implementation, at which point she discussed the importance of having basic skills and knowledge of the methods prior to conducting a problem-solving investigation. She also explained why application was an important part of students' science learning, being most like how science is done by actual scientists. In her final interview, she stated:

> I don't really see labs for teaching content, as much as I see labs for teaching the idea of how science works. That's my personal bias. I can teach you mitosis in a lecture, BUT, if you go DO something with it, and you put your hands on it and you have to think about it and you see not just mitosis but you see, well something about biological variation and something about technical problems and something about trouble-shooting and something about communication, and I think ALL of those things have to collectively roll up to train somebody to function in science. (Interview 3)

Following her implementation of the lab, Professor Garrett also felt that students learn best when they take ownership of their learning experience, letting go of the attitude of "you tell me, I do" (Interview 3). The SCTIL approach was a tool that helped her encourage her students to get past this perspective. She explained:

> I do think in some of the historic approaches to labs, it is organized in such a way as they come in, they do, they leave, and they forget it. So the fact that they are working with something over a little bit more TIME, and they have a little bit more OWNERSHIP in it, and you know, again maybe they had to think about how to USE the ideas of statistics in interpretation, they actually had to write that and EXPLAIN that. I do think those things are helping them. (Interview 3)

An additional concern Professor Garrett shared was her students' difficulty in connecting concepts in the inquiry article lab experience. She noted this was a persistent issue in her courses, and this context was no different. Her students see things as separate "sound bites—they're not connecting those concepts" (Interview 3).

Professor Garrett's frustration that students want to be told what to learn for exams was present before and after the SCTIL program. There was no significant change in her perception of her students' motivation to learn. She attributed this to non-science majors' maturity level and felt that there was nothing she could change about her instruction to influence this issue.

Overall, Professor Garrett's beliefs about how students learned changed from a simplistic view of strictly learning strategies (i.e., through problem-solving and application) to thinking about the learning context for students, her learning goals for them, and their conceptual understanding of concepts.

Inquiry-based teaching. In describing her role in an inquiry-based classroom, Professor Garrett saw herself as a guide, informing the students about the content and then walking through the process of doing the scientific investigation. She reflected on the SCTIL approach and how it aligned with her own teaching in upper level courses. She valued skill development in her upper level science majors' courses and felt there was a tension in using the SCTIL approach with skill development labs. For example, she felt students should know how to do a protein assay, and she was uncertain about how to develop a module using the inquiry article format to teach this skill. Therefore, the SCTIL inquiry article approach did not fit all of her course goals and she was reluctant to force the approach in those situations. Therefore, she felt the SCTIL inquiry article format was appropriate for some labs, but not for all labs, particularly those focused on developing specific lab skills.

After learning about the SCTIL format, Professor Garrett described the difference between her previous lab designs and the SCTIL design. She stated:

> I think [my labs] have been, some have been more structured and some have been less structured. More structured in terms of, "Here are three unknowns—you need to figure out what this stuff is." And then it's up to them to think about "how might I go about doing that," it's very tasky [*sic*]. Or, it's been, "We have four weeks, I'd like you guys to come up with a project you might like to do, whatever it is. Then we'll see if it's

> doable," and it's WIDE open. And that works great when I have classes of eight and ten, and so, this I'm seeing as something in the middle that maybe with this larger class, still let them have a little bit of individual input into what they're doing, but still not wide open to where I have to scramble to come up with equipment, supplies, reagents, and so on. And I think I could use this at an earlier level class. I tend to use the other [type of lab] at my 400 level classes. Whereas this, if we worked at it, we could bring this back down into our intro bio series. I think it's not as structured as the, "Here's the unknown, what are they?" That's very scripted. But it is more structured than, 'What might you like to do?' (Interview 2)

During the second interview, I asked Professor Garrett to identify where she felt her cell cycle inquiry article lab fit on the Inquiry Continuum (Brown, Abell, Demir, & Schmidt, 2006) (See Figure 5). As she marked on a printout of this figure, she explained why she felt her labs fit in those locations. In the following statement, she explained where she placed her SCTIL lab:

> Well, I guess I'm thinking we're sort of middle-road, still. I think we're certainly kind of here (Figure 5, Point 2). Because obviously there's some teacher-delimited scope, so it's obviously not 100% student directed. I'm only going to provide them with X number of things. They can't come up with something so totally different. If they said they wanted to work with yeast, I might say, "Well, that's great but I don't have that ready to go." So, it's kind of in this mode, in that they're going to have flexibility within the constraints that I've defined. I'm hoping that it's getting up in here [motions towards full inquiry] insofar as I expect them to articulate a question, define a hypothesis, develop a plan, collect actual data, present that data in a scientifically appropriate manner whether it be a table or figure, statistically analyze their data, interpret that analysis and write a conclusion. So in THAT sense, hopefully they will be getting at MOST of those elements. They're certainly not doing an enormous amount of background research or thinking about novel questions, so obviously it's not TOTALLY free inquiry, the nature of the questions I think will be somewhat limited in creativity and scope. (Interview 2)

She explained that after making changes to her lab design during the workshop, her implementation goal for the lab was at Point 2 in Figure 5. In addition, she noted, "I think it's unrealistic to say it's going to be way up here [motions towards full inquiry], and if it was way over here [motions towards lower right-hand corner] I'd call it independent study, which we're not ready to do yet" (Interview 2). When asked to identify where she felt her original version of the lab would fit on the Continuum, she stated:

> Well I think when I first started this lab, before it got into this format, it was definitely, it was probably way over here (see Figure 5, Point 1). Yeah, the version I brought to the workshop was very much teacher-directed. I made all the treatments, here's the methodology, here's what you need to do, blah blah blah. It was PARTIAL inquiry insofar as it was another one of these examples. They had some treatments that they didn't know what they were that they had to try and characterize. So that was kind of, they were given the question, 'what might this be and why? Based on your data, what conclusions can you make?' (Interview 2)

Professor Garrett explained the changes she made during the workshop focused on structuring—giving students multiple steps to follow, possible treatments, and starting points to use in their own investigations.

After implementing her inquiry article lab, Professor Garrett identified her lab at the same location on the Continuum as her post-workshop version. During Interview 3, she explained her reasoning:

> I think it's still there [pointing to Figure 5, Point 2, spoken matter-of-factly]. I mean I don't think its full [open] inquiry in that they just don't have an open agenda. Their questions were somewhat constrained by what we had to work with, and the materials we gave them to start with. And you still had to provide some direction and in helping them shape and think about their question, and think about what is a control, and why do you need a control, and what would that look like. I don't know, I guess I still think it's kind of in the middle still. And I think that maybe for this lab, where this lab is at, that's probably okay. I don't know where you guys think it ought to be. And hopefully, as they progress with their experience, you might move along this continuum a little bit [motioning towards more student-directed]. (Interview 3)

Professor Garrett felt that each student group may be at a different point on the continuum. For example, one of her student groups asked a question that was out of the scope she had framed for the students. She noted:

> Well, that group was maybe a little bit more over here [motioning towards student-directed]. So they were maybe a little bit more independent in their thinking about the question, but MOST of the groups did NOT move too far up field from the little tidbits that you had seeded in the inquiry article that you gave them. (Interview 3)

Through her experience in the SCTIL program, Professor Garrett's broadened view of inquiry-based teaching supported her understanding of student learning. She entered the program with an open-ended view of inquiry that she

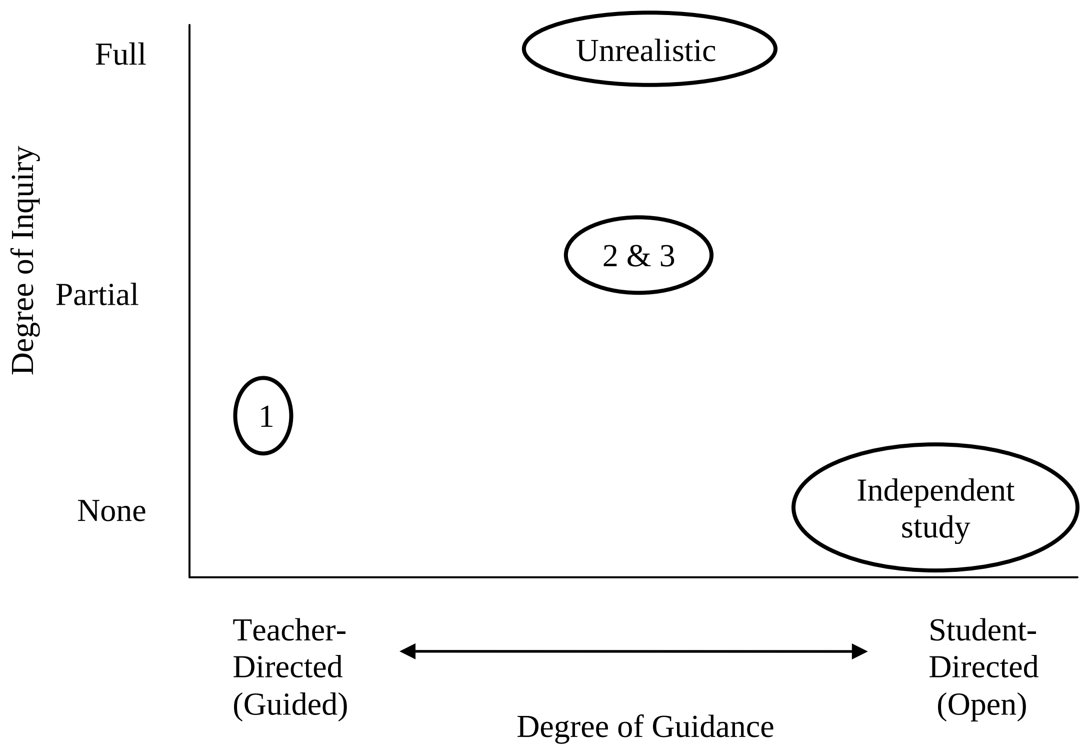


Figure 5. Professor Garrett's Inquiry Continuum (modified from Brown et al., 2006)
1=Pre SCTIL program; 2=pre implementation; 3=actual implementation.

felt was only appropriate for small upper-level classes. The SCTIL inquiry article format gave her a framework in thinking about inquiry for her introductory course. She was able to think about her instruction in terms of the inquiry continuum, including a range between full to no inquiry and teacher-directed to student-directed learning. She continued to struggle with how this format was appropriate for all labs, noting difficulty in applying it to skill development labs.

Environmental Constraints

Prior to Professor Garrett's participation in the SCTIL program, she identified environmental constraints that she anticipated would affect her implementation of the inquiry article labs. She focused on a lack of adequate space, resources, and most importantly, the students' poor attitude and lack of motivation for laboratory learning. After meeting her students in her spring 2008 Genetics course, she confirmed her anticipated constraints prior to implementation, as well as identified additional constraints of large student groups and different learning paces.

First, she felt her students were not adequately prepared for the skill level of her lab, faulting their learning experience in prior courses and lack of motivation to practice basic skills. In discussing their preparedness for her lab, she stated:

> Embedded in the lab I have graphing and table standards, so I'm asking them to work on those things in lab so that they leave lab having gotten it correct, because it turns out those basic skills are a problem for some of them. And in large part I think their intro classes don't spend enough time on them, those intro labs are often times workbook-based, so they're not used to doing this themselves. (Interview 2)

Professor Garrett was frustrated with students' negative attitudes and lack of motivation in her laboratory course. She explained that it could be a characteristic of students in this generation as a whole and not solely in her courses, but she felt they did not want to put forth the effort to have a meaningful learning experience in science. During her implementation, she expected students to practice using the necessary methods for the lab, such as utilizing microscopes and creating slides of treated cells to analyze. She noted:

> About half of them didn't practice until the time they had to do it. They all had to have had at LEAST a year of Biology before they've come up into this class. The very first week or two before we started this lab was basically all microscope work on mitosis and meiosis. So I would say they were introduced to it, they obviously didn't learn it, because they weren't able to use it. And some of them got there, and some of them got there quicker than others. But again I think it's a reflection of, that they often see their lab work as, 'you show up you go through the motions, you fill in the blanks, you leave, and then the next week it doesn't matter. You do something different, so…oh well. I still don't know how to focus the microscope but, who cares I probably won't use it again.' So there's this cultural shift that has to happen along with some of this. (Interview 3)

In the same discussion, she noted that she felt her expectations were somewhat biased by her own extensive laboratory experience. She stated:

> I think the microscopy part was hard for some of them. Some of them just really could not look through a microscope. And I take that for granted, because I have spent four to eight hours a day for 18 years looking through a microscope, so I forget how hard that can be. (Interview 3)

After implementing her lab, she elaborated on barriers previously mentioned, including students' skills, laboratory space, and limited resources. Students' writing skills were a significant barrier in implementing the inquiry article format. Professor Garrett noted that students in her course did not enter the course with knowledge of how to write a scientific lab report. She expected this barrier and had encountered the issue in previous courses. She explained:

> I make them write lab reports in EVERY lab that I teach, regardless of whether it's a cookbook-type lab or not, and I make them use the same format regardless, and even in my 400-level courses, I gave them back and said, 'Rewrite.' I think part of the problem is that, up until maybe many of

> them start taking classes with me, they've not written lab reports. They've done labs that are fill-in worksheets, so that's a problem. Number two, they tend not to WRITE! And so it's like ANY skill, if you don't use it, it's not going to be well-developed. Number three, they really don't like to follow directions. And these are 300 and 400-level classes, and I say, 'Here is your guideline for how to write, i.e., here are the instructions to the authors. I'm not going to read them to you, you can read!' And some of them just choose not to follow them. And so, try again [referring to giving them their report back to rewrite]. (Interview 3)

When asked if she felt this barrier was limited to science writing or could be generalized to general writing, she responded:

> No, I think it's probably broad. I think it's that, unless you're an English major or maybe a history philosophy major where every class requires you to WRITE, they don't write enough. And they don't write enough because it's more work to grade [laughing]. And so people don't have them write! (Interview 3)

Professor Garrett noted the barrier of laboratory space and how that influenced group work in implementing her inquiry article lab. She stated, "Certainly our facility is limiting. There's no getting away from that. Work space is limited, equipment is limited, so the nature of things we can do is just inherently limited" (Interview 3).

Another issue in implementing her lab was the size of the small groups. She wanted students to work in pairs, but ended up having two groups of four students each. The students had originally developed questions that were on similar topics, and consequently, the students joined together to form a larger group. She explained why she would insist on smaller groups in her next implementation:

> Well, it requires now four people to communicate. That's an issue. I think in part there was this attitude that, 'well it's a group of four and I don't feel like going to lab today, so one person miss one week, one person miss the next week.' If you're working in pairs, it's you and your lab partner--you're going to have to deal with your lab partner. So it made it easier to duck and hide—whereas in pairs, you have more responsibility. So I'd rather they take smaller questions, and bring it back to something that they can do. (Interview 3)

Professor Garrett's greatest challenge was being available to answer questions and guide students who were having more difficulty than others. The SCTIL teaching approach allowed students to move at different paces, and she noted that this made her instructional role more difficult. She explained:

> The biggest constraint on teaching with this approach is making sure you have adequate time and attention to each and every group, because their questions and their issues are uniquely different. And some of the group members are inherently stronger than others, and you want to make sure that you give them enough to let them leapfrog ahead if they're ready to do that. On the other hand, you could easily have some very weak groups that are struggling with the basics, and you've just got to make sure that you're getting their attention as well. When EVERYbody is doing the same thing, then the stronger students tend to move through it and be done, and it's a little easier to know which students maybe need a little bit more help. When EVERYbody is doing something a little bit different, it's harder to catch that. (Interview 3)

Overall, Professor Garrett discussed several environmental constraints that made her implementation difficult. These included space, resources, students' lack of motivation and poor attitudes, large student groups, and different learning paces. The constraints she identified prior to her implementation remained while after implementation she identified the additional constraints of dealing with large student groups due to their self-selection and trying to accommodate students' different learning paces. As a result, Professor Garrett was frustrated because she had not met everyone's learning needs, yet she was not overwhelmed with the issue. She seemed confident in knowing how to handle the implementation better in the future.

Self-Efficacy

While Professor Garrett's efficacy towards teaching with this inquiry-based approach was somewhat moderate prior to participating in the SCTIL program, her efficacy increased after the SCTIL summer workshop. She stated:

> Every lab is an adventure. I think it will just be something different to try. I don't feel uncomfortable doing it, I don't know that I've anticipated every possible thing that a student might come up with or every possible issue that might arise, but I don't think you ever do. . . . Even in well-scripted labs, they just don't work that way. And to some extent, I don't really expect it to go or want it to go too perfectly, because science doesn't go that way. (Interview 2)

Following her implementation, Professor Garrett's confidence in her ability to teach using the SCTIL inquiry article format increased. She stated that she felt very comfortable with it, noting, "It's doing science! You know, after 30 years, it's what I do. This is pretty easy" (Interview 3). Therefore implementation was critical in impacting her self-efficacy. This continual increase in self-efficacy occurred after she understood the teaching approach and saw how it aligned with her own teaching practice.

Attitude

Prior to the SCTIL program, Professor Garrett was apprehensive of the workshop experience, worried about being surrounded by other college faculty members with more teaching experience. Following the workshop, she expressed a more positive attitude towards learning about the inquiry article approach. She stated, "I think this should be fun! [Spoken energetically]" (Interview 2). After implementing her lab and receiving her students' responses, her positive attitude maintained. When asked about her overall impression of her implemented lab, she seemed discouraged because her expectations were not met (See the section on Environmental Responses); however, she looked at the overall picture and explained:

> I was really pretty happy with it, actually. I mean, I think the students took it to heart, they read it, they got in line, they looked up stuff, they did

> some background work, they came up with their question, they were able to state a hypothesis, they were able to come up with a miniature proposal or procedure of what they were going to do. They needed some help refining those, but they got the basics there. They certainly did it willingly, and cheerfully, and you know, without a lot of [growling noise]. (Interview 3)

Her students' response to the implemented lab contributed to her overall positive attitude.

Knowledge and Motivation

Professor Garrett gained new knowledge during the summer institute about the inquiry article format. She drew from the inquiry continuum in learning how to create a more student-directed learning experience and incorporating more features of inquiry in her design. Professor Garrett did not identify any changes in her motivation for participating in the SCTIL program.

Environmental Responses

Overall, Professor Garrett felt her students' response was fairly positive, although there were a few issues. Prior to implementing her inquiry article lab, she hoped her students would respond more positively to this type of lab compared to her typical labs. She stated:

> Well I HOPE they'll like it, in terms of finding it more interesting. In previous classes where I've done things less structured, the initial reaction is somewhat discomfort with the ambiguity. So you need to kind of coach them past that and help them create their own structure, how to get it done. That's usually where I find the frustration for them comes, is that they're so used to having it so scripted, then when that's not there for them, they're like, 'We don't know what to do.' And I've had other classes where they're like, 'What do you mean we just have to do this today? Where's the detail?' So, there may be some of that that they need to get through a little bit, but I think once they get past that they'll see it as hopefully a little more fun, and they'll come out of it at the end of the day with a better appreciation of what lab science is really all about, in terms of what you do. (Interview 2)

After implementing the lab, Professor Garrett shared that her students generally were successful, but had a difficult time because they lacked the necessary Excel skills, microscope skills, and writing skills. When students submitted their written reports, she read and returned them without grades due to the overwhelming number of student errors. She stated:

> They had a week to write their lab reports, which I returned with copious notes, and requested that they do a revision [spoken as though she was trying be nice, but felt strongly about it]. So they got my feedback, they got comments, we spent time in class, we went through common sources of error, you know I'm using this Knisely book as the template for how to write in this format. I gave them some of her pages, she's got kind of a checklist of what should be in which part of your paper, and where you could go if you don't quite get this point, as well as an extensive section on revision, because their use of language is just out there. (Interview 3)

Her frustrations surfaced when I asked her to describe why the students had difficulty writing. She explained that some of their papers were "so flowery and overdone that you're like, 'What are you talking about? We don't write this way in science. We need to think about writing precisely and concisely'" (Interview 3).

In general, she felt her students found the inquiry article approach more interesting than her typical labs, depending on the amount of effort they contributed to their investigations and writing. They appreciated the flexibility and hopefully saw the "big picture of the whole process of science" (Interview 3).

Professor Garrett's administration was supportive of her efforts to implement the SCTIL inquiry article approach. She noted, "We are lucky that we have a fair amount of autonomy in our labs, but certainly our department chair who knows we're all doing this is positive" (Interview 2). Professor Garrett did not indicate that her colleagues' practice and response influenced her decisions about her own teaching.

Change in Instructional Practice

Professor Garrett discussed changes she planned to make in future implementations of her cell cycle inquiry article lab, as well as other inquiry article designs in her courses. When talking about changes to this lab, she explained that she would need to develop basic technique skills prior to beginning the lab. She stated:

> In this particular lab, some of them really had difficulty working on the microscope. And so, since the endpoint was intensively a microscopic endpoint, you had to look through the scope and look at cells and make a decision and score, it took some of them a LOT longer than I thought it would to DO that because their technical skills were weak. So maybe, thinking about how much technical skill is required for the type of endpoint that they would likely work with, and making sure that they're either adequately trained, or it's within their, you know, I thought it was something that they could have done, and I said every week, 'There are materials here to practice with, there are materials here to practice with, there are materials here to practice with,' but about half of them didn't practice until the time they had to do it. (Interview 3)

For future inquiry article implementations, Professor Garrett talked about the importance of matching the approach with the appropriate content and skill development. She explained:

> I think the challenge is making sure you pick the appropriate type of activity that is doable. I think you can pick a lot of different content, but I think WHAT you want them to do is tricky. The challenge is weaving a nice mix of methodology and technique into the various topics you choose so they're not just getting exposed to the asking-the-questions concepts, but also exposed to different technical skills, which I think is important for them to learn as science majors. (Interview 3)

Overall, Professor Garrett's future implementation of her cell cycle inquiry article lab would require prior skill training with microscopes and basic techniques. She also valued skill development in using other inquiry article labs, which is a conflict with her view that skill development may be difficult to use with this inquiry-based approach. While she did not indicate how she would resolve this issue, she seemed confident in being able to match her goals with the inquiry article designs.

Summary of Change in Professor Garrett's Belief System

Professor Garrett entered the SCTIL program with moderate self-efficacy, hesitant but positive attitude, and somewhat neutral beliefs about inquiry-based teaching and learning, being new to teaching and the role of a faculty member. After learning about the inquiry article format, she saw how similar it was to what she was already doing, and therefore her belief system was reinforced—her efficacy and attitude increased, she seemed to add depth to her beliefs about inquiry-based teaching and learning, and was enthusiastic about using the inquiry article format in her laboratory sections. Once she implemented and received her students' somewhat positive responses accompanied by several implementation constraints (i.e., time, resources, space, etc.), this fed back into her belief system resulting in a maintained positive attitude and altered beliefs about inquiry-based teaching. She explained that she felt the inquiry article approach was not appropriate for all types of labs, especially skill development labs. Her expectations for her students and for the experience were not met to the extent that she had hoped because of her students' lack of motivation and writing/technical skills; however, she planned to continue using the inquiry article approach in future implementations. She planned to do more SCTIL labs in the coming semesters, yet was hesitant about the constraint of time needed for planning and concerned about matching her learning goals with her lab designs.

Case #3: Professor Propes

Professor Propes's case is presented in four sections. First I introduce him by describing his current faculty position, his teaching experience, and his self-reported teaching practice. In the second section, I describe his belief system about inquiry-based teaching prior to participating in the SCTIL program. The third section focuses on his planned inquiry article lab and why he chose not to implement the lab during the 2007-2008 school year. In the final section, I describe the evidence-based changes in Professor Propes's belief system about inquiry-based teaching following this decision.

Context of Professor Propes

Professor Propes's teaching experience, current faculty position, and teaching practice played an important role in influencing his experience in the SCTIL program.

Faculty Position and Teaching Background

Professor Propes was a third-year Assistant Professor in a Biology department of a large research university in the fall of 2007. During his first 2 years as a faculty member, he taught two graduate-level science courses and one undergraduate upper-level science course. Prior to accepting this faculty position, Professor Propes had experience as a wetland/wildlife consultant, which involved talking with the public about local wetlands and wildlife biology. He explained, "I was pretty comfortable talking in front of people, it was just a question of whether they're actually learning anything . . . are they becoming less a novice and more an expert in some area" (Interview 1). After this job, he enrolled in a graduate program in Botany where he taught a few science courses almost every semester. He continued teaching during his two post-doc experiences. Professor Propes began his faculty position with 13 years of teaching experience, most of which were in the laboratory course setting. He explained that his graduate program administration allowed teaching assistants to take the lead on designing instruction for their lab courses. He noted, "We were encouraged to develop our own things and so most of us did" (Interview 1). When asked what experiences he drew from in designing his courses, he stated:

> In addition to my own experience as an undergrad, I basically had minored in college science teaching. So I'd taken several courses . . . like Pedagogy, Inquiry-based Learning, and some other three or four classes. There was also a brown bag lunch kind of series for faculty and grad students to go to, and I participated in that, too. (Interview 1)

When observing lecture courses during his graduate program, Professor Propes stated that the teaching style was "pretty much a lecture kind of model, there wasn't any sort of new pedagogy in the lecture part—nothing very innovative, pretty traditional; same stuff I had as an undergrad" (Interview 1). In designing and implementing a few lectures in undergraduate courses during his graduate program, he reflected on the difficulty of fitting into their mold:

> I felt a little bit more bounded, keeping the format of the way the class was. I didn't like [Pause] I pretty much gave a talk—I didn't do what I do here now at [his current institution], which is not hardly lecture at all. (Interview 1)

Based on these experiences with his college science teaching coursework, designing and implementing his own laboratory and lecture courses, and observing what he described as ineffective classroom teaching, Professor Propes developed his own sense of what effective college science education should look like prior to beginning his position as an Assistant Professor in Biology.

Self-reported Teaching Practice Prior to PD

When talking about his teaching style, Professor Propes focused on his undergraduate course, Plant Systematics, with an enrollment of approximately 40 students. The class met four times a week—twice a week for an hour lecture and twice a week for two hours of lab. Professor Propes redesigned the course when he began teaching it. He explained that he "threw it out and started over," using more non-traditional methods within the two types of classroom environments:

> So what I did, traditionally this is a class where people get lots of verbiage and lots of vocabulary and lots of details and they kind of get that lectured out to them and then they, in the lab, look at stuff. And what I decided to do was completely eliminate that almost entirely from the lecture and move that into little mini lectures in the lab, and then the lecture time I spent presenting sort of opposing arguments or people read a paper and we basically discuss them. And I also had a number of activities where they would do a quiz or work in pairs or small groups on some project and then share what they thought with the rest of the class. . . . And I tried to have sort of a weekly rhythm to that where I'd present some stuff, give them something to sort of engage them and then they would have some activity or discussion to explore the topic, and then we would talk more about it. . . . I'm not going to, you know 'this is a Brassicaceous, it has 3 stamen, 2 whatever,' Bueller, Bueller, Bueller [laughing]. (Interview 1)

Professor Propes taught the lecture courses; however, he had teaching assistants (TAs) to lead the three sections of laboratories twice a week. He met with the TAs every Friday to talk about the upcoming week of labs, and often attended the first labs to make sure they ran smoothly.

In his discussion about his teaching practice, Professor Propes focused mainly on his lecture teaching. He explained the importance of changing up his instruction every 10 to 15 minutes in order to get the students active in some way. He noted that he liked to walk around the classroom, often running to the back and then working his way down to the front of the room. This kept students from trying to hide in the back of the room and feel that they would not have to participate in class. When discussing his typical interaction with the students, he explained:

> I'd say to them, 'well what do you think of this situation,' or 'I know you did the reading that was assigned for today, how does this example that I just talked about relate to the reading,' or something like that. So that's as un-engaging as it gets. (Interview 1)

He would often give students readings prior to the class. During class, he would not prepare a PowerPoint or any form of instructional guide—the class would strictly be discussion of the reading. He explained, "I give them some questions to think about in advance and I'll say, 'alright, question number one goes to whoever,' and we'll just call on somebody random, and then just go through a paper and talk our way through it" (Interview 1). He went on to say that when students read ahead of time, the discussion would tend to go well, but if they did not and he felt that the discussion was slow, he would stop the discussion and get the students into groups of two to four. He would ask them to take ten minutes to look at the next set of questions and then they would move back into the whole class discussion. He stated, "I try not to [Pause] I just let it sort of organically happen in class and see where it goes" (Interview 1). It was important to Professor Propes to be flexible in his instruction and willing to change during class to support his students' learning. He talked about other strategies he often used in class to support his students' learning. One example is given in the following statement:

> Maybe we'll do an exercise or a game. Like one time we did Plant Taxonomy Survivor. So I played survivor music and then, so this is one of these things where I wanted them to learn a lot of vocabulary, but I wanted to make it fun. So I said 'you're on a desert island or an oceanic island or Gilligan's Island, whatever. You need to build a village. What are you going to build a house out of, what are you going to eat, what are you going to use for medicine,' blah blah blah. And they had to [Pause] team one is going to get everything from monocots and team two is going to get everything from the Rosid family . . . So they were slightly different and then at the end we sort of shared, and the first person to get the sort of message in the bottle at the end—so there's a little competition . . . but at the same time it also sort of forced them to go through the book or the

> reading in a way that was fun but also they could apply it in a way that made some sense. (Interview 1)

As Professor Propes discussed his laboratory courses led by teaching assistants, he explained that he felt there was a disconnect between the lecture and the laboratory portion of the course. While he made significant revisions to the lecture portion, he felt the lab portion of the course still followed a more traditional teaching format. He stated:

> In the lab, it's much more traditional, except for the fact that what normally is in lecture is now like maybe a 15-minute PowerPoint that the TAs will go through. 'Okay, today we are going to learn these three families, and here's the formula, and here's the common names, and here's the blah blah, and this is the taxonomy.' Otherwise it's stuff that they read on their own. And then the rest of the lab is hands-on with the plants. So we spent a lot of time, you know, having a lot of material that they can all dissect and look at. But I try to, in the lecture, I only try to give the big background picture for that. And then…actually learning how to key out plants, which is what some people just take the class for. They're studying mammals or fish and they just want to learn how to key out, identify some plants. . . . So the lab is more sort of hands-on. The lecture is more sort of engaging their little gray cells. (Interview 1)

As Professor Propes talked about his use of assessment in his teaching, he focused on traditional approaches such as quizzes and exams, but also talked about more formative approaches to help him understand what students were learning. He explained:

> I also talk to them. I really value the half hour or 45 minutes right after lecture before the lab starts. There's some students in the hallway and I really, instead of running off, I really try to talk to them about where they are in the class and do they think something's hard or easy or [Pause] and so quite a bit of it is actually sort of that informal just talking with them. But I've really learned that they, overall, I have to assume they know almost nothing. Even for a 400 level class . . . because some of them have had genetics but not botany, and some have had botany and not genetics, and some of them have had nothing. Or they are transfer students and I have no idea what their background is. (Interview 1)

While he preferred exam questions that required students to explain something and why they answered the way they did, he often had his students write up their own exam questions, which tended to be much harder than his own questions. He stated:

> They ask much more interesting and difficult questions than I would ever have given them. But it's okay because they came up with them themselves, and so they have some ownership over coming up with it. It wasn't like I did it to them, they did it to themselves. (Interview 1)

Overall, Professor Propes's teaching practice prior to participating in the SCTIL program reflected his knowledge of effective pedagogy through his use of different individual and collaborative learning strategies, a student-centered focus of instruction, and use of both formative and summative assessments to inform his practice and support his students' learning experience.

Nature of Belief System about Inquiry-based Teaching Prior to PD

In the following sections, I describe Professor Propes's belief system about inquiry-based teaching prior to the SCTIL professional development program.

Beliefs

Science as inquiry. When asked to define inquiry, Professor Propes interpreted the term as an approach to learning and described an understanding of both scientific inquiry and classroom inquiry. He wanted his students to "learn that most science is failure," noting that he felt that learning through laboratory experiences was critical to understanding the process of science (Interview 1). His beliefs about classroom inquiry were explained when he discussed student learning and inquiry-based teaching.

Student learning in science. Prior to participating in the SCTIL program, Professor Propes believed students learn science best by actively "doing it" (Interview 1). He explained:

> I think of inquiry-based learning as being, well I guess there's at least two pieces of it. One would be that people have to, they're given a question or some engaging phenomenon, and they have to explore that as opposed to being given some answer that they have to, or fact they have to memorize. And the other thing is I usually think of it as being something open-ended, where it's not like, think about your standard chemistry lab, make aspirin and you're just following a cookbook, you know. Yes, you're discovering but really the answer is already known, whereas I try to give them something where there could be multiple answers or there could be different ways of approaching the problem, and then they can talk amongst themselves about, and then 'oh well you want to do it that way, go ahead and do it that way, you want to do it this other way, and then you guys can compare and see, oh well I want to do this part like she did and I want to do this part like this other person did.' And so I guess that's what I think about inquiry is that they're producing their own knowledge. (Interview 1)

Professor Propes valued students being engaged in their own learning experience. He was opposed to the common perception that science learning involves only memorization. He stated:

> I think too many students think science is static and there's these facts and they have to memorize these facts and then they apply, I don't know. One thing I really like about [his institution]—the most effective teaching I do isn't even in the classroom, it's in my lab. (Interview 1)

He also expressed his value of students' learning the process of science in terms of its collaborative, interactive nature. He stated:

> They're not just learning the subject but they're learning how to work in groups and learning how to talk about a subject and learning how to give a presentation . . . so if you want those outcomes then of course, [Pause] what's the cartoon I saw once it was great—the professor was like just a tape recorder and the students were a bunch of little tape recorders. And there were no actual people in the room. It's like well why not just take the course online? Why have a college? Why not have everybody do distance learning? Why have a university? That assumes a model of learning where there's a transmission of ideas, and here's an idea, and I encode it in PowerPoint or some piece of paper or whatever, and I send it to you and you decode it and that's not how thinking occurs. That's not even how communication occurs. (Interview 1)

Professor Propes believed that engaging students in authentic scientific research was a valuable piece of learning science. He expressed that “most people work better when they’re engaging in research itself, and not just learning from somebody else,” which was reflected in his belief about inquiry as an active, authentic learning experience. When talking about the difference between his graduate students’ learning as compared to his undergraduate students, he noted a difference in their willingness to learn in his courses. He stated:

> For a graduate seminar or something, people really should be in charge of their own learning. But sometimes I’ve found that with undergraduates they really [Pause] they don’t want to go too far off the traditional model, you know, they’d just as soon sleep in and download the PowerPoints and read it, you know whereas when they show up and I make them work, meaning they have to LEARN…they don’t necessarily like that [laughing].

Inquiry-based teaching. Professor Propes described his own teaching prior to the SCTIL program as inquiry-based. Dividing the lecture from the lab portions in his Plant Systematics course, he explained, “I definitely teach with inquiry in lecture. The lab, I think it’s a hands-on lab. Is it inquiry-driven? I guess. I don’t know. I need to spend more time on that” (Interview 1). He explained that he viewed inquiry-based teaching as challenging because “it’s harder to create an environment and a situation where students can actually do [inquiry]” (Interview 1). As he elaborated on his reasoning, he explained why he felt this way:

> Because it’s easier to walk people through a story or to teach them different [Pause] okay, here’s basic vocabulary, here’s intermediate vocabulary, here’s advanced vocabulary, as opposed to what happens in real life which is ‘I want to know how to make canola resistant to these insects,’ or ‘I want to know how to make corn sweeter,’ or whatever. Where do you start? There’s no logical start. I mean there’s several ways you can start with attacking that problem or trying to think about how to address it. And so if you get students to start thinking about [Pause] you

> want to give them a problem where it has some boundaries to it that you can manage in a classroom hour or semester or whatever, but at the same time, not be completely open-ended so that, you know, somebody's doing particle physics while somebody else is writing a poetry essay. Although sometimes those are fun, but not for the whole class, right. And so there's very few…even just probe kinds of questions or whatever, for evolutionary biology, there's no like website where they can see, oh here's problem-based learning, inquiry-based learning or whatever. I've had to make it all up from scratch. And if you do astronomy or physics, there's all kinds of things where they've been, 'oh yeah just go to the Arizona website and they have all these great examples of things you can give to students.' And there's no such thing for phylogenetics, for example, except for a couple articles. (Interview 1)

As Professor Propes talked about his own course, which used phylogenetics, he described a lack of inquiry-based teaching resources. At the time of Interview 1, Professor Propes was working with a science education graduate student on "how to come up with problems that are good for students" (Interview 1). He explained that it was not a trivial undertaking:

> You think it's easy and it's not. So I think it's much harder to do that as opposed to just sort of saying, 'here's a phylogenetic tree and here's the terminology used to explain that. Here's how it's used in this article and memorize that and spit that back to me in the next lecture,' or something like that, as opposed to, 'you want to tell the history of life, is it even a tree to start with? Or is it an ooze in a maze or a web or,' you know. (Interview 1)

Professor Propes viewed the role of the teacher in an inquiry-based classroom as the person responsible for creating an environment conducive for open student discussion. The students' role is to be engaged learners in the thinking process. He described the difference between this type of environment and what he saw as more traditional lecture classroom environments:

> [An inquiry-based learning environment] is exactly the opposite of what a lot of content-driven lecture classes are and [students are] not just there to copy and repeat. There's some of that, but what I try to do is I try to make that the homework and then the actual lecture time is them thinking,

> problem-solving, talking to each other, communicating, and I try not to actually over think where it could go, because often, especially if I've just made up an exercise, they'll come up with things I never would even think that they would come up with as alternatives, and so I usually just try to trial some stuff out and go, oh wow, they have this misconception that I totally forgot that I used to have or that I never had but they have for whatever reason, the education background is different or something like that. So I try not to over plan those activities. (Interview 1)

When asked if he felt he was an expert at teaching with inquiry in his courses, Professor Propes responded that he was not, but that he didn't know anyone who was an expert. He stated:

> This is why I feel like I'm not an expert—because I gave a pre-test and a post-test in this class, and there was some improvement but it's not like people aced this post-test that I came up with. So even though we kept emphasizing certain skills or certain ways of thinking, there were a lot of students who still hadn't quite picked it up. I'm not sure why yet. . . . Some things that I assumed that they all knew as background that they learned, I would've hoped, in introductory biology and genetics, they didn't know. So I need to give them more of a background on that before I can get into the phenomenon that I was really interested in having them learn. (Interview 1)

Finally, Professor Propes talked about the importance of modeling inquiry behavior throughout his entire course, not after several weeks into the course. He explained:

> You don't wait until week five, you do it day one or day two at the latest, right away. You get them talking. If you expect them to talk in class, then you have to have them doing that immediately. I do that all semester, no questions asked. (Interview 1)

Therefore, Professor Propes's beliefs about inquiry-based teaching and learning were strong and grounded in his experience and prior knowledge of science education.

Social Norms

Professor Propes's biology department boasts the largest number of undergraduate students in any department at his university. He explained that this was a driving force for his administration to ensure a quality experience for students to remain in his department. He stated:

> The department is very keen on staying number one, in terms of having the largest major on campus. So to that degree, they want to make sure that student advising and teaching is very good. And students have a good experience. So I think [teaching] is actually valued at the department level, but in terms of getting tenure and being a new professor, it's a different message. It's 'just don't blow it,' right? You need to bring in money, publish, develop a reputation, and teaching. (Interview 1)

Professor Propes talked about his department's expectations of the faculty members' time commitments. He explained:

> Although we supposedly sit on the three pillars of research, teaching, and service—research is [actually] 90 percent, teaching is 9 percent, and service is 1 percent. And say 'no' early and often when it comes to [service]. So there are not three equal pillars by a long stretch. Maybe for the public it is, but in terms of what's expected of us day-to-day, it's not. And it's tough, because you know, you can easily spend 20 hours a week teaching. So for me the challenge is actually to spend less time, not too much. I mean keep the eye on the prize in terms of research, because that's what we're paid to do. (Interview 1)

While teaching is not highly valued in terms of tenure, Professor Propes noted that his departmental chairman, Professor Brown, is an advocate for quality teaching. He often left flyers in faculty members' mailboxes or sent out e-mails with ideas for teaching strategies. At each of their faculty meetings, Professor Brown spends about 15 minutes talking about effective teaching by having a faculty member share something they do that is "different," (Interview 1). He noted that he adopted his Survivor game from seeing someone else use a similar approach in one of their courses. In general, Professor Propes believed that his department "actually has a pretty healthy attitude about teaching, but again, some individuals care more than others" (Interview 1).

He described his department's typical teaching method as "more lecturing and not as much inquiry-based learning—a little more sage on the stage kind of thing" (Interview 1). While several faculty members use approaches that support student learning, like breaking up the class period with different strategies and posing questions to the students throughout their lecture, he felt that most faculty "do a lot more talking during the lecture time—[faculty would say] it's a lecture, not a student learning time, necessarily" (Interview 1). He explained that their reasoning was usually due to the large class sizes of over 200 students, and therefore faculty members tend to think "it has to be that way" (Interview 1). However, Professor Propes was quick to follow his claim with a disclaimer: "But I know it doesn't have to be that way—I've seen in models that it doesn't" (Interview 1). He noted that a few members are passionate about quality college science teaching, and he often goes to these people as resources, valuing their input and ideas. A couple of colleagues, in particular, are "split hires" between the biology department and the education department. Professor Propes discussed this type of position, which he noted were in a few of the institution's science departments, as "brilliant" (Interview 1). He stated:

> I think that's a great model of sort of putting those science ed faculty out into the field, if you will, and I love working with those faculty. And also we co-mentor students together. So I'm not just doing teaching, we're doing RESEARCH. You know, so when I'm doing that, I want to have every second I spend on my course count and so if I can also publish with a grad student that you know, I help mentor, that's great. That makes my teaching better. I learn how to better teach or, if you will, facilitate. I can better learn how to facilitate student learning and assess student learning if I have somebody who's actually a professional at doing that in the classroom with me. So that I think has been great and the department has been really supportive of that. If I'm getting research publications out and also research and teaching publications out. So yeah, it's not like research and teaching are separate, they're the same. (Interview 1)

In general, while Professor Propes's department primarily values research in their tenure and promotion process, his department chairman's value of quality teaching is evident in his effort to include teaching discussions in each departmental meeting and encourage collaboration with science education faculty on campus.

Environmental Constraints

Professor Propes did not anticipate any significant environmental constraints prior to participating in the SCTIL program. He did express his concern for coming up with a "good enough" research question for his students to use in his lab (Interview 1). He felt that his biggest constraint was his own ability to develop a question that was open-ended, but focused at the same time. He stated:

> They need to know enough vocabulary—vocabulary is not the right word, just sort of scientific literacy—to be able to confront an issue but still be open-ended enough that it gives them room to think about things, you know. So that's difficult. And like I said there's nothing, at least for what I do, there's nothing out there that you can borrow and crib, or at least very little, so I've had to really come up with it myself. It's coming up with good questions. What's a good question that's focused enough to be well-bounded but big enough and open enough and important enough that they think 'oh yeah, how many genes does it take to make a corn cob, versus a grass that doesn't have a corn cob? Ten genes, 100 genes, how many genes does a plant have? So that's actually a good question, because, is it the same as humans have? Is it different? How would you tell? How would you go about?' So what does that mean [for the students]? That means they have to understand that not all genes are equal, some genes are more important than others because genes are networks. And so genes that sit on the top of the hierarchy controlling the network are the ones that are important, we call those transcription factors, and so then they learn oh, what are transcription factors? They didn't mean to. Because what they really want to know is, how do you make a corn cob, and then they have to learn all this jargon about how there's transcription factor genes, there's other kinds of genes, and you think about the part of the transcription factor, the promoter region, and they didn't want to know anything about a promoter region. But if they're still that stuck on how do you make a corn cob, then they sort of have to build that up. (Interview 1)

Professor Propes was most concerned with designing a question that would guide students in learning about the content they would need to answer his question, yet not send them down an unwanted path. This tension was strong for him, and he expressed his worry about creating a learning environment that was supportive of his students' learning and not waste time searching for answers to a question that was unnecessary for his/her particular topic.

Self-Efficacy

Professor Propes's confidence level towards implementing an inquiry-based lab format was somewhat high going into the SCTIL program. He explained:

> I'm willing to do it—I've tried it, but I don't consider myself an expert because I haven't quite gotten them where I want them at the end of class. I feel better than average—I'm not afraid, let's put it that way. (Interview 1)

He entered the program with a willingness to learn about the inquiry article format yet seemed cautious about being overly confident until he experienced it in his own context.

Attitude

Before the SCTIL workshop, Professor Propes's attitude towards learning and implementing the inquiry article format was neutral. When asked how he felt about using the SCTIL format in his lab, he seemed interested in trying the new approach, yet hesitant because he didn't know what to expect at the summer institute. He stated:

> I have no idea what to expect [he is fiddling with a pen and now flings it off the table]. I really don't know. We were asked to bring some lab data and there's a couple exercises that I'm trying to improve so I'm going to bring those and see what happens with it. I really, I haven't even seen the agenda for these, what is it three days of training? I hope it's good. I don't know. I'm willing to gamble three days of my time to hopefully get a couple of nuggets of good stuff. (Interview 1)

His attitude was neither positive nor negative based on his lack of knowledge about the program.

Knowledge and Motivation

Professor Propes entered the SCTIL program with extensive knowledge and experience in inquiry-based teaching; however, he was unfamiliar with the SCTIL inquiry article format. His experience in the program was his first introduction to this approach. When asked why he decided to participate in the SCTIL program, he gave one response—Professor Anderson. His sole motivation for signing up to participate was because one of the co-leaders of the program was someone he greatly admired for her work in science education. He stated, "[Professor Anderson] is fantastic. Therefore, the SCTIL program is fantastic" (Interview 1). He equated the success of the program with the involvement of Professor Anderson.

SCTIL Inquiry Article

At the end of the first day of the SCTIL summer institute, participants were asked to convert one of their labs into the inquiry article format. They submitted this first draft to the SCTIL staff members and peers for feedback. In the following section, I describe Professor Propes's design of his first SCTIL inquiry article, as well as his plans for implementation. Since Professor Propes chose not to implement this inquiry article during the school year, I will also discuss his explanation for this decision.

First Version of Inquiry Article

The first lab Professor Propes converted into a inquiry article format was for his Plant Systematics course (see Appendix F for Inquiry Article version 1). His learning goal in this investigation was for his students to understand how to group organisms, distinguishing phenetic from cladistic methods. He was open to trying the SCTIL format and noted that his typical labs for this course did not follow a "cookbook" format, as discussed in his self-reported teaching practice.

The title for Professor Propes's first inquiry article investigation was "Phylogeny of hypothetical plants." It was difficult for him to fit his non-cookbook design into the structure of the SCTIL format; therefore, in his abstract, he explained how his first draft would be reflective of the inquiry article format:

> Phylogenetic relationships within evolutionary biology are explored by a tree-building exercise from a given set of hypothetical plants. This is an introductory exercise that would precede a more elaborate lab (which would be more conducive to the inquiry article format with a meaningful abstract). Hypothetical plants given to students to put into groups and then to construct phylogenetic trees for: [several images of plants given]. (Inquiry Article Version 1, Professor Propes).

This abstract noted that he would use this lab as a pre-requisite to a more extensive lab, designed to follow the SCTIL inquiry article format.

In his second interview, Professor Propes explained how he came up with the design for this lab and how he planned to implement it in his course:

> After talking with [Professor Anderson] and some other people—and I had to come up with a whole new idea, which was, well what if I had the students make a phylogeny from unknown plants we put in front of them. And at the beginning of the course they would plant them, so they'd know how to grow plants, they would make observations during a plant's life history, and they could code morphological characters, you know like flower shape, petal number, petal character, whatever, and they could make a little evolutionary tree of a couple of different species, say of the mustard family. And then if we had time, we would do a demonstration or something where they could then sequence some DNA and see like, 'well if you build a tree from DNA would they be morphologically different,' and I know they'd be different, so I could do something like that, but that would be to learn a totally different set of things than what is currently in the lab, content-wise. (Interview 2)

Professor Propes expressed a frustration about fitting this type of inquiry-based teaching into his course goals. The labs he brought to the SCTIL summer institute were not conducive to the inquiry article format, and he had to develop an entirely new lab with the help of SCTIL staff and his colleagues. He explained that another faculty member at the SCTIL institute (and a participant in this study) had similar difficulties in converting her labs. He explained:

> Well, [Professor Wilson] was sitting next to me, and she brought some labs that would fit, but another one that she had was, what if you had a lab where people were just going to learn how to use blasts. She said that's just kind of an exploratory, learn your way around some software kind of lab. There's no hypothesis, there's no scientific question, the purpose of the lab is to become familiar with a piece of software. Or you can imagine that if someone was in a human clinical lab and their purpose was to dissect a cadaver and learn parts of the body, there's no hypothesis, it's totally descriptive, so what would you have, an inquiry article that says 'I opened up the body and I think that something shaped like this is a kidney.' [Pause] There's no test. (Interview 2)

After discussing this concern with SCTIL staff members, Professor Anderson made a suggestion that helped Professor Propes modify his first draft of his inquiry article into a more appropriate design for his specific course. He explained:

> So [Professor Anderson] brought up the point that, in a systematics course, maybe over the course of a SEMESTER, the hypothesis is, okay you're going to go out and collect plants in two different habitats, and you're going to compare them. And so there is this overarching motivation that is maybe hypothesis-driven. But any particular WEEK, there is no, 'Okay, you're comparing X and Y.' No, it's 'this week we're doing, how do you identify the tomato family, the sunflower family, the grass family,' and then given exemplars of those, could you use a KEY, it's more of a skill-building class, not a 'you're testing a hypothesis' kind of class. (Interview 2)

Professor Propes decided to use this suggested design for his inquiry article, although no written document was created to represent this plan. He explained that he would plan to implement this semester-long design in the spring semester of 2008. While he felt that this would not follow a strict inquiry article format, it would still be an inquiry-based approach to teaching and learning in the lab based on its student-directed nature. He noted that the students would still be "coming up with their own questions and their own datasets, and pretty much their own everything . . . so they can PICK what kind of plants they want to study, what to measure, how to create a tree" (Interview 2).

Professor Propes identified his goals for his students' learning in the semester-long lab design as wanting the students to "be motivated to ask a phylogenetic question, to gather the necessary data to answer that question, be it morphological or molecular, analyze the data, and then be able to present and talk about it" (Interview 2). It was important to him that his students learn about the process of doing science, as well as learn the content and research skills.

Change of Plans

In January 2008, Professor Propes met with two students who assisted him in developing/implementing this course, as well as with two SCTIL staff members and myself (as an observer), to discuss his plans for implementation in the spring 2008 semester. He allowed me to observe and record the meeting and interview him afterwards. This unique interview structure took place between his scheduled 2nd and 3rd interviews for this study. One of the students present was an undergraduate student (Mallory) and the other was a graduate student (Katharine), both science education majors. During this meeting, Professor Propes shared his decision to start over in designing his SCTIL inquiry article lab for his spring course and to work collaboratively with Mallory, who would be developing this lab as part of her independent study project for her science education degree. Mallory was not a participant in the SCTIL program.

In this group discussion, Mallory and Professor Propes continued their conversation of coming up with a design idea for this lab, indicating that it was still in the development stage. They had e-mailed a SCTIL staff member the previous day to share their ideas and were continuing discussion based on the response they received. Their plan was to give the students a hypothetical situation in which they found an unknown plant. They would be given the plant's family information along with an evolutionary tree, and would be instructed to fit their plant into the tree, comparing details with morphological features. Professor Propes explained:

> They'd start around the 3rd or 4th week, and they'd be doing this throughout [the semester] . . . so while this is a long-term project, one piece of it, ONE lab could be just that they have to make the key. And the point is—literacy, but that's going to give them some tools. So it will be modularized. (Group Meeting Interview)

Professor Propes emphasized that he didn't know the phylogeny of the unknown plants, so there would not be an available answer, the students "may actually discover something" on their own (Group Meeting Interview).

Final Decision and Future Plans

Professor Propes decided not to implement his SCTIL inquiry article during the spring of 2008. While the purpose of my third interview with other participants was to understand how their belief systems changed as a result of implementing their lab, I conducted a third interview with Professor Propes to understand why he chose not to implement the lab, and how that influenced his belief system.

When asked what led to his decision not to implement, Professor Propes explained:

> So I think there are two reasons why—one is just the nature of the course, although I totally believe in the 'less is more' philosophy, we're still

> hammering out the nuts and bolts of the class. This is only the second time I've taught it. So, we're trying to quote 'fit it in,' but there is also this other material to fit in. And then the other thing is just not having a really good handle on what the outcome would be in this particular SCTIL lab. So between that and, the people who I thought were going to implement it had various things happen to them so they couldn't really get around to it, so I said, 'Okay, I'm not going to implement it this semester.' So I'm not [Pause] I think there's still a possibility of doing this in the future, it's just not going to happen this semester. (Interview 3)

Professor Propes discussed the difference between his latest version of an inquiry article lab and a typical science lab. He stated:

> Well, [the SCTIL format] wasn't really meant for the class that I'm teaching, in the sense that we don't really have any cookbook experimental labs where people gather data—they're more descriptive labs where people learn parts of plants, and descriptions of plant families. So a lot of people, like in the Physics things, they already know what happens when you drop the pendulum or do this or that, and so their SCTIL lab was, 'Okay, I dropped the pendulum this way,' and then their SCTIL lab was, 'Okay, you guys figure out how, what else to test, you know, add more weight, have more time, make the thing bob longer,' you know, change some variables, where as we were trying to get people to grow, pick different species of plants, and do some computer algorithms to make phylogenic trees, and anyway it just became much too big. . . . It became clear to me that we were trying to address a research question where we don't know the answer to it. So it's a little bit more open-ended, and I think we decided it was too open-ended for this semester. (Interview 3)

While Professor Propes planned to implement a version of his inquiry article lab in a future course, he did not implement the SCTIL laboratory activity during his spring 2008 course because it did not fit his purpose and learning goals for his students. He also needed more time to fit this type of learning experience into his semester timeline. In talking about his future plans, he explained, "I would still like a lab where, it MAY go the inquiry article format route, but it would be one lab setting it up, and then doing it, and then maybe a 3-lab period [spoken hesitantly]" (Interview 3).

Change in Belief System about Inquiry-based Teaching

In the following sections, I describe the changes, if any, in Professor Propes's belief system about inquiry-based teaching through his experience in the SCTIL program and his decision not to implement his SCTIL inquiry article lab in the 2007-2008 school year.

Beliefs

Science as inquiry. Professor Propes's view of scientific inquiry did not change through the SCTIL program. Experiencing the summer institute and planning an inquiry article lab gave him a new framework of how scientific inquiry can be used in the classroom; however, he did not think this model was the best fit for his particular class. He stated:

> I think inquiry is appropriate [for this class], I mean people do a lot of field collecting, they do various things, I just think it's the experimental model of inquiry that I think [Pause] but we just weren't able to pull it together for this semester. (Interview 3)

He maintained an appreciation for incorporating scientific inquiry into the classroom but struggled to adapt it to his teaching context.

Student learning in science. Professor Propes's beliefs about student learning remained the same at the end of the SCTIL program. He still valued active learning and thought that a student's experience in his lab was the best way to learn science. During his second interview, he stated:

> Really what we were imagining as a SCTIL project was going to be what would be a much better 10-hour per week undergraduate research experience in the lab, as opposed to something that everybody in the class would do over the semester, at least the way that I've been thinking about it recently. (Interview 2)

He talked about the importance of his students understanding that not all of science is known, and that he did not have all the answers. He stated:

> This is actual research that we're doing, so they have to understand that, we don't KNOW! I mean I hope to say quite often, 'well we don't know the answer to that.' Or if they say, 'oh, well has anyone looked at the chemicals in this?' And it's like, 'oh, well we looked at the pathway of this one, this one and this one, but nobody has ever looked at the one that's sitting in front of you.' And they say, 'oh!' I mean, I do this all the time with my new grad students. When they're doing research, I mean half the research is just trying to get shit to work, and then after that they run some gel and it works and you're like, 'oh, you're the first person in the world to know that!' And they're like, 'that's actually kind of cool!' So, just to get the idea that, you know, not all knowledge is known out there. (Group Meeting Interview)

Professor Propes's view that collaboration is an important part of learning science also remained throughout the SCTIL program. He noted that the most effective way to do inquiry-based learning is in small groups, from two to four students per group. Overall, his views of student learning in science did not change.

Inquiry-based teaching. Learning about the inquiry article format as a model of inquiry-based teaching did not change Professor Propes views of inquiry-based teaching. He stated:

> I thought it was interesting and I can imagine doing it, applying it to maybe some aspects of this class that I teach, or maybe different aspects of the class that I teach, but it's probably not something I'm going to be able to do immediately. (Interview 2)

He explained that his belief about active and collaborative learning translated into how he teaches his classes. During the group meeting interview, he repeated a statement he had made in his first interview:

> They have to do a lot of stuff outside of class—I want to spend class time having them interact. Otherwise, why go to college, might as well just take the whole university online. Why be here? Why go to college? Really! I mean what's the point of being at a major research university?

> My favorite Newsbury cartoon was a picture of a classroom, and then all the desks are tape recorders, and then the professor just had his tape recorder there playing. And there was nobody in the room! I mean that's the classic, you know, teaching is transmission of content. (Group Meeting Interview)

During the 2nd and 3rd interviews, as well as during the group meeting discussion, I asked Professor Propes to identify where he felt his current inquiry article lab fit on the Inquiry Continuum (Brown et al., 2006), which was discussed at the SCTIL summer workshop (see Figure 6). During our second interview, he identified two locations of his lab; he first identified where it was on the Continuum during the summer institute (see Figure 6, Point 1), then where it was after the summer institute (see Figure 6, Point 2).

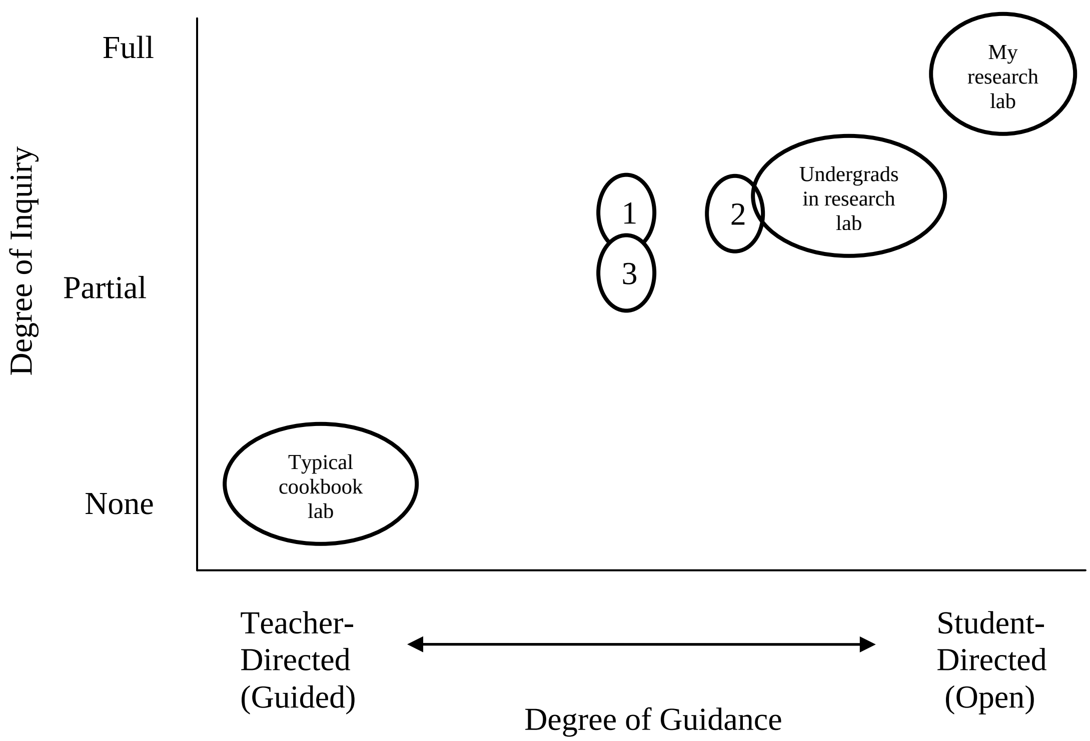


Figure 6. Professor Propes's Inquiry Continuum (modified from Brown et al., 2006)
1=During SCTIL summer institute; 2=end of SCTIL summer institute; 3=pre implementation.

He noted that it started at a more central location on the figure, but he wanted it to be more student-directed. He was modifying his lab to include more opportunities for students to take ownership of the process, so they would have "a lot of choices of how to go about doing it" (Interview 2).

During our follow-up interview to the group meeting discussion, I asked Professor Propes where he felt his new version of the lab, the long-term implementation, would fit on the Inquiry Continuum. He replied:

> I guess it depends on [Pause] well, I mean, it's ah, there are just not as many variables that they can play with. I mean I guess it depends on what you think this mythical bubble is up there [drawing a circle in the upper right hand corner of the figure]. I mean, if you think that that's . . . I think that is a lab. Like my lab. Like they would walk into my research lab, like what a grad student would do. You're limited by the machines and the equipment that's in there, and you're working with me, but otherwise it's mostly you. And undergrads are, so if I have undergrad researchers in my lab, I put them here [drawing a circle mid-way between the upper right hand corner and the center of the figure]. So this here is your normal cookbook lab [drawing a circle on the lower left hand corner of the figure]. Yeah. And so this SCTIL lab, if SCTIL is here [pointing to the center of the figure], I'm happy. That's my goal. And it may not even be here, it might be here, because it's not going to be full, it's going to be some kind of partial. So, if I can make halfway on both those scales, I'd be happy. (Group Meeting Interview)

During his third and final interview, Professor Propes reflected on the Continuum and where he felt his latest version of the lab fit. He noted that it depended on his goals, whether they were to develop literacy or some sort of skill. He stated:

> So, maybe the real SCTIL lab is if I say that the normal cookbook lab is in the lower bottom corner, completely teacher-directed, that we give them something that we at least know the answers to, and is a BIT more cookbooky, but not complete, like they're working in my lab. I don't know. For my class, this [pointing to the 'undergrads in research lab' point] may be too much of a goal, and maybe we need to move it back to X marks the spot [pointing to center of the figure]. So the center of this may be more of what I could do in the classroom, and if they want to do work in the lab [pointing to the 'undergrads in research lab' point], then

> maybe they'll be there. This is totally hokie [seemingly frustrated with the continuum], but it's fine. I guess, given the paradigm here, I would say, I started here, we went ¾ of the way up to the top right corner, and now I'm saying, well maybe in terms of the limitations of this class, maybe that's too big of a project. IF we were going to implement the lab that I designed at the workshop, as opposed to a larger group project which may be inquiry-driven but not follow the SCTIL inquiry article at all, I'd design it be more here [see Figure 6, Point 3]. (Interview 3)

Overall, Professor Propes's beliefs about effective inquiry-based teaching were constrained when trying to fit the SCTIL inquiry article model with the goals of his course. Throughout his experience in the SCTIL program, he maintained a strong belief that active learning in a research lab environment represents a high degree of inquiry and a high level of student-directedness.

Environmental Constraints

Prior to Professor Propes's experience in the SCTIL program, he anticipated his biggest constraint would be coming up with a research question for an inquiry article lab. After learning about the SCTIL inquiry article format and thinking about how he could use this in his own lab course, he encountered many unexpected constraints that led to his decision not to implement the lab.

The first constraint was the lack of a cookbook-type lab to convert into the inquiry article format. Entering into the SCTIL summer institute, Professor Propes was not prepared to develop this new type of lab because his existing laboratory course design was not conducive to this particular approach. He explained:

> I understood what the motivation was for the inquiry article and, trying to turn cookbook labs into non-cookbook labs, but my challenge was that I didn't really have a cookbook lab to transform into a non-cookbook lab. Or more specifically, that I didn't have a hypothesis-driven lab that could be turned into an inquiry article type of lab. Because a lot of these systematic classes, we really learn the vocabulary of how to identify plant families, what's the diagnostics characters for this. There is no

> hypothesis, there is no 'we are testing this,' so the inquiry article format doesn't really FIT with that kind of lab. (Interview 2)

The second constraint Professor Propes identified was an entire semester of course content planned out with little room to incorporate new things. He noted that he already had "a full schedule of things for them to do," and he was hesitant to bring in this extensive design of a new approach (Group Meeting Interview).

An additional constraint was the use of living plants that could potentially die before students collected their data. Also, he would have to orchestrate their growth so that all 20 plant species would flower at the same time, something that he thought would be "a HUGE effort" for the plants that required a longer growth time (Interview 3). He noted that he had not previously conducted this research, so he was not able to anticipate students' outcomes for their research; however, he was enthusiastic about having the students conduct authentic scientific investigations.

During the third interview, Professor Propes explained that he felt the biggest constraint in the lab was the teaching assistants. When asked to elaborate, he stated:

> Because they, well, two things. One, they have no idea what this SCTIL business is, and although they're all for inquiry-driven stuff, they're very skeptical of this sort of semester-long project. And the other one is, they are sort of advocates for the students, and so they have to hear the students whine about how the class is SO much work already. Anyway, that was interesting because I do give the teaching assistants a lot of latitude and say about what goes on in the lab, I didn't say, 'Okay, this is how it's going to happen, on top of everything else you're already doing.' So I think that was sort of an unanticipated restraint, that they had resistance. . . . And when I said, 'Okay, look, this isn't going to happen,' they were relieved. (Interview 3)

He went on to explain that he thought the teaching assistants were relieved "because we don't know the answer, it's too open-ended, and it would have been a potential nightmare to keep track of, more work for them. I mean, they're here to get a PhD, not to teach a class fulltime [spoken sarcastically]" (Interview 3). Professor Propes noted that he agreed with his graduate students that the SCTIL lab would add a considerable amount of work for them.

In summary, Professor Propes encountered several constraints to designing and implementing a SCTIL inquiry article lab in his course, both those that he had control over and those that he did not.

Self-Efficacy

Professor Propes's efficacy level remained somewhat high after experiencing the SCTIL program. Prior to the summer institute, he expressed hesitancy when talking about the students' outcomes. Following his experience with the program, he still talked about not knowing if it would "work" or not (Interview 3). He remained confident in his ability to implement the teaching approach. He stated:

> I'm not afraid to try new stuff and have it flop, or let a teaching assistant try something new and let it flop. Whether it works or not, I don't know. I mean usually things don't work the first time, and that's sort of what I think this semester was. (Interview 3)

Therefore his self-efficacy for teaching with the inquiry-based model in the future was unchanged regardless of his constraints during the development process.

Attitude

Professor Propes's attitude varied throughout his experience in the SCTIL program. Prior to the summer institute, his attitude was neutral; however, after learning about the inquiry article format, he had a positive attitude towards the idea of using this type of inquiry-based teaching approach, yet a negative attitude towards having to design and implement it in his particular context. He felt that it would be forcing the fit in his course, and tried to design a version of it simply to meet the requirement as a participant in the SCTIL program. He stated:

> I'm not trying to be a reluctant person [spoken defensively], and if anything I'm going to DO one just to DO ONE so I can say, 'Okay! LOOK, I DID ONE! Fine! Leave me alone. [laughing] I've got to do other things now.' (Interview 2)

By the end of the program, Professor Propes had a somewhat positive attitude towards the instructional approach and a somewhat negative attitude towards the implementation of this approach.

Knowledge and Motivation

Professor Propes gained new knowledge about the inquiry article format through the summer institute and trying to the use the model in his own context. The SCTIL instruction included information about the essential features of inquiry, the inquiry continuum, and the design of an inquiry article. Through Professor Propes's second and third interviews, his discussion of plans for an inquiry article lab reflected his new knowledge. Professor Propes's original motivation for participating was strictly because of one of the SCTIL staff members, Professor Anderson. Later in the program, he expressed that he appreciated the networking aspect of the program and taking time out of his busy academic life to think about his own teaching. He explained:

> If for no other reason it was nice to just take three days to just think about your teaching and hear other people talk about their teaching, and [Pause] 80 hours a week you're doing research and everything else you've got going on, so it's nice to be reflective about your practice. (Interview 3)

He also expressed his interest in conducting a different type of research outside of his own laboratory environment, connecting with science education faculty and graduate students, and getting a publication out of his work. He stated:

> I have NO idea what [the students] are going to find—that's part of why I want to do it! Because I want to know! That's what I like about doing research in this education stuff—we're going to make lots of mistakes and a lot of it is not going to work. . . . But I really want to get this off the ground in the next two years to the point where it's well-done. I hope to get these people onboard, and get a publication out of it, and move on. Keep on doing it, or if it's not working, do something else. (Interview 2)

Overall, Professor Propes's motivations were to get publications, network with colleagues in education, and try something new in his course for his students, regardless of if it worked or not.

Environmental Responses

Professor Propes discussed how he expected his students to respond to his modified SCTIL lab. He explained:

> I expect I will get a wide range, I mean even just the way I normally run my class during lecture there are people that really just want to be consumers of information and not really think. But other people like it, you know, so I don't know. (Group Meeting Interview)

Since he was unable to implement the lab, Professor Propes was not able to talk about the students' actual responses; however, he did reflect on his colleagues' responses to his participation in the SCTIL program. Prior to our third interview, Professor Propes had his annual faculty review session with his departmental administration. He explained:

> Of course for a third year professor, all they really care about is your research and your grant money. And teaching they're like, 'you're spending way too much time on your teaching.' And that's true! But my response to that is, well I'm getting publications out of this by working with Katharine. But that has nothing to do with the SCTIL. That has to do with the phylogenic literacy part of the course, and so, and since Katharine is now a grad student, this is my chance to work with her on that. So this SCTIL thing was like, you've got one more thing to experiment with and develop that just wasn't a priority in light of everything else. So who knows if or when it will get implemented [laughing]. (Interview 3)

This response demonstrated the value his department places on publications and research over teaching. This priority fueled Professor Propes's desire to continue his collaboration with education colleagues for the purpose of getting teaching publications; however, this was not a priority for him. He has to be careful about balancing his time appropriately as a faculty member.

Change in Instructional Practice

Professor Propes's experience in the SCTIL program encouraged him to think more about how to align his lecture with the laboratory sections. He had not made a decision about definite changes to his instructional practice; however, he was thinking about it as indicated in the following statement:

> Well, I think like I said before, right now in this class, there's a big distinction between what goes on between the lecture/discussion time Tuesday/ Thursday morning, and then what they do in the lab, which is sort of more of a practical, you know like moving parts of the body or something like that, as opposed to anticipating a hypothesis. So I think in the future I am going to involve more phylogenetic problem-solving in the lab portion, but I don't know if the plant identification portion is going to become more inquiry-driven or not. They have a project where they go out and do a plant collection, and that's certainly inquiry-driven, but in terms of learning the vocabulary of plant morphology, plant anatomy, I'm not sure if its efficient or not to do it with an inquiry fashion or not. (Interview 2)

He continued to think about how inquiry could fit within the context of his course, and how he could use other versions of inquiry-based teaching, rather than the SCTIL model, to achieve his learning goals for his students.

Summary of Change in Professor Propes's Belief System

Professor Propes had a somewhat high self-efficacy for teaching with this type of approach, and strong knowledge and beliefs about teaching and learning. His attitude was neutral because he did not know what to expect, but he was interested in learning a new inquiry-based approach. Professor Propes's initial motivation for participating in the SCTIL project was to work with Professor Anderson, a science educator whom he respected. After learning about the SCTIL teaching approach, he saw significant constraints in aligning it with his course content and learning goals for his students. After trying to modify different forms of the approach for his context, he ultimately decided not to implement. He therefore had no reported responses from his students in the classroom.

Overall, his belief system was not significantly influenced by the experience other than a change in attitude and motivations. He had a positive attitude towards the approach but a negative attitude towards the design and implementation of it. His motivations for participating in SCTIL grew from working with Professor Anderson to implementing versions of the SCTIL format in the future in order to gain publications.

Case #4: Professor Rogers

The following case about Professor Rogers is divided into four sections. First I introduce him by describing his current faculty position, his teaching experience, and his self-reported teaching practice. In the second section, I describe his belief system about inquiry-based teaching prior to participating in the SCTIL program. The third section focuses on his written inquiry article lab and his plans for implementation. I present how this written document and his plans for implementing it changed between its first draft, written during the SCTIL summer institute, and the final draft, implemented during his course in the Fall of 2007. In the final section, I describe the evidence-based changes in Professor Rogers's belief system about inquiry-based teaching.

Context of Professor Rogers

Professor Rogers's teaching experience, current faculty position, and teaching practice played an important role in influencing his experience in the SCTIL program.

Faculty Position and Teaching Background

During the fall of 2007, Professor Rogers began his second year as an Assistant Professor in the physics department of a large research university. During his first year he taught one course in the fall and was released from teaching in the spring semester. The course was a Physics content course designed specifically for elementary education majors. No science majors were enrolled in this course. Professor Rogers planned on teaching this course again during his second year. He described this course as having "a very low-level of physics but a lot of hands-on stuff—the idea is sort of that most of the projects they do in class, they could do with grade school kids in the future" (Interview 1).

Professor Rogers received his doctorate in physics in 2004. During his time as a graduate student, teaching was a requirement for his doctoral program; therefore, part of the first year for all doctoral students included weekly meetings on how to be a teaching assistant. He led recitation sessions for undergraduate science courses to meet his teaching requirement. He noted that this was different from his experience as an undergraduate science major at a small liberal arts college where all course instructors were professors rather than graduate students. As a post-doc in a national laboratory, he helped implement a 1-week summer school designed to train graduate students in using the techniques they used in their facility. He stated:

> So basically at the start of the week there were a series of overview lectures about various techniques and then throughout the week, they broke into groups and did actual experiments. I was basically in charge of one of the introductory lectures. (Interview 1)

Overall, Professor Rogers entered the SCTIL program with limited teaching experience.

Self-reported Teaching Practice Prior to PD

Professor Rogers's first year of teaching was a smooth transition for him. He worked with a colleague in the physics department who was also teaching a section of the same course and he followed what she taught. He stated:

> So I was sort of brought in as an additional teacher to teach an already developed course, which made it a lot easier. In fact there were two sections, so I was only teaching one of them. And so I was able to basically, you know, copy what the other professor was doing. I had the second class, so the other professor had Mondays and Wednesdays and Fridays, and I had Tuesday and Thursday and Friday. So I, you know, I would sit in on that professor's class and basically duplicate it in my section. (Interview 1)

When asked to describe a typical class, he responded:

> It's about one hour and 50 minutes twice a week, then 50 minutes once a week. Last year I had about 18 students, so it's not a huge class. They get

> broken down into groups of three where each group has their own table where they'll do experiments as a group. And then [Pause] so there'll be a little bit of lecturing. Then they'll have activities to do and a lab book that will give them instructions about what to do. And I'll tell them to do particular experiments and then we discuss it and have groups come up and talk about what they did and what their results were. And they do a lot of writing on white boards. They have their own small portable white boards where they draw out their problems and their experimental results and whatnot on. Getting them to present what they did to the rest of the class is also a big part of this. (Interview 1)

Overall, Professor Rogers reported that he relied on the other professor teaching the second section, his science workbook, and group work strategies in his teaching approach of this course. When asked if he planned to teach the course differently in his second implementation during the fall of 2007, he replied:

> I'd like to try to do some more hands-on activities for the mechanics section. There are a lot more lab activities in the electricity section than in the mechanics section. But, you know, figuring out good experiments to do within a class period that they can really get is [Pause] I'm not sure how I'll be able to come up with anything new in that regard. (Interview 1)

Professor Rogers's self-described teaching practice consisted of his use of hands-on activities, small group work with students, and short lectures. His future plans included adding more hands-on activities to his courses.

Nature of Belief System about Inquiry-based Teaching Prior to PD

In the following sections, I describe Professor Rogers's belief system about inquiry-based teaching prior to the SCTIL professional development program.

Beliefs

Science as inquiry. Prior to the SCTIL program, Professor Rogers was unable to articulate his definition of inquiry. He explained that he was fairly unfamiliar with the term, and that in terms of scientific inquiry in his field, he would guess that "you would have some problem, you'd try to figure it out, a standard hypothesis, experimentation analysis sort of process" (Interview 1). He was quick to note that he thought this was different from inquiry in the teaching context, but he could not elaborate.

Inquiry-based teaching. While Professor Rogers initially felt uncomfortable discussing inquiry-based teaching due to his lack of understanding of the term, he gradually opened up about his views during Interview 1 and was able to discuss the teaching approach based on his assumptions. He conjectured that the purpose of the approach was "to try to get students to think about questions and problems before they get handed a set of facts" (Interview 1). He presumed that in such a classroom, the teacher would "help pose the problem and help shape the boundaries of the problem, because obviously there are more questions out there than you can possibly teach within a semester, but you still have particular things you want them to learn" (Interview 1). When discussing what skills he might need in order to implement inquiry-based teaching, Professor Rogers focused on understanding his students' incoming knowledge in order to guide their steps to "where you want them to be" (Interview 1).

In reflecting on his own teaching in physics, he noted that based on his understanding of inquiry-based teaching, "a lot of what I do would fit within that [definition]" (Interview 1). In describing an example of inquiry in his classroom, he stated:

> Well, for example, we start them out with a battery and a light bulb, so essentially a battery and a resistor, so they learn voltage and current. And then you introduce, 'okay well what happens if you stick in a second resistor,' and so it sort of gets posed as a problem and they have to try and figure it out and learn from what they measure, what that means in terms of voltage and current and those sorts of things. And then you go, 'well we did this in resistors in series, well what happens if you put them in parallel?' And sort of build on it from there. (Interview 1)

Professor Rogers explained that he felt this approach was not appropriate for all science courses. For example, upper-level science courses are usually made up of highly-motivated students, and therefore the teacher's role is to directly give them the content. He stated:

> If you're teaching an upper division section on something very specialized where the students have a pretty good well-developed skill set and you just need to build on that, then a lot of times, and they're good students, they're studying the subject they want to study. Sometimes what you really need to do at that point really is, you know, shovel more information in them and they're ready to take it. And if you try to force an inquiry technique on that it may just end up slowing things down. (Interview 1)

Professor Rogers felt that using an inquiry-based approach was most appropriate for lower-level courses, teaching students who he felt needed to build their skills and knowledge in the content.

One disadvantage he identified to using a problem-based approach was the restriction for breadth of content. Professor Rogers expressed concern about having to give up physics content within his course. He explained:

> [In learning science with problems,] you don't get to cover as much material. And you know, that's something that I'm not positive where the tradeoff really is because that is one downside. I hope that they're learning it really well, but there's a lot of stuff that we're just not touching. (Interview 1)

Student learning in science. As Professor Rogers discussed his beliefs about how students learn science in general, he noted the importance of life application to inform them as citizens of the community. He stated:

> I think they really need to see how it connects to their lives. If they don't know how some of the abstract concepts make any difference, then they're really not going to care. . . . If they don't know how it connects to their lives, they won't really remember it and they'll get it confused. That has

> long-term consequences in terms of things like you know, public policy that's affected by science. If they learn something about particle physics in high school and they have some screwy notion about nuclear reactions and they get the concept completely screwed up because they didn't see why it ever mattered, then you know, when it comes time to, you know, are we going to allow a new nuclear reactor to generate power down the road? Ideas form just from, you know not making the connections can end up having an effect on….that it really shouldn't. (Interview 1)

As he reflected on his students' learning in his own class through his problem-based approach, he explained that he thought they excelled in this type of learning environment because "they have things to do—they're not just reading the whole time, they're not just listening the whole time, they actually get to do stuff" (Interview 1). He placed great value on the hands-on approach to problem-based learning.

Social Norms

As a new faculty member, Professor Rogers explained that he was currently not familiar with the teaching culture within his department. He drew from what he learned during his job interview process to discuss the department's value of teaching for tenure. He stated:

> I haven't had a lot of discussions about teaching. Largely it seems to come up when you know, issues of course assignments and whatnot come up. I do know that this was something that I probably paid more attention to during the interview process in terms of what expectations were and whatnot. And I do know from that that in terms of the tenure process, that bad teaching can sink you. So, if you're a bad teacher and you're not doing anything to get better, that that will spell your doom. But as long as you're decent, then it's not the teaching that will get you. And then if your research is doing bad, great teaching can't save you. (Interview 1)

Professor Rogers also talked about the physics department's interest in recruiting more students, and therefore the administration does not want to "turn off" potential students with bad teaching (Interview 1).

He explained that the typical teaching style in his Physics department depended on the class, but was primarily the lecture format. He noted, “The upper division courses are where you start getting smaller groups of students, and you get more intimate class environments to allow you to interact more with the students” (Interview 1). He didn’t think it was a common occurrence for teachers to teach using the problem-based approach that he and his colleague used.

Environmental Constraints

In anticipating possible environmental constraints in implementing the SCTIL inquiry article lab approach, Professor Rogers focused on students’ poor laboratory skills and the complication of the activities. He stated:

> Well it’s time consuming because, you know, a lot of these kids have never really had a lab course before and, they’ll run into problems and some of the problems are them not knowing what they’re doing—some of the problems are that equipment sometimes malfunctions. Light bulbs die. If they can’t get their light bulb to light, is it because they’re not hooking it up right or because the bulb is dead, you know. So it does need a lot of attention to get the kids through the activities. (Interview 1)

He also explained that his students were at different learning levels and therefore it would take some longer than others to learn the scientific concepts. He stated:

> Some of them pick it up pretty easily, some of them it takes a long time to get concepts, and so do you slow down for the slower kids, do you keep going fast to keep the faster kids interested? Playing that balance is tough. (Interview 1)

Professor Rogers’s primary concern regarding implementing the inquiry article approach was his tension between guiding his students in their learning process yet also meeting their varied learning needs.

Self-Efficacy

Professor Rogers described his efficacy of teaching with a problem-solving approach as being at a moderate level; however, he was hesitant with his ability to design this type of course. He explained:

> I'm pretty comfortable with it so far. What I don't really think I have yet, which I thankfully haven't needed, is a good handle on designing this sort of course—because I came in with the whole course basically mapped out, all the activities prepared. So that stuff was already done by the time I got here, and so all I had to do was really implement it. And now I think I have the basic skills for it. Part of it is just practice. But in terms of how do you develop a course like that, you know that's something I've never done, so if I wanted to either really change it or create a new course with similar techniques, that's something I feel like I couldn't do easily at this point. (Interview 1)

While Professor Rogers was comfortable with implementation, he was uncomfortable with designing inquiry-based lessons.

Attitude

Professor Rogers had a fairly neutral attitude towards learning and implementing the SCTIL inquiry article approach. He made the following comment with little emotion: "Well I'm not exactly sure what [the SCTIL program is] trying to give, so I'm pretty open in terms of what it's going to provide" (Interview 1).

Knowledge and Motivation

Professor Rogers had no incoming knowledge about the SCTIL inquiry article format. The summer institute was his first exposure to the inquiry-based approach. He had three main motivations for participating in the SCTIL program. The first was because he was curious about the inquiry-based approach to instruction. Second, he was encouraged by a fellow physics professor, Professor Lee, who was planning on participating in the SCTIL program and recruited Professor Rogers to join her. Both professors would be teaching different sections of the same physics course for elementary education majors in the fall of 2007. Professor Lee was not the same colleague he worked with during his first implementation of the course. And finally, Professor Rogers was motivated to participate because he felt he should make an effort toward improving his teaching for the purposes of tenure. He stated:

> Although teaching generally isn't the make or break of tenure, it's still you know, if the research is on that dividing line, then teaching might tip it over and it's, you know, an opportunity to work on your teaching isn't something you should turn down without a reason. Not for me at this stage. (Interview 1)

In summary, two of Professor Roger's motivations were external, coming from colleagues and the tenure process.

SCTIL Inquiry Article

At the end of the first day of the SCTIL summer institute, participants were asked to convert one of their labs into the inquiry article format. They submitted this first draft to the SCTIL staff members and peers for feedback. In the following section, I describe Professor Rogers's first draft as compared to his final draft of his first inquiry article implementation during the fall of 2007.

First Version of Inquiry Article

The first lab Professor Rogers modified into the inquiry article format was on the topic of wire resistance (see Appendix G for Inquiry Article version 1). His inquiry article investigation was titled "The effects of wire thickness on electrical resistance." This lab focused on the concept that increasing wire length increases resistance, and increasing wire thickness decreases resistance (Inquiry Article version 1, Professor Rogers). The inquiry article write-up included an abstract, introduction, materials and methods, results, and discussion section. He also included a figure representing the relationship between resistance and wire thickness. Professor Rogers did not discuss the format of his pre-modified version of this lab nor how different it was from his first draft using the inquiry article format.

Final Version of Inquiry Article

In the implemented version of Professor Rogers's inquiry article lab, he modified the requirement of testing two independent variables (wire thickness and wire length) to giving students the option of which of the two variables they wanted to test (see Appendix G for Inquiry Article version 2). He noted that he made it more open-ended in this regard. In the following statement, he explained the changes he made to this inquiry article lab:

> So the [inquiry article] I had at the end of the workshop was about the resistance of various thickness wires. And I had REALLY written it as thickness versus diameter of the wire, and then suggesting, well how else could you characterize the cross-section? But I've actually scaled back what I'm going to be giving them, a step further back, just to an experiment they've already done which is resistance versus length of the wire, and then I ask the question about, what about the cross-section. So then they could do it in terms of the cross-sectional area OR the diameter. (Interview 2)

Professor Rogers continued his discussion by explaining why he decided to scale back his lab focus and also discussed his goals for this lab:

> Because I think the way I had written it, I think enough of them are going to have a problem figuring out what the next step is in terms of evaluating the cross-section dependence [Pause] because the ultimate thing to get them to realize would be that the resistance is inversely proportional to the cross-sectional area, not the diameter, if you only vary one direction of the cross-section it will vary in proportion to that, and so, blah blah blah. But so, that's what I want them to get. . . . If you take a step back, even if they can JUST get to that, 'resistance goes down with the diameter going up,' then they still learn something new, without you having to essentially take them by the hand and lead them right to the answer. (Interview 2)

In discussing his implementation of the lab, Professor Rogers reported that he had experience in implementing an inquiry article lab prior to his own. In working with

Professor Lee, his colleague who also participated in the SCTIL program, they both implemented the same labs; therefore, he had practiced implementing an inquiry article lab using her lab on magnetism within his fall 2007 course. He noted that he made a slight modification to her lab during his implementation. He explained:

> And we actually ended up doing it differently in the two classes, not in terms of what they had to do in class and coming up with experiments and doing measurements, collecting all the data, but apparently she had set up the inquiry article so that the abstract and introduction could be duplicated from the inquiry article SHE gave them, and then they would fill in the methods and results and discussion section. I did it where I basically had them rewrite the whole thing, so write their own abstract and introduction. But, that was interesting and I'm mostly pleased with what they've done, but I can tell that they don't fully get it yet. Which is not surprising for the first time, I didn't expect them to, but there is definitely still a bit of a disconnect from, what do we find out in the lab, and what do we REALLY PROVE from that, and how does that relate to the broader question that we want to ask. (Interview 2)

After implementing his colleague's inquiry article lab in his course, Professor Rogers decided to keep the same writing expectations he had originally set for his students for his inquiry article. He handed out his inquiry article on Monday and introduced the problem, answering questions from the students about the process of the lab. On Wednesday, the students conducted their experiments, took measurements, and created tables and graphs. He instructed his students to turn in their inquiry article labs on Friday, then the students exchanged papers and did peer reviews, discussing their comments with each other. When asked if the students had engaged in peer reviews before, Professor Rogers replied, "We did that with the other professor's inquiry article" (Interview 3). Following the peer review session, students took their papers home and made revisions over the weekend, turning in their final product the following Monday for a grade. He made no changes to his plans for implementation or expectations for his students' final product throughout the week of the inquiry article lab implementation.

Change in Belief System about Inquiry-based Teaching

In the following sections, I describe the changes, if any, in Professor Rogers's belief system about inquiry-based teaching after implementing his first inquiry article lab within the SCTIL program.

Beliefs

Science as inquiry. Professor Rogers's beliefs about inquiry expanded from scientific inquiry to include an understanding about classroom inquiry. He was able to put his views of science as a process (i.e., ask a question, form a hypothesis, investigate, etc.) into the context of the classroom using the inquiry continuum. These views are expressed in his beliefs about student learning and inquiry-based teaching.

Inquiry-based teaching. During Interview 2, Professor Rogers explained what he learned through his experience in the SCTIL program:

> So one of the big things of course was [Pause] what the staff sort of means when they say inquiry, because it is a broader definition than what I was expecting. And that's helpful to get more familiar with the terminology being used. . . . Basically, my previous ideas were more in line with what they called full inquiry. The sort of idea that you could scale it back as much as you needed to, and still sort of fall within this category, as sort of, it wasn't something that I understood to be part of the term, previously. . . Yeah, so there's a range of different things, but still falls into this word. (Interview 2)

He was able to articulate his view that inquiry in the classroom is not strictly full inquiry or no inquiry. In reflecting on his own teaching practice, he felt that he included inquiry in his previous instruction, but the SCTIL program gave him a framework for improving his implementation of it. He explained:

> What I'm teaching, it is geared in that direction to some extent already. But I learned, of course, new ideas of how to implement that in class, sort of finding new directions, in terms of how to structure the class so you don't have to GIVE them what questions to ask, but still push them towards the sort of subjects you need them to examine. Because if you just get completely hands off then they may head in completely useless directions, but to get them coming up with questions on their own, without too much danger of them going in absolutely wrong directions, but also without having to spoon-feed them everything. (Interview 2)

Professor Rogers was hesitant to move towards a more open-inquiry, student-guided approach for fear of giving up full control to the students. He explained, "They're really not very independent about thinking about science—it does not come easily to them at all" (Interview 3). Therefore, he felt his instruction should accommodate their level of learning. He was concerned that they were unprepared for that level of responsibility and would be unsuccessful in his course. He explained his role in implementing an inquiry-based teaching approach in the following statement:

> I would be setting up the basic overarching question . . . setting up the framework for what the basic question is, framing things so that they can figure out what question exactly they want to ask and why, and then DURING the lab the big thing is going to be helping them make sure things technically work out. (Interview 2)

During the second interview, I asked Professor Rogers to identify where he felt the wire resistance inquiry article lab fit on the Inquiry Continuum (Brown, et al., 2006), which was used in discussion at the SCTIL summer workshop (see Figure 7). As he pointed to the figure, he explained why he felt his labs fit in those locations:

> So I think it was about here [pointing to Figure 7, Point 1] and now it's probably [pointing to Figure 7, Point 2] I haven't shifted a lot, probably shifted a bit. . . . Basically because I haven't presented them with one way of measuring resistance dependence on the cross-section, then they're no longer constrained, 'oh we can use everything except that.' And since that one thing that I gave them in the original lab was the most obvious one, taking that away, I think will make it easier to sort of play around with, 'Okay, what do we want to look at?' (Interview 2)

During Interview 3, Professor Rogers explained that his identification of the lab during Interview 2 remained the same through his implementation (see Figure 7, Point 3). He had decided to make the change in independent variables prior to implementing the lab; and therefore, no changes were made between the two time points.

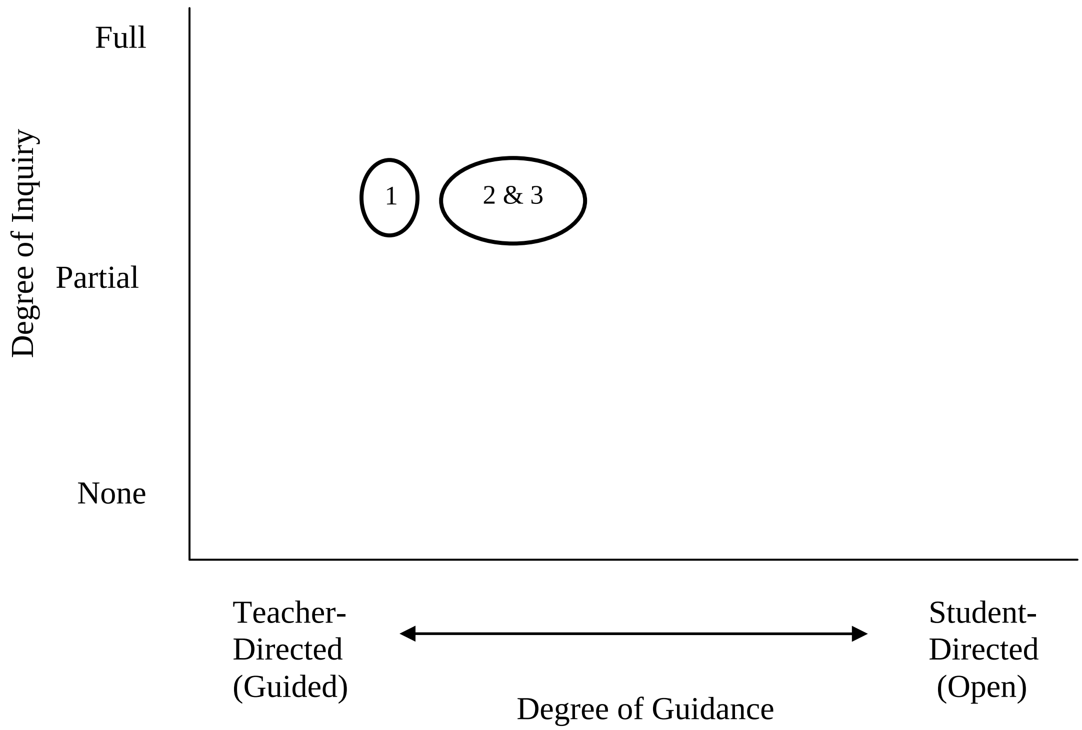


Figure 7. Professor Rogers's Inquiry Continuum (modified from Brown et al., 2006)
1=Pre SCTIL program; 2=pre implementation; 3=post implementation.

Student learning in science. Prior to the SCTIL program, Professor Rogers expressed that he felt students learned science best when it was applicable to their lives and informative to them as citizens of the community. He also thought his students enjoyed his problem-based approach to learning physics because it kept them active and involved in the class activities. Following the summer institute, Professor Rogers was enthusiastic about the inquiry article approach because, as he explained, "it would help them familiarize themselves more with the process of science as an endeavor" (Interview 2). He felt students would build on what they know with each step of the process. He particularly thought it would be excellent for his education majors who would be teaching kids with similar misconceptions to their own, and this process would help them understand how science is authentically done (i.e., how tentative conclusions are made, etc.).

During the second interview, Professor Rogers had met his students and could discuss his perception of their future learning experience with the inquiry article approach. He indicated several concerns, including their math skills:

> The [education majors'] geometry and math skills are both really bad, so just things like the fact that, how you vary the diameter, the mathematical relationship between that and how the area is varying, they don't KNOW that, it's very simple stuff but they don't know it. You have to hold their hand and walk them through. Just the fact that you double the diameter of a wire, the cross-sectional area is four times as big. They don't KNOW that. [speaking in a matter-of-fact tone] You have to show them, it doesn't occur to them on their own. (Interview 3)

In the following statement, he compared the math skills of physics majors to education majors:

> Compared to the physics majors, if the physics majors are having math problems it's at the calculus level, it's not at the algebra level it's not at the arithmetic level, it's at a higher level. And so there are a lot of things you tell them and they will just get and you don't have to spend a lot of time figuring out the misconceptions that they have because they can't get the math. (Interview 2)

He was frustrated with his students' lack of physics and mathematical knowledge and seemed to be discouraged by their incoming misconceptions. He also expressed a concern that education majors see science as wrong or right, as indicated in this statement:

> I think [they're having problems] partly because they expect that we give them assignments that they're supposed to come up with an answer, and if its not a definitive answer, then they think that we give them problems that only have definitive answers. That's what they're used to. 'So what's the RIGHT answer?' (Interview 2)

Following his implementation of the wire resistance inquiry article lab, Professor Rogers responded to questions about what he felt his students had learned within their lab experience. He stated:

> Well most of them learned that they were wrong at least . . . most of them predicted that if you make the wire thicker that the resistance will go up, and that's completely backwards. They figured out that they were wrong. I think a lot of them don't really understand WHY they were wrong, they don't really understand why it's this way and not the other way around, but they all know that, the ones that predicted the wrong thing, they do all know that they were wrong, I just don't know if they understand why yet. (Interview 3)

When asked if he thought his students would eventually understand this reasoning, he replied, "I hope so" (Interview 3).

Environmental Constraints

Professor Rogers explained several constraints that hindered the effective implementation of his inquiry article lab. Overall, these constraints included students' lack of skills, knowledge, and imagination, as well as the classroom's lack of supplies in carrying out their ideas for investigations. When discussing the constraints in this lab, Professor Rogers focused mainly on his students' shortcomings. First, they did not have the technical skills to use basic equipment in the lab, such as a multimeter, which measures voltage, and Excel computer software, which is used to create graphs and figures. He was disappointed with their lack of preparation in these areas. In Interview 2, he reflected on their ability to use basic equipment in previous labs as he prepared to implement this lab. He stated:

> DURING the lab the big thing is going to be helping them to make sure things technically work out, using multimeters—they're not that complicated but things sometimes go wrong, and they're not at a stage where they can figure out whether something's going wrong or something's just not giving them what they expect. They don't know the difference yet. . . . They don't know that something's wrong with it, rather than just, 'oh it's not meeting my expectations, I need to figure out about what's going on.' They don't know when it's a technical problem or when it's a problem with their understanding. (Interview 2)

An unexpected constraint was their lack of skill in using Excel. He explained:

> We had them work on Excel spreadsheets to plot out their data, and there was a fair amount of mechanics with that that they were unfamiliar with. So, how to plot things in Excel, and even just the idea that with the same set of data, you can plot it different ways. (Interview 3)

The ability to use Excel and make sense of the mathematical relationships in their calculations was something Professor Rogers expected his students to grasp. He was concerned with their lack of mathematics knowledge at this point in their academic career, and explained that this was a common occurrence with his elementary education majors. He stated:

> It's kind of worrying in some respect, because it means that their math education is terrible, it's ghastly. If you walk them through with a square, they can see that, if you double the size of a square then the area is four times as big. They can kind of get that. But if you just, 'Okay, that's what happens with the square, what happens with the circle?' It doesn't just immediately click that it's going to be the same relationship. So [Pause] that issue with bad math skills is something we have to struggle with all the time. And it means that, the final thing I want them to get to, the thing I want them to arrive at, that area is what matters, that they have to go through some of these steps that if they have decent math backgrounds wouldn't take any time at all. (Interview 3)

Professor Rogers expected that even non-physics majors should have basic mathematical skills. In his effort to implement this inquiry article lab, he felt that he could not reach his desired level of depth because of the constraint of needing to take extra steps in supporting his students' learning. He noted, "This lab was harder than I expected to implement" (Interview 3).

The final constraint Professor Rogers discussed during his second interview was the fear that his students' ideas for investigations would require supplies or different measurements that were not available:

> One of the big unknowns at this point is, I don't know how inventive they're going to get about alternative measurements to do, because we already have a set up where they could do the most obvious measurements, but if they want to do something more creative, I want to try to accommodate that but, there are certain things that [Pause] may be difficult to do. (Interview 2)

After implementing the lab, I ask him if this was a problem. He replied:

> Not really, they were slightly disappointing in that respect that they weren't very imaginative. [Slightly laughing] They hit the varied wire diameter and they were satisfied and didn't really care to press it any further. And so it is what it is. (Interview 3)

In summary, actual constraints that Professor Rogers reported as an issue during his implementation were the students' lack of imagination, mathematical skills, and Excel skills.

Self-Efficacy

While Professor Rogers initially held a moderate self-efficacy towards his teaching of the inquiry article format, this decreased somewhat after participating in the SCTIL summer institute. After practicing the inquiry article implementation using Professor Lee's lab, he felt uncomfortable in his instructional skills. He explained how his comfort level in normal, non-inquiry article labs, was high compared to this type of lab:

> All the other labs in the book, basically I've done them before, so I'm comfortable with them. Some of them work well for directing the students, some of them they go through the motions, I don't know if they learn much from them. But doing them is an easy operation. And there aren't really snags that I don't know of for the other ones. The other pitfalls are generally equipment failure; you know what to do about equipment failure. But for this [Pause] I don't expect anything really show-stopping, lurking, but you never know until you try. (Interview 2)

As Professor Rogers prepared to implement his lab, he expressed concern about the unexpected responses he might receive from his students. He preferred to know every step of the lab, from the tasks the students would do to the answers they should give. The unknown that came with a more inquiry-based lab approach contributed to his decreased efficacy towards his implementation.

After having implemented his inquiry article lab, Professor Rogers expressed an increase in his self-efficacy towards his ability to implement the inquiry-based approach. He explained:

> It seems like what I'm finding is that I have to expect that if I'm introducing a new [inquiry article lab], that I really have to think about it as a work in progress, at least the first time it's, it isn't going to go right, that there aren't going to be any problems. But, you know, given that and given that inquiry articles can be changed, even if not just the written part but at least how to handle the class in class, that that has to be learned for each activity. That you just have to go through it and figure out as you're doing it, what works. (Interview 3)

During Interview 3, Professor Rogers demonstrated a reflective nature as he discussed his teaching in the inquiry article lab implementation. He seemed to become aware of his strengths and weaknesses in how he implemented the inquiry article lab, and began to consider changes he would make for future implementations.

Attitude

Professor Rogers expressed a more negative attitude towards the SCTIL inquiry article after implementation. He explained that he was “reasonably satisfied” with his design of the inquiry article prior to implementing (Interview 2), and expressed a dissatisfaction following implementation of the lab. He explained that while he was interested in the teaching approach, “it’s definitely a lot of work” and he felt he could only aim to implement two or three within future courses, if he chose to do so (Interview 3). He was frustrated with the time it took away from covering more material and explained why he felt he could only implement a small number of inquiry article labs within a course: “I hope there’s a payoff in terms of their comprehension, and there may very well be, but there’s still enough material that we need to cover that I don’t think we can do it very often” (Interview 3).

When reflecting on his implementation of the lab, he expressed a somewhat negative attitude, stating that he was “off in his expectations” (Interview 3). He explained what difficulties he had with the implementation of the lab in the following statement:

> In some respects, the two errors I made kind of balanced each other. One of the errors I made was, the methods for varying the cross section of resistors to test, doing anything other than just varying the wire thickness was harder to implement than I expected. It didn’t really work out well. That was balanced by the fact that [Pause] more of them predicted the wrong thing, than expected. The MAJORITY of them, in fact, predicted the exact reverse of what actually happens. (Interview 3)

This frustration with the students’ response contributed to his negative attitude towards implementing the inquiry article format.

Knowledge and Motivation

Following the summer institute, Professor Rogers’s new knowledge about the SCTIL inquiry-based teaching approach was evident as he discussed his labs and the modifications he made to his plans for implementation. He focused on aspects of the inquiry continuum with the possibilities of having full inquiry to no inquiry, and teacher-direction to student-direction. He also gained knowledge about questioning strategies that would shift his teaching style towards focusing more on students' explanations of ideas rather than a didactic, one-way approach. His motivations for participating in the SCTIL program did not change by the end of the study.

Environmental Responses

Prior to implementing his inquiry article lab, during Interview 2, Professor Rogers anticipated how his students would respond to this type of learning approach. He stated:

> I think they won't have much of a problem DOING it, but [Pause] I'm not sure how easy they'll be able to make those sorts of conceptual connections. The actual exercise of the lab, measuring the resistance of fatter wires, that's easy to do, so I'm not anticipating too much of a problem in running the lab itself. But I don't know what their reports are going to look like. (Interview 2)

In his implementation, Professor Rogers reported that his students did experience difficulty in completing the lab. He explained:

> I, apparently mistakenly, thought that [their incorrect predictions] would be MORE of a problem when they were dealing with discrete resistors than when they were dealing with just the straight wires. I THOUGHT that they would intuitively understand that a thicker wire would have less resistance. And, in a certain respect, you don't even have to know that much about circuits to figure that out because, you can just imagine if you shrink the wire, and keep on shrinking until it disappears, at the point it disappears the resistance has to become infinite. So, you shouldn't expect it to get smaller and smaller and smaller and then jump to infinity, that doesn't make sense [talking in a matter-of-fact tone]. So, I expected more of them to be able to get it on at least a gut level that the resistance would drop when it was thicker. (Interview 3)

When asked why he felt the students couldn't get to that level of thinking, he responded, "I'm not sure. I don't know if they're just over thinking it or what, but it's very curious, I’m not sure exactly why they make that mistake” (Interview 3). Professor Rogers expressed high expectations for his students’ learning in this course. When they responded below his expectations, he was confused and unable to articulate why they had difficulties.

Professor Rogers appreciated having Professor Lee as a colleague, implementing a similar course at the same time. He was able to draw from her experiences in physics pedagogy. He stated:

> Well, it was helpful because, you do have to sometimes prod the students a little bit, in terms of ideas for what they contest and how they contest it, and so sort of, having someone who has done it and had students do a whole bunch of different ways to test the strength of the magnets so that you can sort of push students towards various ideas, that was definitely helpful. (Interview 2)

By the end of the SCTIL program, Professor Rogers discussed negative environmental responses from students, who generally had a difficult time with the learning approach, as well as positive responses from his physics colleague, who provided him with a support system to guide him in implementing this new teaching approach.

Change in Instructional Practice

Professor Rogers reported a small change in instructional practice during his participation in the SCTIL program. Although it was not a focus of the SCTIL program, he felt that his ability to improvise improved, as explained in the following statement:

> I do notice that I’m finding myself not, we have a workbook that we go along with that has planned activities, and I do find myself, I don’t know how much of this is a result of the workshop or just this education class, but I’m improvising more in the activities that they’re doing, and not just following exactly with the workbook concept. For example, if they have to build some particular circuit, and I notice that one class does it in a different way, maybe in a wrong way but still something interesting, then

> sometimes I'll then take that and have the rest of the class fiddle with that as well. (Interview 2)

When discussing his future plans for implementing inquiry article labs during Interview 2, Professor Rogers described a second lab on batteries that he developed through SCTIL and planned to implement in the remainder of the course. He explained:

> It's a little more direct. Basically what I want them to toy around with is, what happens when you use multiple batteries in a circuit. And so, it's very open-ended in terms of what kind of circuits do they want to design and resistors, but in terms of materials to use, it's all batteries, resistors and wires, that's it. You can put them together in all sorts of weird combinations, but THAT's all the material you need. So from that perspective it should be a lot more straight-forward. (Interview 2)

During Interview 3, he did not specifically describe his plans for future use of the SCTIL format in his course; however, he did draw from his experience in implementing to discuss what he would focus on if he did decide to incorporate the format in his future practice. He focused on the importance of spending more time on data analysis with his students so they would develop necessary technical skills. Knowing that his students struggled with using Excel software and simple equipment in the physics lab, he felt it would be important to extend this portion of the lab.

Summary of Change in Professor Rogers's Belief System

Professor Rogers entered the faculty development program with a moderate self-efficacy towards his teaching ability and low self-efficacy towards designing an inquiry-based instructional session. His neutral attitude and primarily external motivators for participating in the program, coupled with his weak knowledge and beliefs about teaching and learning contributed to a tentative belief system prior to entering the SCTIL program. After seeing how his students responded to his SCTIL lab (with little imagination, lack of math and lab skills, and not meeting his expectations in their learning of the content), Professor Rogers reported a slight increase in his self-efficacy for his instructional ability and a decreased attitude towards the overall approach. He did not like the idea of trading breadth of content for depth of content. While he learned about inquiry as being part of a continuum and adapted his instruction to be more student-directed, he did not seem to enact his belief that students learn by building on prior knowledge, and was frustrated when they seemed to have trouble with the concepts. He was unable to articulate why they had difficulty learning.

Professor Rogers did have an interest in learning about the pedagogy of inquiry-based teaching and had a colleague in the physics department who supported him; however, this was not enough to support an overall positive experience in the faculty development program. His attitude and primarily external motivators seemed to contribute to an unsuccessful experience and discomfort with learning this new teaching approach. While he implemented a SCTIL lab in his course as a requirement for participating in the program and planned to implement an additional SCTIL lab in the remainder of the semester, he did not express an interest in incorporating the format into his future practice.

Case #5: Professor Wilson

Professor Wilson's case is presented in four sections. First I introduce her by describing her current faculty position, her teaching experience, and her self-reported teaching practice. In the second section, I describe her belief system about inquiry-based teaching prior to participating in the SCTIL program. The third section focuses on her written inquiry article lab and her plans for implementation. I present how this written document and her plans for implementing it changed between its first draft and final draft implemented in her course in the spring of 2008. In the final section, I describe the evidence-based changes in Professor Wilson's belief system about inquiry-based teaching.

Context of Professor Wilson

Professor Wilson's teaching experience, current faculty position, and teaching practice played an important role in influencing her experience in the SCTIL program.

Faculty Position and Teaching Background

During the fall of 2007, Professor Wilson began her third year as an Assistant Professor in the Biochemistry department of a large research university. She typically taught one course a semester and spent the majority of her time conducting scientific research. She received her doctorate in biology with an emphasis in genetics in 1991, and had taught at the college level during her graduate program for 2 years. Her teaching experience included serving as a teaching assistant for the laboratory portion of two courses: genetics and developmental biology. Her role as an assistant for these courses involved preparing the laboratory for each activity, serving as the primary contact person for the students, and implementing the lessons created by the course instructor. She explained that the activities “were entirely set, as in ‘here’s your recipe, there’s the chemical room, this is your protocol, put it together and have [the students] do this.’ So we were told not to deviate from the protocols at all” (Interview 1). When asked what she learned from this teaching experience, Professor Wilson stated:

> I learned how to make solutions and [Pause] to some degree how to interact with the students, being not far beyond them at that point, it was more of a peer learning kind of thing, so I think that was good. I saw how to interact with students as a peer, and guide them through experiments. . . . And I think it gave me an appreciation of how much better a lab would go if you had time to go through it beforehand. (Interview 1)

During her first year as a new faculty member, Professor Wilson was asked to teach an upper-level Biochemistry course for science majors, a course that is based in the laboratory on Tuesdays/Thursdays with one additional recitation/lecture session on Mondays. She taught this course once a year each of her first 2 years at the research university. As she prepared to teach this Biochemistry course for the first time, she was given materials and advice from previous instructors of the course. Professor Wilson explained:

> This is a case where I was given a class saying, ‘this has been running for decades, this is what we do—fix it and make it better.’ And so I was actually given PowerPoints for the Monday lectures and labs and told they worked to various degrees, and basically to bring it to the 21st century. So the first year I just went through it as was, figuring I needed to know what’s broken before I can fix it [Pause] and just to see how it works. (Interview 1)

She noted that after her first semester, she began to revise the course and think about changes she wanted to make for future implementations.

Self-reported Teaching Practice Prior to PD

As a junior faculty member, Professor Wilson was in the early stages of developing her own teaching practice. As described in her teaching background, she spent her first year of teaching implementing the existing course design. She was not pleased with this design, as indicated in the following statement: "The way the program was handed to me, it was very cookbook, and I could tell from the first semester it was boring and the students got nothing out of it. I didn't like it" (Professor Wilson, Interview 1). Therefore, during her second year, she gradually began to introduce change into her course. She wanted to motivate her students to read prior to class, help them in conducting effective experiments, and design the week in a way that the class sessions built on each other:

> What I've slowly been doing the second year I was teaching was, assuming they KNOW the fundamentals, and some of them do, some of them don't, or at least that they have read the lab before they came to lecture, and that's something I'm trying to get them to do a little more forcefully. And then basically, spending that time not telling them about hydrogen ions but WHY it affects a buffer, how to make a buffer, how we use it in the real world, and basically guiding them through tricky parts in the lab itself. Then they do the lab the Tuesday and the Thursday, and then the FOLLOWING Monday, I've been going back and saying, 'Okay well what have we learned from the previous Monday,' and sort of do it as an introduction, they do the work and then the next week is sort of a review, plus a preview of the following week. It's become a huge time management issue, more than anything. (Interview 1)

As she explained the changes she made to her course, she discussed using a form of the SCTIL inquiry article lab after having attended a professional development seminar the previous year led by SCTIL staff members. This experience early in her teaching career greatly impacted her thinking about how she wanted to modify her lab design, and she subsequently modified and implemented a series of inquiry article labs during the following school year. When asked to describe a typical week in her Biochemistry course, she described one of the modified lab units she developed based on the inquiry article format:

> I probably start [on Monday during the recitation session] with a PowerPoint on an introduction to the topic, “This is pH, this is how you understand it,” and then go into specifics for the details of little tricky parts for this experiment, “When you get to this part, make sure you to do this,” things like that. Little tips that if they’ve read the lab and thought about it, they’d come up with, but they don’t usually read it in that much detail. . . . And then an overview of working applications, “How do you think this would happen,” so again one lab that I’ve revised a bit is working on pH and indicators. So I tell them about pH and what an indicator is, and then say, “Okay this is the cookbook lab. Based on this cookbook, this [pointing to report] is my dataset. This is my report,” so they have both the cookbook protocol and my inquiry article write-up. And my write-up basically is an abstract, materials and methods, and then my results and I described the results and the data, and I don’t do the conclusions because those are the questions that they’re going to answer. So I say, “This is the report, this is the expectation, this is how you write this up, these are the data that I got when I did the experiment based on this cookbook. So based on what you know of pH and indicators and rates, reactions and temperature and things, how would you make this different? You were supposed to do this lab but phosphate buffer isn’t available, so what would you change to figure out what parameters are really important?” So they come up with all the obvious changes . . . and they were able to basically think through it before they did it, on Monday. Then when they went into lab on Tuesday, they had to prepare buffers and make solutions and stuff, and basically it was the same protocol I had given them, but with the same parameter THEY had chosen to vary. So in some ways it was still cookbook. So Thursday, near the end of when they started to collect data, I had them give me their values and put them up on the board. So we went through ‘correct’ answers, and how you can be precise yet inaccurate, and that the data are what they are. How you interpret them makes a difference in the outcome and conclusions, and getting them to understand that you don’t simply throw away a data point because it doesn’t look right. . . . So I’m still trying to figure out how to assess that, and how to really appreciate what they get and what they don’t. (Interview 1)

She explained that while students collected data in teams of two, they wrote up individual reports. This experience with the inquiry article approach prior to participating in the SCTIL program was a unique aspect among the participants in the study. In reflecting on the changes she made to her course, Professor Wilson noted that she was pleased with the outcome and hopeful for continued improvement in her third year. She stated:

> The second year was much, much better, and I'm really optimistic for this upcoming year now, changing a lot more of the labs and bringing more technology-base, more inquiry-base, less cookbook kind of stuff, more discovery, what I consider a discovery-type of experiment. So, we'll see how that goes [laughing]. (Interview 1)

Overall, Professor Wilson's self-reported teaching practice was still evolving and she was eager to refine her use of inquiry articles.

Nature of Belief System about Inquiry-based Teaching Prior to PD

In the following sections, I describe Professor Wilson's belief system about inquiry-based teaching prior to the SCTIL professional development program.

Beliefs

Science as inquiry. Professor Wilson entered the program with experience as a scientific researcher and experience in using the SCTIL format. In her first interview, she associated the word inquiry with classroom inquiry and had trouble distinguishing it from scientific inquiry. She described inquiry in the classroom as discovery-based, providing students with a balance of independence and guidance. She defined inquiry in the following statement:

> In some ways, it's asking questions, but again, rather than inquiry [Pause] again, I'm not sure what they [SCTIL staff members] mean by inquiry. I think of it as more of discovery—giving them these tools and basic information and knowing you can go in these other directions, 'where would you go? How would you use this? What kinds of questions would you ask?' (Interview 1)

Professor Wilson's beliefs about science as inquiry were not explicit in her interview as she focused on the context of the SCTIL program and model during her interview.

Student learning in science. While Professor Wilson valued discovery-based learning in science, her elaboration led her to question her own learning style:

> That's one of the things I'm still trying to figure out, because if I knew how they would learn, I'd know how to teach. I have a hard time knowing how I learn [spoken hesitantly]. Well, I'm a very hands-on person. I can sit and read something but I understand it better if I can DO it with some guidelines about what I'm KINDA sorta supposed to get out of it. . . . Not everybody learns that way, and I KNOW that. Some people learn best by the cookbook method, um, some people really learn more by doing and learning and seeing. (Interview 1)

Professor Wilson's personal learning preference of active, hands-on learning played an influential role in her views of how students learn. This was reflected in her passion for research and engaging students in conducting investigations through her courses.

She emphasized the importance of students understanding that science is not always "black and white," but dependent upon the question asked (Interview 1). She stated:

> One thing I really picked up on last semester, was that these students have had SO much chemistry, and especially quantitative, and they would come to me and say, "Well is this the right answer?" And I'd say, "Well there isn't always a right answer, there is an answer you got based on the question you asked, hopefully based on the question you asked, there's an answer you get based on the experiment you did, and does that answer really fit the question you asked?" So if somebody's asked you, "Is it raining out?" And you say, "The sky is gray." That is an answer, but it doesn't fit the question. (Interview 1)

When discussing her goals for her students' learning experience, Professor Wilson emphasized that she wanted her students to be "overwhelmed by what's out there in the real world," connecting science to their everyday lives (Interview 1). She wanted them to understand that Biochemistry is already a part of their daily activities, as described in the following statement:

> Biochemistry isn't just in the laboratory, it's in your kitchen, when you're cooking it's biochemistry, when you're digesting it's biochemistry, and it doesn't stop when you close the textbook. To some degree it's not going to change how they cook or what they eat, but understanding that when they're not feeling well and they've been eating nothing but French fries

> and milkshakes for the last two weeks, that yeah there are probably some essential amino acids they're not getting. And even if it's not, well I'll eat right but pop a couple of vitamins. It's fundamental information that changes behavior and how they live their day-to-day life. (Interview 1)

Inquiry-based teaching. Professor Wilson described her role in an inquiry-based classroom as "literally, just to reign them in, when they head off on a tangent, bring them back in [Pause] because you know they'll spend hours off in a little corner where they'll just be circling the dust bunnies" (Interview 1). She explained that when she gives them their assignment and time during the lab session, they have multiple pathways they could take, and her role is to walk around the class and ask questions such as "what did you find, what is your protein, does it have a structure, what does that structure look like, what does that do *in vivo*?" (Interview 1).

Professor Wilson discussed the written product of the inquiry article lab as "a good way for me to assess what they're learning . . . I think that's where I get my best feedback, in the reports, much more than the exams" (Interview 1). In her Biochemistry course, she used a rubric developed by the previous course instructor to implement with her inquiry article labs. She modified the original version by expanding her content expectations. She noted, "I learned with students that you really need to be explicit about what you want, because they will interpret it however they want" (Interview 1). Her rubric consisted of a single list of components, along with the number of points each component was worth. When asked if students received all of the points if they included all components in their product, Professor Wilson stated:

> Yeah, well my thought is that if they do the bare minimum, they probably will get an A- to B+. The difference there is showing real understanding for scientific concepts, which pushes them more to the A+ level. So basically if everything is present, they get a 90%. From there, it's

> application to real world, taking the questions to a more global level, rather than just yes or no. (Interview 1)

She went on to explain that students could also lose points, but that she wanted them to show their work so that she could understand if they ended up with an incorrect answer. She stated:

> And they lose a point…and again this is something that freaks them out, I tell them I don't care if you don't come up with the right answer because you pushed the wrong button on your calculator. What I want is to see enough steps, to show their calculations, because if you don't have the right answer but you just shifted the decimal, or did a different formula, then I'll at least know where you went wrong. If you just give the wrong answer, then you lose serious points. And again, teaching them that it's the process of manipulation of the numbers, not the final answer that matters. (Interview 1)

Professor Wilson's experience in using the inquiry article format allowed her to reflect on what was most difficult about implementing this type of lab prior to the SCTIL program. She stated that the biggest difficulty for her was "assessing them, really understanding what they're getting and what they're not." She expressed concern that her students were not meeting her learning goals:

> Because again, they will say things in lab and you think they're getting it, and two days later you're reading their report, and they have NOT gotten it. And you think, maybe they wrote the report before you talked to them. I try to get them feedback before they write the following report, because you can't criticize them for not fixing something that you hadn't told them was wrong. So hopefully I can get them on the right track before they move forward, so I can say, 'it wasn't clear to me that you understood—THIS is what I wanted you to get out of this.' (Interview 1)

Therefore, based on her experience with inquiry articles prior to the summer institute, Professor Wilson felt that her feedback in between inquiry article lab reports was critical for students to be successful in this approach.

Social Norms

Professor Wilson described her department's primary teaching method as being the traditional lecture approach. She explained, "The instructors lecture to the students, sometimes they lecture directly out of the book. You hear students say, 'I don't know why I came to class, I could have slept in and read the book'" (Interview 1). Her department chair did not set specific expectations for teaching. When asked what she thought about making the inquiry article approach a requirement among her department lab courses, Professor Wilson explained:

> I'm one of two labs in their second semester of their senior year. The only thing between them and graduation is me. That's pretty late in your career to be seeing these kinds of inquiry-based things, to be able to learn and assess and put things together and put it into a big picture, and really get that enthusiasm and excited about science. I would definitely be enthusiastic about having others implement those [types of] labs as well. And it would be really cool if the chair would say, "It has to be done this way," but I don't see that happening. He doesn't dictate quality or quantity or style, there's no way he would say, "These are good for the students, you should do these." He really leaves the teaching up to the individual PIs. You hear about it when your assessments aren't good. You hear nothing when your assessments are very good, so you're not rewarded for excelling in this department. (Interview 1)

As a new faculty member, Professor Wilson teamed up with another new faculty member in her department, Professor Clark, to teach sections of the Biochemistry course for majors (Professor Clark did not participate in SCTIL). She explained why they were given this teaching load:

> The chair made it very clear that [Professor Clark] and I got the course we did because we were the youngest hires and the newest people, the ones most likely to be most enthusiastic and interested about the new technology and the ones most able to bring that up to par. They had proportionally dumped a huge amount of work on the two youngest people in the department, but he has also admitted we have REALLY made serious advances in the courses, and the student evaluations have come

> back and say ‘this is the best lab course I’ve ever had at this school.’ (Interview 1)

Her partnership with Professor Clark has been significant in preparing for and implementing this upper-level course. She stated:

> We were hired at the same time, so we spent many hours together literally going through the labs that first summer along with the TAs so that we had datasets and went into the labs knowing, ‘so this one works and this one doesn’t.’ And then after going through, we agreed on which ones would be our first year’s dry run. Since then we’ve talked less, and just communicated about which ones are working and aren’t, so less interactive stuff and more sharing our success or not. It’s always strange that some of his best labs were some of my worst, and vice versa. (Interview 1)

Overall, Professor Wilson felt she had a positive relationship with her colleagues. She went to different people to answer different questions she might have, whether they concerned content in her lab or basic technical issues. She described the type of advice she often sought:

> Sometimes its technical information, “Well that didn’t work, try using these mutancies and use this assay instead,” sometimes it’s, “Well that lab never works, don’t worry about it,’ and sometimes it’s really good information about ‘well I know cow’s blood doesn’t have this particular enzyme, so if you can get some cow’s blood and run this assay in that, it might be different, here’s a couple of references, why don’t you track it down.’ (Interview 1)

The role of the TA is significant in her department. She explained that the faculty members were discussing the development of a training course for TAs that focuses on “how to teach” and “what to teach,” as well as their expectations for a TA in their department (Interview 1). She went on to say that she was personally interested in this course because she was “curious to know what we’re going to tell them—am I aligned with that myself” (Interview 1).

In general, Professor Wilson's experience in converting the senior-level Biochemistry course to include more inquiry-based learning took a great deal of effort on her part, in collaboration with her colleague, Professor Clark. While she saw improvements through her course evaluations, teaching was not rewarded in her department, and therefore her changes did not receive recognition or accolades.

Environmental Constraints

In anticipating possible environmental constraints in implementing the SCTIL inquiry article lab approach, Professor Wilson focused on students' poor writing skills. This was a problem in her previous implementation of the lab format, and she expected it to be a continued problem. She reflected on what she would change during this implementation to address this constraint in the following statement:

> I'm not sure what the most politically correct way is to do this, but I want to show them an "A" paper and show them a "D" paper, and how do you make that D paper non-descript enough that nobody gets in trouble, except for me to write a really poopy report myself. But to be able to show them one that has been turned in that really doesn't meet my expectations, and one that vastly exceeds it. And to say, you will fall somewhere in between these, and this is the one to aim for. (Interview 1)

Her experience in a 2005 summer writing intensive course with other faculty members contributed to her knowledge of writing style, grammar, and degree of communication. She drew from this experience to consider how she would address the writing skills constraint in the coming year.

Self-Efficacy

Professor Wilson entered the SCTIL program having learned about the design of the inquiry article approach in a previous professional development experience, and implemented her own modified versions with little to no support. Surprisingly, during

Interview 1, she described a low efficacy of teaching with this format. She first explained that she understood the inquiry-based approach: "I like the concept, I understand because that's how I learn, I'm just trying to figure out how to TEACH that way" (Interview 1). When discussing her efficacy of teaching with the inquiry article approach, she stated, "I think I'm crawling [spoken with laughter]. I'm definitely not walking confidently, I'm definitely not running" (Interview 1).

Attitude

Before the SCTIL workshop, Professor Wilson's attitude towards learning and implementing the inquiry article format was positive. She looked forward to improving the laboratory experience for her students, as noted in the following statement:

> Anything away from the cut and dry cookbook should be good, and one thing that comes across from the assessments that students make to me directly are, 'I don't feel challenged,' or 'these are simply boring.' So I think that challenging them, making them think a little more in the lab will improve it on a lot of levels. And yeah, I'm actually looking forward to implementation. Definitely. (Interview 1)

Professor Wilson entered the program eager to learn and implement additional inquiry article labs, contributing to her positive attitude.

Knowledge and Motivation

Professor Wilson entered the program having already learned about the SCTIL inquiry article approach through a college science teaching seminar. Using this knowledge, she modified and implemented one lab unit in her Biochemistry course and chose to bring this lab for further feedback and modification to the SCTIL program. She sought to learn more about inquiry-based pedagogical strategies in using the SCTIL format in her classroom. Her motivation for learning and implementing the SCTIL inquiry article format was focused on gaining the pedagogical skills for this teaching approach. She stated:

> I'm trying to figure out how to TEACH that way… I think that's one of the things I'm hoping to get out of this SCTIL program, is getting other people's input, figuring out what other people understand inquiry to be, am I going about it the wrong way, do I have the wrong experiments but I'm asking the right questions, am I asking the right questions but having the wrong expectations? The same thing for ME, am I getting the answer for the question I'm ASKING, but I'm not asking the right QUESTION? (Interview 1)

She understood that the faculty members who would be participating in the SCTIL program would enter the program with different types of courses and different expectations from the program, so she expressed an interest in being able to draw from the other participants and compare courses with them. She expected the summer institute to be a writing-intensive course, similar to the one she had been a part of in 2005. In comparing that experience with her expectations for the SCTIL program, Professor Wilson stated:

> [The 2005 writing intensive course] got me to think about things in a different way, which was useful, and I still have the writing intensive book and I do go back to it periodically and pull little things out of it, and worse-case scenario I figure that's what this SCTIL thing will be. (laughing) . . . Not even writing intensive but while that was addressing writing with people who write and I was peripheral, this is really how to teach a lab, and in some ways that should be the focus but I know it's for non-majors, and to that degree I'm sort of peripheral because my expectations will be different from theirs, but if I can find good ways for them to teach science to non-majors, it shouldn't be that far of a leap to be able to apply it to a majors course, a capstone majors course. And that's why I'm hopeful that I should be able to learn some fundamentals I can easily apply to my course, which can help me either ask different questions or revise expectations or explain things differently, that I can be more effective at getting these points across. (Interview 1)

Therefore, Professor Wilson entered the SCTIL program with the motivation to learn about effective pedagogy in implementing this type of teaching approach in her classroom.

SCTIL Inquiry Article

At the end of the first day of the SCTIL summer institute, participants were asked to convert one of their labs into that design. They submitted this first draft to the SCTIL staff members and peers for feedback. Professor Wilson's first draft of her SCTIL inquiry article lab was identical to her original modified version previously implemented in her Biochemistry course. In the following section, I describe Professor Wilson's first draft as compared to her final draft of her first inquiry article implementation within the SCTIL program during the spring of 2008.

First Version of Inquiry Article

Professor Wilson's first inquiry article investigation was titled "Use of indicators, pH and spectrophotometry to visualize the principles of the Henderson Hasselbalch equation" (see Appendix H for Inquiry Article Version 1). This journal focused on determining the "absorbance of a solution containing an indicator" (Inquiry Article version 1, Professor Wilson). Her goal in this study was to allow a "visual appreciation of pKa and provide a better understanding of the role of a buffer and application of the Henderson Hasselbalch equation (Inquiry Article version 1, Professor Wilson). Her write-up included an introduction, methods, and results section leaving the abstract and conclusions for the students to complete during their own investigations. She provided detailed methodology of her experiment with measurements, written calculations, graphs and tables to represent her data. In the closing section, she did provide her own conclusions, but explained to the students the purpose of this section. She wrote:

> Use this section to answer the questions provided in the handout. . . . This write-up is the starting point for YOUR experiment this week—I have provided you with the data from the original protocol. Based on these data and the protocol and what you have learned by reading your background material for this week, how would you go about VARYING this protocol to learn more about the fundamental principles involved? What are the variables? How could we test them? What would we learn from the answers we obtain? (Inquiry Article version 1, Professor Wilson)

Within this design, she did not provide alternative variables for the students to use, but encouraged them to think about the possibilities themselves.

As Professor Wilson reflected on her previous implementation of this lab, she stated, “It was a resounding failure in many ways” (Interview 3). She noted that during this implementation, she handed out both the revised inquiry article version and the original cookbook version to the students. She explained:

> I DID hand out this report PLUS the cookbook version and I think they used the cookbook one for extracting the protocol and this one to be able to visualize the changes—and to see how a report was written up [Pause] cause that was what they needed to turn in. (Interview 3)

Professor Wilson seemed frustrated in finding a balance between providing her students’ with materials needed to complete the assignment and guidance in filling in the missing components of their own follow-up inquiry article.

Final Version of Inquiry Article

Professor Wilson implemented her SCTIL inquiry article lab in a Biochemistry course in which eight science majors were enrolled. The design of her final version was very similar to her original version with the addition of a written abstract section (see Appendix H, Inquiry Article version 2). Her focus and goal of the inquiry article lab remained the same and she made minor modifications to her methods description in the journal, clarifying the process for the reader. She decided to leave the conclusions section as it was written for the original version, and explained her reasoning for this decision in Interview 2:

> I actually didn't write a conclusions section here, because . . . they're supposed to answer questions. And I thought, well if I answer them, what are they actually getting out of this? And I thought, well I can actually rewrite the discussion so they can see what a discussion looks like, but it doesn't answer the questions, so they can still apply those questions to their data. So, it's sort of skirting the whole issue but giving them, again, something to work with. (Interview 2)

She felt that giving her students the experience of writing the conclusions section on their own would provide them practice in writing a journal article. She explained:

> Because, theoretically, if you nail them to the wall, they'll say, "Yes I work in a research lab, I have read journals, I have seen them," but then they'll turn around and say, "But I don't know how to write a journal-type paper." (Interview 2)

As Professor Wilson discussed her plans for implementation during Interview 2, she explained that the lab would be implemented during a one-week period, which would include a Monday recitation session and two lab meetings. She talked about how she modified her plan based on advice from a SCTIL staff member:

> So we'll talk about it on Monday, Tuesday they'll collect the data, Thursday they'll collect the rest of the data and then we'll go over it, and then at the end of Thursday I was going to release the cookbook version so they can see both halves. Because the next week, they get a cookbook version [a different lab] and they have to write a report. So having the two side-by-side makes sense, but actually [a SCTIL staff member] said 'if you give them the cookbook version, they'll use it as a crutch, they won't read the journal the way they should.' So actually talking with him helped me realize that I need to hold off. (Interview 2)

Therefore, she planned to give the students her inquiry article the previous Thursday, have them read it and develop a plan to bring to the recitation session on Monday. She said that she would tell students, “There are eight of you, there will be four variables on this, if you come up with one or two variables, you’re set! If you can come up with more, you’re helping the rest of the group” (Interview 2).

Professor Wilson described her goals of this lab in the following statement:

> I want them to understand concepts of pH, of indicator color changes, of the buffers, and learning how to pipette and be confident of your hands, to know that your data are what they are, and if you don’t trust them to KNOW there might be something wrong here. (Interview 2)

Following her implementation of the SCTIL lab, she described two changes she had made during the process. First, she had originally planned to allow the students time to collect and analyze their data during the Tuesday and Thursday lab sessions. Students concluded their work on Tuesday and didn’t need time on Thursday; therefore, Thursday’s lab was completed within one hour. She spent that time discussing their results and presenting each groups’ data based on figures they had e-mailed to her. She reflected on this change in her timeline in the following statement:

> The first thought was, in previous years, they’ve always needed more time, somebody doesn’t know what they’re doing, it takes them longer than expected, they have trouble with the pipetting…over half of this group has research experience, so they just know what they’re doing. (Interview 3)

She said that next year she would increase the number of tasks associated with this lab activity to fill the extra time in the lab unit. When asked if she felt that she met her goals for this implementation, Professor Wilson responded quickly stating, “Oh yes. I think I exceeded the goals on this one. Because I wanted them to understand pH and I think they got A LOT more out of it than that, definitely” (Interview 3).

Change in Belief System about Inquiry-based Teaching

In the following sections, I describe the changes, if any, in Professor Wilson's belief system about inquiry-based teaching after implementing her first inquiry article lab within the SCTIL program.

Beliefs

Science as inquiry. Professor Wilson's definition of inquiry changed slightly after experiencing the SCTIL summer institute, but did not change following her implementation of the lab. She stated:

> I guess it's still sort of a modified discovery process…in that it's still [Pause] there is no right or wrong answer. I guess to some degree, my thought of inquiry with respect to the labs themselves, has become more focused in that, 'these are the tools—what are they good for, how can you use them and apply them,' rather than just, 'well go figure out something.' (Interview 2)

Professor Wilson held her previous belief that science is not black and white and that students should be more accepting that "my answer may be different from your answer" (Interview 2).

Student learning in science. Professor Wilson's beliefs about how students learn in science did not change significantly; however, her expectations increased for her students' contribution to their own learning. She stated:

> [I expect them to] come in with an open mind as far as what they're going to be doing, working a little bit harder to extract the protocol instead of being spoon-fed. And just being a little more willing to try something new, and again in labs, in some ways, they complain that labs get kind of boring and dry, and yet if you challenge them, I think they don't realize yet it's going to take a little more ATP on their part. I guess more like hydrolysis of ATP--it's there, they just don't use it [laughing]. (Interview 2)

She felt that students learn differently in the inquiry-based labs as compared to typical science labs because “it’s not being spoon-fed,” and “they have to do more up front thinking—but then inquiry-based to me means more work up front, which is what I’m not sure yet that they are willing to do” (Interview 2).

After implementing the lab, Professor Wilson noted that students learned several unexpected skills that will be useful throughout the remainder of the course. These skills focused on more technical aspects of conducting an investigation, which included keeping their glassware clean, checking their pH buffers, trusting their reagents, and double-checking their protocols to be sure they are internally consistent. She felt that in some ways these skills were “life lessons” that the students would use beyond this course (Interview 1).

Reflecting on the level of difficulty the lab entailed for her students, she commented on using this format with science majors versus non-science majors. During Interview 2 she discussed her feeling on why she felt it was more appropriate for science majors. She explained:

> They’ve had the concepts and they should be able to pick it up and run with it. It’s funny in some ways because I know that this was designed to teach non-majors at any level, and I see it working best for senior majors [Pause] because they’re more prepared, because they have the foundation, because this ASSUMES a certain amount of knowledge. It assumes you have the techniques and fundamentals, and that you can assemble all that mentally in the lab and run with it. (Interview 2)

While she was a proponent of using this lab with her science majors, she expressed concern after implementing the lab. She felt that the limited amount of available materials in the lab restricted the students’ learning experience. She stated:

> Yeah, I think it’s great with majors. The question is, with giving them [this lab] this early in the semester, and giving them a taste of it and

> having them go for it, as we work more [inquiry-based labs] into [the course] later, will I constrain them by saying 'yes you can do THIS, but stay within these parameters because this is all we have.' [laughing] Yeah, I'm thinking majors may quickly outgrow the concept as a whole, or not outgrow the CONCEPT but they may run with the concept but outgrow the reagents we have to provide them. (Interview 3)

Professor Wilson maintained a strong belief that science learning should be applicable to students' daily lives. She noted that "they can see how it applies and they can understand how this works" in her lab setting (Interview 3). She felt that the inquiry article approach allowed the students to connect the content to real world situations. Focusing on the pH indicators, she talked with them about where this information would be beneficial in our society--for example, in testing drinking water at a local water treatment plant.

Overall, Professor Wilson's beliefs about how students learn science through inquiry-based labs expanded to include higher expectations for students to take more ownership of their own learning and put forth more effort in this learning process. This fed back into her thinking about teaching inquiry-based labs, wanting to provide more of a challenge for her students.

Inquiry-based teaching. Prior to the SCTIL program, Professor Wilson believed that inquiry in the classroom was teacher-directed yet open-ended. Through her participation in the program, her thinking about the design of inquiry in the classroom was refined. As she learned about the different features of inquiry according to the standards (NRC, 1996), she developed her understanding of inquiry-based teaching to include more concrete ways to guide students through the scientific process. She also felt that using inquiry and the inquiry article format provided her with a strategy to help students build skills that they would use in their lives.

Her concerns were still in place after the summer institute in terms of implementing the inquiry article format. As she explained in the following statement, she felt that if students were unprepared or unmotivated to participate in this type of learning experience, it would fail:

> It's still intimidating. Because you don't know where it's going to go, you don't know how it's going to turn out. If the students are interested and interactive, it can be a lot of fun and you can go in a lot of different directions. If you get students who haven't read the lab before, and they come unprepared, the inquiry still falls flat on its face. It REALLY depends on the students. (Interview 2)

When discussing her role in teaching with inquiry articles, she explained that giving more of the decision-making process to the students could be detrimental and lead to resorting back to a more traditional teaching approach. She stated:

> You can kind of push them and nudge them, but if they haven't done the reading or they're not thinking, or they haven't had their coffee yet, I don't know, nothing is going to happen, and I guess to me in some ways, that's still a bit of a concern, a fear, that won't go away until you know you've got a group of students that really will do the work before they come to class. Because bottom line is, in some ways, and I guess as a teacher this is what is terrifying, inquiry means you putting it back in their laps. If they choose not to, or they are unable to participate, you're not going anywhere. To some degree that's no different from lecturing at them, not to them but at them, but at least you're an active participant when you're lecturing. You're up there lecturing, they'll either get it or they won't, and you can't do anything about that. With inquiry, or this guided kind of discussion, they are active participants and you really CAN manipulate them but only if they want to play the game. [laughing] And I guess to me, inquiry does now have this level of fear, what if they can't or don't want to play the game, then what do you do? The fear is, you resort to what you know and you lecture AT them, but I try not to do that though. (Interview 2)

In reflecting on the effectiveness of this approach, she discussed her view that this type of inquiry-based teaching is best for labs that are not intended to fill students' "toolboxes" of techniques and strategies for doing science. She felt that she was being "devious, making them think this is all their idea," noting that this particular approach works well for certain labs and not for others (Interview 2).

After implementing her SCTIL inquiry article, Professor Wilson's concerns subsided once she saw that her students prepared for the course and "played the game" (Interview 3). She noted:

> I think they end up doing a lot more than sometimes you give them credit for . . . . It doesn't really change the idea of inquiry, it reinforces the idea, the concept that yes, they can in fact do this, that you can kind of throw it out at them in a limited, as in not just totally open-ended, but a more focused way, and they can take it and run with it at that point. So I'm a little more confident that they'll do better with this type of lab in the future as well. (Interview 3)

She explained that she would be more successful in her teaching if she had more datasets from implementing the inquiry-based lessons; therefore, she felt that in the coming years, her teaching of the inquiry article assignments would improve by having more content to use in her original write-up.

During the second interview, I asked Professor Wilson to identify where she felt the pH inquiry article lab fit on the Inquiry Continuum (Brown, Abell, Demir, & Schmidt, 2006), which was used at the SCTIL summer workshop (see Figure 8). As she marked on a printout of this figure, she explained why she felt her labs fit in those locations:

> So I think initially, this lab itself was basically right down here [pointing to Figure 8, Point 1]. That would be at the beginning of the workshop, before I attended. . . . The workshop made me think that it could be [Pause] at that time we were going to talk about it but I was going to guide them to what we were going to be looking at. So initially, when I wrote the report, I was going to have them tell me 'I want to use Tris and not phosphate,' and 'I want to use phenol blue rather than phenol red,' so it would have been a little more inquiry, probably here somewhere [pointing to Figure 8, Point 2], AT the SCTIL workshop. But with these additional things where I'm giving them unknowns and they now have to go and tell

> me, so I still want them to say 'different buffer, different indicator,' but I will give them unknowns at least for the indicators, because that will be obvious . . . so with giving them an unknown, they still do the experiment, we still brainstorm beforehand, and then they say 'give us an indicator,' so I think they're inquiry has gone up A LOT [pointing to Figure 8, Point 3]. And it's definitely more student-directed to get the answer, so I think it's probably somewhere in this range now. Hopefully. I'm curious to see where it's going to go next [laughing] . . . . and again it really depends on how much preparation they do. (Interview 2)

After implementing her inquiry article lab, Professor Wilson felt that the lab moved more towards full inquiry and student-directed primarily due to the students' response to the work and their action of going above and beyond what she expected. During Interview 3,

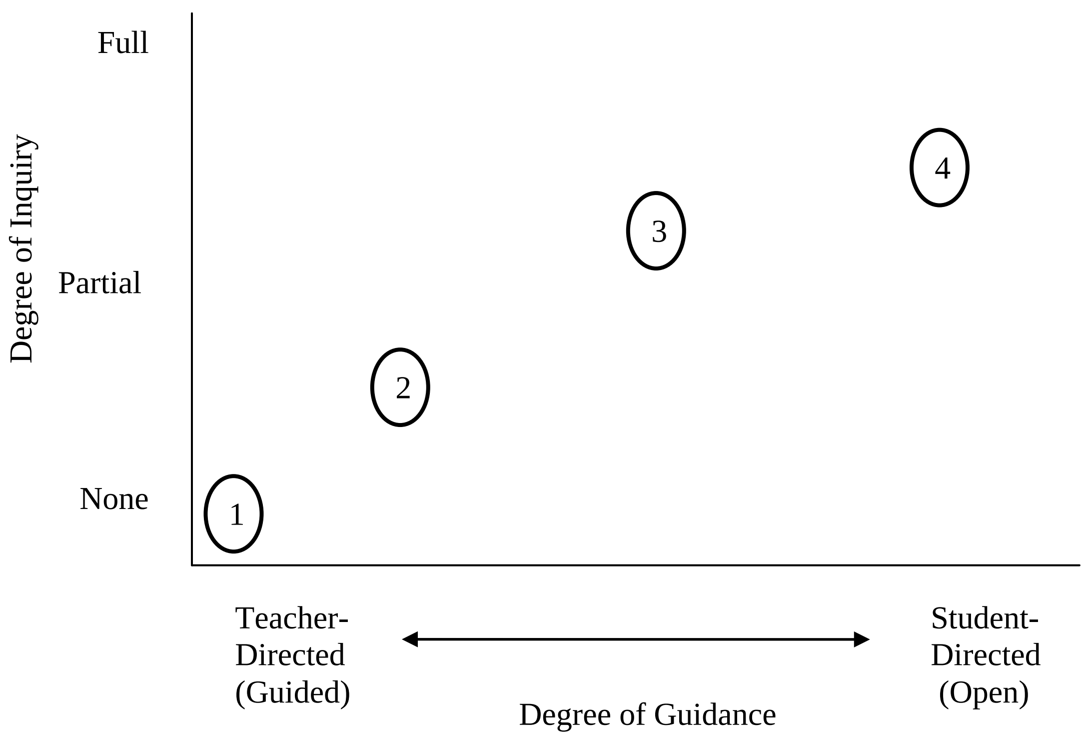


Figure 8. Professor Wilson's Inquiry Continuum (modified from Brown et al., 2006)
1=Pre SCTIL program; 2=end of SCTIL summer institute; 3=pre implementation; 4=actual implementation.

she explained this move on the continuum:

> I think it's a lot more, it's ended up being a lot more student-directed with much less teacher-guided, absolutely (pointing to Figure 8, Point 4) . . . . Simply because I didn't expect them to be doing some of the things that they ended up doing. They ended up giving me back a few things I never saw coming. So from their own observations, whether intentional or by accident, because I have no idea why they plotted that way, but it was a perfect way to plot it in retrospect. So yeah, I think they really grabbed this one and ran with it, for reasons that I don't know why. I think they did well on this as far as taking it under their wings and really going with it. (Interview 3)

Professor Wilson's value of student-direction in inquiry-based teaching increased after seeing her students' succeed with her SCTIL inquiry article lab.

Environmental Constraints

Professor Wilson expressed a concern prior to the SCTIL summer institute that she felt poor writing skills would be a constraint. By Interview 3, she was very pleased with the students' writing and felt that it was, in fact, not a constraint in the effective implementation of the lab. She also expressed a concern that she would not have all the reagents students would want to use in their investigations, and again, this was not an issue in the laboratory.

Professor Wilson did describe two constraints in the classroom environment, both of which centered around the students. She had eight students in her course, which she noted was a small number compared to her typical class size for this course. This particular group varied greatly in their research skills. In Interview 2 she stated:

> Eight students, they're all over the place. [laughing] There are some who have been working in labs and they know that they want to go and get PhDs, there are some who've done a chemistry lab and this is their first biochemistry lab and they have NO idea what they want to do when they graduate, and it really spans the entire gamut. And a bigger class I think would have given me a few more points in between, and in some ways that would have helped. Because the worry is to challenge the ones at the

> top, those who have the broader background, and not to lose the ones who haven't done this quite as much. (Interview 2)

She found it difficult to accommodate the varying needs of the students as they had different backgrounds/goals. She described the same constraint of class size during her third interview in the following statement:

> Having a small group was limiting; had it been larger we would have had more interaction. But in some ways, this is the most experienced group I've had, and for this early in the semester, they're also one of the most vocal groups. So it was probably a combination of those, but overall, a larger group would do wonders with this lab. (Interview 3)

The design of her inquiry article lab involved students working in pairs when conducting their investigation. She allowed students to self-select their groups. She described the grouping as being an issue in balancing the class during this lab session:

> If you've got a really good person paired up with a weaker person, that's a good situation. Right now the two who have the most experience work in the same lab, and they clearly work together very, very well, but they're always the first ones done. And then they're outta there. So, the question is, how do I slow them down, OR challenge them enough so that they share what they know with the other groups, and basically pull them back in. And that's kind of where I want the peer learning to go on, is that for those two to really share with the other groups, and I'm not sure that that's happening, so that's what I'm trying to manipulate if possible. (Interview 2)

In the end, Professor Wilson explained that her actual constraints in implementing this lab were a small class size and the variation of skill level within the self-selected small groups. During her reflection of these constraints, Professor Wilson seemed confident in her ability to handle them in future implementations.

Self-Efficacy

Professor Wilson's self-efficacy towards her ability to teach with an inquiry-based approach increased because of her students' success with the approach. She did not attribute her increased confidence level to the development of her pedagogical skills. She stated:

> [I feel] a lot more confident than I was at first. [laughing] I was pretty scared that the students wouldn't interact, that they would just sort of clam up or sit there, and there was definitely some of that, but it turns out there's one person from each group who is vocal . . . . So I'm much more confident of my ability, maybe simply BECAUSE this is a really good group. Again, I'd be happier with a bigger group, and larger datasets, but yeah—I didn't think it was going to work at all. [laughing] (Interview 3)

Professor Wilson's increased self-efficacy indicated positive feedback from her students' response to her belief system following her implementation.

Attitude

Professor Wilson's attitude towards the SCTIL inquiry article format remained very positive as she began to prepare for the implementation of her lab. She stated:

> I think I'm excited about it, which is unusual. The first half of the semester is usually quite boring, at least the first 4 of 5 weeks. Again, they're all toolbox labs, learning how to do techniques and methodologies; it's all very basic stuff. It's unusual to have a lab that I'm REALLY excited about this early in the semester . . . . I hope they don't notice the change in my energy level the week after, when we're back to the carbohydrate level [spoken with a sad voice]. (Interview 2)

Following her implementation, she maintained a positive attitude as she noted her surprised success with the lab:

> It went MUCH better than I expected. Amazingly well . . . . And it was their idea to use the indicators, or that was the direction I guided them in, and because they were different, they were really able to compare and contrast, and they were able to really look at the data, and I think it turned out really well. So I was actually thrilled with the way it turned out. (Interview 3)

As she discussed her plans for future implementations of SCTIL labs in her course, she expressed her excitement in comparison to her typical laboratory activities. She stated, "I'm actually looking forward to the other two SCTIL labs. I figured, well let me get through this and then get back to the boring labs, but now I'm dreading the boring labs" (Interview 3).

Knowledge and Motivation

Due to her incoming knowledge about the SCTIL inquiry article format, Professor Wilson expressed little new knowledge gained through the summer institute. She focused primarily on modifying her lab towards a more student-directed design after understanding where such changes could be made. She also focused on understanding instructional strategies that would help her with implementation, such as collaborative learning with her small course. Professor Wilson did not provide any additional motivators for participating in the SCTIL program after her first interview.

Environmental Responses

Overall, the students' responses were positive. Prior to implementing the lab, Professor Wilson described her students' reaction to her explanation of the inquiry article lab format and how that was different from their usual lab format. She stated:

> I told them, "Thursday really was a very cookbook lab," so with that behind them, I said, "Next week is completely different." So I think [Pause] they know things are changing, they don't seem to be adversely opposed to it at this point, I think they're willing to try something new. (Interview 2)

After implementing the inquiry article lab, she described the students' response to the new format:

> It's a small group and early in the semester, I didn't know how they were going to interact with me or each other . . . a lot of times they just sit there like duds. There are two or three who are really interactive, and one or two of them got to say things and I got some others to respond, and it started a lot more discussion. Having the tubes in front of them, having a couple of days to think about it, I was actually very fortunate they collected all of their data on Tuesday, so they came in having thought about it a little bit, having done a little of the number crunching, and we

> got into discussions and observations that I didn't anticipate finding. (Interview 3)

In particular, she was impressed with one student's surprising action of plotting a calculation in a way that she did not assign or expect. She explained:

> A student had plotted data, for reasons I don't understand, but he plotted data in a way that I didn't expect him to plot it, but it showed something really interesting, and it was something that I need to actually pursue. There was probably a mathematical reason it worked out, but I don't know what it is. So it was not in the instruction to plot that, I don't know WHY he plotted it that way, but it's legitimate to plot it that way. If it holds true, I could work it in for next year. But I didn't expect that. (Interview 3)

She went on to discuss her surprise with the student's action in the following statement: "I've always said, normally with a negative connotation, that undergrads do the darndest things. [laughing] And sometimes like THIS, it ends up in the positive direction" (Interview 3).

Her overall impression of the students' responses was summed up in her closing comment about implementing the inquiry article lab:

> In general I think they seemed to really like it – it DID add a bit more variety and a lot more interest to what was otherwise (in previous years) a very cut-and-dry lab. I think they appreciated the variety, liked having to identify their own sample and didn't mind that their sample was not the same as anyone else's. (Interview 3)

Professor Wilson was pleased with her students' responses to the implementation of her inquiry article lab.

Change in Instructional Practice

Professor Wilson planned to implement two more inquiry article labs in her course during the remainder of the semester in the spring of 2008. As she explained her plans for the upcoming labs, she noted that she would change her original cookbook format to be more student-directed. She stated:

> I think these are REALLY going to work well with this, because in both cases they're one-day labs, but they prepare them for the next week. So in some ways it's a cookbook lab but we're going on from HERE, and I think that can easily be made into an inquiry article exploratory kind of thing. It kind of turns out being that anyways, in that "you need to load a gel, pick any of the samples you want," evolves very easily into "this is my report, this is my gel, this is the sample I've chosen and why I did it," so again its sort of a guided inquiry kind of thing. On one level, what the students do is no different, and what I make them do is no different, but rather than just saying, "Well just pick," guiding them a little bit more, and yet at the same time making them see that it's up to them and it's really in their hands how they choose to do it. (Interview 2)

As she considered how she would modify the pH inquiry article lab for next year's Biochemistry course, she was focused on filling the extra lab time. She said that she would "give them a new buffer—so really give them two variables, and compare and contrast" (Interview 3). She also talked about the discussion questions she had posted on Blackboard for the students in the pH inquiry article lab. During this implementation, she decided to rewrite her questions to be on a deeper level, and noted for her upcoming two labs, she would "definitely revamp the other questions, in fact I'm not even going to post the first set of questions. [laughing] Because I KNOW we'll be able to get more out of it than that" (Interview 3).

Summary of Change in Professor Wilson's Belief System

Professor Wilson entered the SCTIL program with a low self-efficacy but positive attitude towards the inquiry-based approach. Her beliefs about teaching and learning were not strong, but she appreciated active learning because of its authenticity to science and valued real-world application. She had a positive attitude because she felt this inquiry-based lab approach would be good for her students and help to improve her teaching. She was motivated to participate because she wanted to increase her pedagogical skills in inquiry-based teaching. After implementing, she reported that her students responded better than expected—they “played the game” with her and took ownership of it, which fed back into her belief system and resulted in a maintained positive attitude and a higher self-efficacy towards using the approach. Her beliefs about student learning in inquiry-based labs expanded to include higher expectations for them, which caused her to want to provide more of a challenge through her instruction. Overall, she was excited to implement this approach again for her students’ sake. Her positive attitude and internal motivation overshadowed her lack of a strong support system.

CHAPTER FIVE: ASSERTIONS

In this chapter, I present assertions based on the five cases presented in Chapter Four. The assertions describe major themes common among the participants' belief systems and are organized around the research sub-questions that guided this study.

Research Sub-Questions and Assertions

1. In what ways, if any, do participants' beliefs and knowledge about inquiry-based teaching and learning change during the SCTIL program? (Assertion 1)
2. What components of participants' belief systems have the greatest impact on their decision of whether or not to incorporate the SCTIL inquiry article format into their future instructional practice? (Assertions 2)
3. How do environmental responses to participants' SCTIL lab implementation influence change in their belief systems about inquiry-based teaching and their future plans for incorporating the instructional approach into their practice, if at all? (Assertion 3)
4. What components of the SCTIL program were the most supportive for changing the participants' beliefs and knowledge about inquiry-based teaching? (Assertion 4)

In discussing each of the four assertions, I refer back to the case profiles and use relevant data from the interviews.

Assertion #1: In the SCTIL program, participants developed more reform-oriented beliefs and knowledge about inquiry-based teaching and learning in which they placed more value on student-directedness and classroom inquiry.

Two themes emerged in participants' beliefs about inquiry-based teaching and learning during the SCTIL program. First, those who implemented inquiry-based labs (Professors Brinkley, Garrett, Rogers, and Wilson) began to value a more student-directed approach to learning in their labs, which is reflective of reform-based instruction emphasizing the importance of engaging students in their learning (Wright, Sunal, & Day, 2004). Second, those who implemented also developed knowledge and beliefs about classroom inquiry. This section is organized around these themes and I present evidence to support the assertion.

Student-Directedness

The first theme is drawn from participants' interview data regarding their beliefs about inquiry-based teaching and learning. Based on the participants' first interviews conducted before the SCTIL program began, their previous approach to lab instruction indicated difficulty in letting students take on more ownership of their lab learning experience for various reasons. Professor Brinkley was concerned about his students' abilities to take on more responsibility based on their status as first-year community college students. Professor Garrett did not believe that her students wanted more responsibility based on their lack of enthusiasm for learning in the lab section of her course. Professor Garrett's high expectations for her students resulted in her taking on a more teacher-directed approach to guide them through her labs. Professor Rogers seemed more comfortable when he was able to guide the students in their learning and discussed his frustration with their lack of incoming knowledge because they were not science majors. Lastly, while Professor Wilson came into the SCTIL program with limited experience using the inquiry article format, she was still concerned about not knowing how her students learned. This lack of knowledge was a frustration for her because she did know how to guide her students in their learning with this approach. Overall, these four participants expressed similar incoming beliefs that inquiry-based teaching and learning focuses on students taking ownership of their learning; however, they believed that their students were not ready for this responsibility and that their students benefited most from a more teacher-directed approach.

Professor Propes did not implement a SCTIL lab. His incoming knowledge and beliefs about inquiry-based teaching and learning were advanced, indicating a deep understanding of the difference between teacher-directed and student-directed learning. He had training in science education courses as a graduate student and discussed his value for authentic, inquiry-based student learning experiences.

During the participants' second interviews after the summer institute, they were asked to elaborate on their views of inquiry-based teaching and learning through a series of questions. Through the interview data, they showed that they gained new knowledge about the essential features of inquiry (NRC, 2000a) and the inquiry continuum (Brown et al., 2006), as well as an understanding of the difference between teacher-directed and student-directed learning. This new knowledge encouraged them to reconsider their teaching approach as they designed their SCTIL inquiry article labs for implementation. They talked about moving the inquiry article format into their own context as they developed their first lab and considered problems they might encounter. For example, both Professors Garrett and Rogers talked about their new understandings of this inquiry-based teaching approach and were excited to see its similarity to their previous teaching styles; however, they still showed concern about their students' responses, citing their lack of skill for writing and lab work. Professor Rogers also identified his incoming beliefs as limited by the assumption that inquiry-based teaching should be full, including all five essential features of inquiry. While he tended to use teacher-directed learning approaches in his own instruction, he saw the value in using student-directed approaches with the inquiry article labs based on his new knowledge from the summer institute, yet still seemed unconvinced of its achievability in his classroom. He noted, "you don't have to GIVE them what questions to ask, but still push them towards the sort of subjects you need them to examine" (Professor Rogers, Interview 2).

During the participants' third interviews following the implementation of their first inquiry article lab, they expressed a change in their beliefs about inquiry-based teaching and learning. While their incoming beliefs reflected an understanding of inquiry-based instruction as being primarily student-directed (and some held an aversion towards using this approach in their own contexts), the participants' experience in the SCTIL program resulted in new knowledge about the variety of approaches possible in using inquiry-based instruction, not limited to full and open inquiry. By the end of the study, four of the participants had implemented an inquiry article lab (Professors Brinkley, Garrett, Rogers, and Wilson) and received responses from their students. The participants' discussion during their third interviews reflected a change in their beliefs based on these experiences. For example, Professor Wilson talked about the value of giving students more ownership in the lab after seeing how successful her students were with this experience. She noted, "I think they do a lot more than we give them credit for .

. . I'm a little more confident that they'll do better with this type of lab in the future as well" (Professor Wilson, Interview 3).

One representation of participants' beliefs about inquiry-based labs is presented in the inquiry continuum (see Figure 9). During their interviews, the participants were asked to label where their original, unmodified lab would be represented on the inquiry continuum, as well as where their implemented version of the lab would be placed. In hearing their reasoning for these labels, we gain insight into their beliefs about teaching and learning. Figure 9 shows that the four professors who implemented a SCTIL inquiry article lab believed they had moved their labs from a teacher-directed design with few essential features of inquiry represented towards a more student-directed design encompassing more inquiry features. The participant who did not implement a lab, Professor Propes, was unable to identify where his implemented lab would be located on the continuum, therefore it is not included in Figure 9. In the following paragraph, I illustrate the changes in each of the participants' lab designs based on their interview data.

Professor Brinkley believed he used inquiry-based teaching in his classroom prior to learning about the inquiry article format; however, his original lab was part of the old curriculum used by previous instructors and he was in the process of revising the course. After learning about the SCTIL format and continually making modifications to his lab prior to and during his implementation in his introductory biology course, he identified his implemented lab as more student-directed with a partial degree of inquiry. He explained that continually adapting his lab to his students' needs was important in order to achieve his learning goals for his students. Reflecting on his incorporation of the inquiry article in teaching his upper level students, he noted, “With the honors students, my goal is to get it more and more student-directed” (Professor Brinkley, Interview 2). Thus, his student-oriented view of teaching, along with his more student-directed lab resulted in an increased value for student-directed learning and a belief that inquiry-based learning should be student-oriented, moving towards full and open inquiry.

Professor Garrett described her original lab as teacher-directed and including some components of inquiry. She noted, “It was PARTIAL inquiry insofar as . . . they had some treatments that they didn’t know what they were that they had to try and characterize” (Interview 2). She wanted her students to understand the process of science, yet was concerned about shifting ownership to her students based on their lack of experience and skill. Following the summer institute, Professor Garrett explained that her converted lab was now in the center of the continuum, labeled as including more features of inquiry and being a combination of guided and open in design, giving students more ownership than she had previously done in her course. She stated, “And hopefully, as they progress with their experience, you might move along this continuum a little bit [motioning towards more student-directed]” (Professor Garrett, Interview 3). The changes made to her lab indicated a release of ownership in her instruction and a shifted belief to value more student-directed learning.

Professor Rogers’s original lab and his implemented lab were close in proximity to each other on the inquiry continuum. When talking about his teaching practice prior to the SCTIL program, he believed that he used inquiry in his classroom. He explained that inquiry-based teaching was most appropriate for building knowledge and skills for lower-level courses, indicating a value for teacher-directed instruction. He felt that upper-level courses benefited most from a non-inquiry approach in order to lecture more content and cover more breadth of information. Professor Rogers was frustrated with the idea of giving up breadth for depth of content based on his early understanding of inquiry-based instruction. In his second interview, Professor Rogers labeled his lab as having a partial degree of inquiry and being more teacher-directed than student-directed. When asked to label his implemented version of the lab, he noted that he had not shifted much, but did modify one component of the lab: rather than giving students one method of measurement to use in his example version of the inquiry article lab, he removed that method allowing them to choose their method. Based on this modification, he labeled his implemented lab as being slightly more student-directed. He explained that he gained new knowledge during the summer institute and wanted to develop a lab that was appropriate for his students; however, this minimal movement reflects a minor change in his beliefs about inquiry-based teaching towards valuing more student-directed learning.

Professor Wilson was the fourth participant who implemented an inquiry article lab in her classroom. As discussed in her individual case in Chapter Five, Professor Wilson entered the program with experience in implementing an inquiry article lab and brought this lab for further modification during the SCTIL summer institute. She labeled her incoming version as being teacher-directed and having no degree of inquiry. As a relatively new faculty member, she had learned about the inquiry article format through a professional development workshop, yet struggled with how to carry out the implementation of that approach. She noted that she valued application and problem-solving in her teaching, but her greatest difficulty was assessing students' learning with the inquiry article design. After participating in the SCTIL summer institute, Professor

Wilson redesigned her lab to include more features of inquiry and develop a more student-directed approach. Before implementing her lab, she was concerned about giving more of the decision-making process to students, noting that it depended on the students and their willingness to participate. After implementing her SCTIL lab, she stated:

> I think it ended up being a lot more student-directed with much less teacher-guided, absolutely. Simply because I don't expect them to be doing some of the things that they ended up doing . . . they really grabbed this one and ran with it. (Professor Wilson, Interview 3)

Her students' response to her implementation allowed her to shift her view of students' taking ownership as being intimidating towards a belief that student-directed learning was possible.

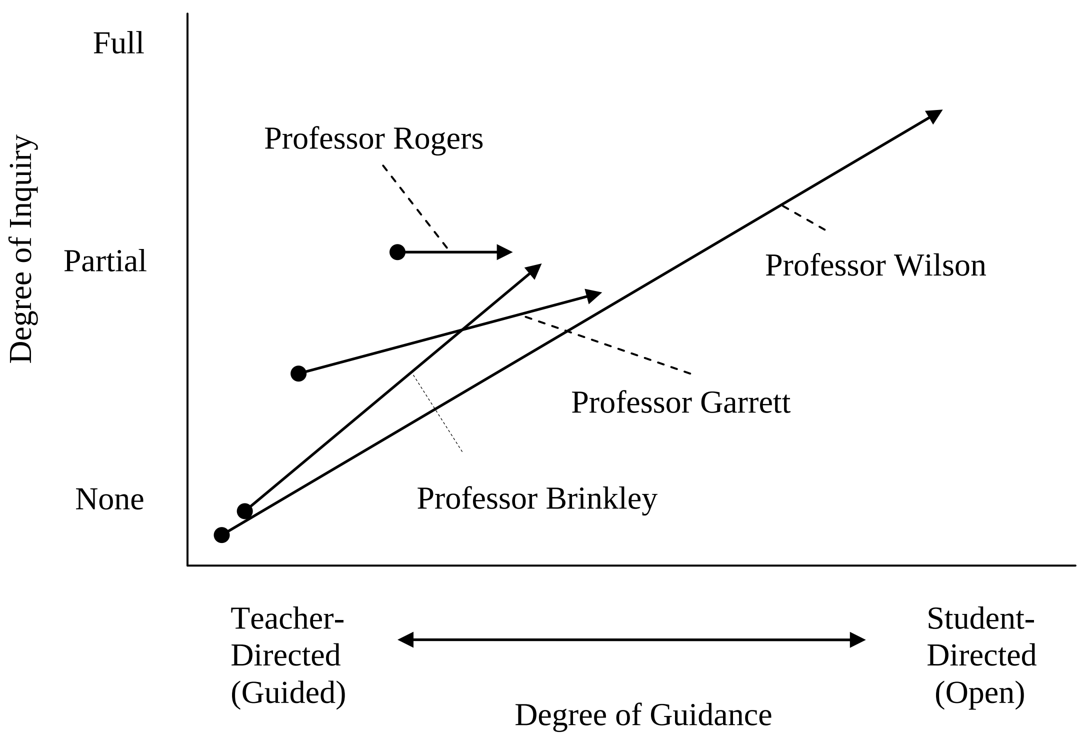


Figure 9. Participants' Inquiry Continuum: Comparing the shift between their original labs and their implemented labs (modified from Brown et al., 2006)

In summary, there was an overall shift of the participants' beliefs to place more value on student-directed learning through classroom inquiry. Some participants had greater changes than others; however, their lab designs and rationales for change indicated that their previous teaching approach was more teacher-directed. Based on their new knowledge gained through the SCTIL program, they were able to develop a more student-directed approach for their labs. Three of the four participants also identified a shift in their lab designs to include more features of inquiry (Professors Brinkley, Garrett, and Wilson). This perspective of moving up the continuum from the lower left-hand corner towards the middle of the figure aligns with the goals of the SCTIL staff members. Staff members wanted the SCTIL participants to rethink their approach to teaching labs and incorporate their knowledge of scientific investigations into their instruction. While the overall shift on the x-axis (directedness) was greater than the shift on the y-axis (degree of inquiry), this movement indicates participants incorporated a more inquiry-based, student-directed approach in their instruction.

Classroom Inquiry

The second theme was a broadening of the participants' knowledge and beliefs about inquiry in the classroom. All participants entered the SCTIL program with the belief that science learning is active, which aligns with their experience as research scientists in the laboratory setting. For example, Professor Brinkley stated, "Inquiry for science learning is to inquire as a scientist does, to utilize the senses and the equipment that we've developed" (Interview 1). Professor Garrett felt that student learning in science was "an active process" involving "problem-solving and application" (Interview 1). Through their doctoral programs and experience as researchers, they had spent countless hours asking scientific questions and investigating those questions through evidence and explanations. The design of the SCTIL inquiry article format is to utilize this knowledge of scientific investigations in teaching college science labs, incorporating a combination of scientific inquiry with classroom inquiry and the pedagogy needed to support this approach to learning. In the following paragraphs, I discuss how participants' beliefs about inquiry changed through the SCTIL program.

In their first interviews, participants tended to think about inquiry as conducting individual scientific experiments similar to independent studies. Professor Rogers explained that, "You would have some problem, you'd try to figure it out, a standard hypothesis, experimentation analysis sort of process" (Interview 1). When discussing the inquiry continuum (Brown et al., 2006), Professor Propes noted that an independent study would be labeled in the upper right-hand corner of the figure, being strictly student-directed and including all five features of inquiry.

After gaining knowledge about classroom inquiry through the SCTIL summer institute and seeing a model of how an inquiry article is implemented, participants changed their beliefs about classroom inquiry. In their second interviews, participants talked about how similar inquiry articles were to their own experience in writing scientific papers and going through the process of science. Professor Garrett explained that she wanted her students to engage in learning science through the role of a scientist. She stated:

> So conceptually, what I'm trying to get them to do is see science as active and get comfortable with this idea of how questions can be solved and answered and how we can use this process to go from a question to potential information that may help answer the question, and get them away from 'here's what to do, step 1, step

> 2, step 3, step 4,' because that's what they're used to. (Professor Garrett, Interview 2).

Professors Garrett and Brinkley expressed frustration with their students' expectations that labs are cookbook-oriented and the answers are in "black and white" (Professor Garrett, Interview 2). They felt that the inquiry article approach allowed them to incorporate scientific inquiry into the classroom by providing them a framework for designing their instruction around its use.

Overall, participants' knowledge of classroom inquiry was expanded to see a larger picture of how to incorporate inquiry in their classrooms. The new knowledge about classroom inquiry, the essential features of inquiry, and an understanding of using inquiry-based teaching in their instruction with the inquiry article format contributed to their changed beliefs as they made connections between their own experience as researchers and their teaching practice.

Assertion #2: Participants' attitudes towards the inquiry article instructional format, attitudes towards implementing it, and motivations for participating in the program were the most influential components of their belief systems as they decided whether or not to incorporate the SCTIL inquiry article format into their future instructional practice.

Based on the Sociocultural Belief Systems Model (Jones & Carter, 2007), two affective components, attitude and motivation, were the most influential determinants in the participants' decision to include the inquiry-based format into their future practice. In the following sections, I discuss each of these components separately drawing from evidence in the participants' interview data: attitudes towards inquiry-based instruction of the inquiry article format, attitudes towards implementation of SCTIL labs, and motivations for participating in the SCTIL program.

Attitudes Toward the Inquiry Article Instructional Format

All five of the participants began the program with a neutral or positive attitude towards the SCTIL instructional format. Professors Brinkley, Garrett, and Wilson expressed positive attitudes based on their interest in improving their pedagogical knowledge and skills for science teaching. Professors Garrett and Wilson were new to college teaching and wanted to learn how to become better teachers. They felt this inquiry-based approach would be beneficial to them. Professor Brinkley entered the program with an interest in learning a new format for inquiry-based teaching. Following the SCTIL summer institute, Professor Garrett's attitude became more positive towards the inquiry article format as she discussed her excitement for using this approach in her classroom. Following implementation of the labs in their courses, these three participants maintained positive attitudes towards the SCTIL format. Professor Brinkley noted in his final interview that this type of teaching approach was "a missing piece" for him in how to design and implement inquiry-based labs (Professor Brinkley, Interview 3). Professors

Garrett and Wilson discussed plans for incorporating the inquiry article format into their future courses.

Professors Propes and Rogers entered the program with neutral attitudes toward the instructional format. They both explained that they did not know what to expect from the summer institute and were willing to sacrifice their time to try it out. By the third interview, both participants' attitudes toward instruction had changed. Even though Professor Propes chose not to implement his lab, he developed a positive attitude towards the SCTIL inquiry-based approach due to his interest in learning a new model of inquiry-based instruction. He explained that he liked the idea of this type of teaching approach regardless of the limitations of his context for implementing it. While he did not plan to incorporate the SCTIL inquiry article format into his future courses, he discussed plans to include portions of it as appropriate for his course goals. Professor Rogers expressed a negative attitude towards the approach and noted that he felt it was "a lot of work," seemingly hesitant about wanting to incorporate it into his instructional practice.

Therefore, participants who entered the program with positive attitudes towards the inquiry article instructional approach were more likely to include this format into their future practice, while those with neutral attitudes were less likely to use the SCTIL design in their future practice.

Attitudes Toward Implementation of the Inquiry Article Instructional Format

Similar to their attitudes towards inquiry-based instruction, all five of the participants' attitudes toward implementation were positive or neutral at the beginning of the SCTIL program. Professors Brinkley, Garrett, and Wilson expressed positive attitudes at the beginning of the program, while Professors Propes and Rogers expressed neutral attitudes. Unlike their attitudes to instruction, however, Professors Propes and Rogers expressed negative attitudes toward their own implementation by the end of the program. Professor Propes was frustrated with wanting to complete the required task of implementing a SCTIL lab within the program timeline; however, he explained that if he had done so, it would have been a forced fit for his course. Professor Rogers's somewhat negative attitude towards implementing his lab was a result of his expectations not being met. He expressed dissatisfaction with the outcome of his implementation. These negative attitudes influenced Professor Propes's and Wilson's decision to not include the inquiry article format into their future courses.

Therefore, participants who entered the program with positive attitudes towards implementing the SCTIL inquiry articles were more likely to include this format into their future practice, while those with neutral attitudes were less likely to use the SCTIL design in their future practice.

Motivations for Participating in the SCTIL Program

Participants identified various internal and external motivators for participating in the SCTIL program. Internal motivators were reasons that drove them to participate in the program with no outside influence. External motivators were reasons for participating based on an influence from an administrator, colleague, tenure, etc. External motivators were based on participants wanting to meet expectations of other individuals. Of the four participants who implemented a SCTIL lab (Professors Brinkley, Garrett, Rogers, and Wilson), those who described primarily internal motivators for participating in the SCTIL program planned to incorporate the SCTIL format into their future practice. Those who gave primarily external motivators did not indicate a desire to incorporate the inquiry-based approach into their practice. The fifth participant, Professor Propes, who did not implement a SCTIL lab, gave both internal and external motivators for participating. In the following paragraphs, I will present the internal and external motivators for all five of the participants.

Of the four participants who implemented a SCTIL lab, three held primarily internal motivators (Professors Brinkley, Garrett, and Wilson). All three of these participants were interested in learning the pedagogy of a new inquiry-based teaching approach. Individually they held additional motivators as well. Professor Brinkley was interested in linking the SCTIL model to his own research agenda in order to gain publications and conference presentations for both himself and his students. He was also interested in networking with other faculty members using this instructional approach since he was the only participant from his institution. Professor Garrett expressed an interest in participating to support her students' learning and make their experience in lab more enjoyable. Professor Wilson was interested in the collaborative approach to learning through the SCTIL program and wanted to see how her peers used the inquiry articles in their courses to gain ideas for her own teaching.

Professor Rogers implemented a SCTIL lab but identified primarily external motivators. While he was interested in learning about the SCTIL inquiry-based teaching approach, he described two primary motivators for participating in the program. First, a departmental colleague was participating in the program and encouraged him to apply for the SCTIL program. Second, he expressed an interest in pleasing his administrators by showing an effort toward improving his teaching, which he felt would be beneficial as he worked towards tenure.

The participant who did not implement a SCTIL lab, Professor Propes, identified both internal and external motivators for participating in the program. He discussed his interest in working with a science educator, Professor Anderson, who was on staff for the SCTIL program. He felt that because the program was associated with her, it would be a beneficial use of his time. In addition, he was interested in networking with peers and having time set aside to think about his teaching. This was rare for him as his primary role as a faculty member was being a researcher. Lastly, he wanted to meet the requirements of his department for publications by gaining publishable work from his experience in SCTIL.

Overall, Professors Brinkley, Garrett, and Wilson implemented SCTIL labs in their courses, held primarily internal motivators for participating in the program, and planned to incorporate the instructional model in their future practice. While Professor Rogers implemented an inquiry article lab, he held primarily external motivators for participating in the program and did not discuss a desire to incorporate the approach in his future practice. Therefore, based on these data, participants with primarily internal motivators were more likely to incorporate the SCTIL instructional approach into their future practice, while participants with primarily external motivators were less likely to incorporate it into their practice.

Summary

Based on the data supporting this assertion, participants who planned to incorporate the SCTIL inquiry article format into their future practice held positive attitudes towards the SCTIL inquiry article format, positive attitudes towards implementing the inquiry article in their own classroom, and primarily internal motivators for participating and implementing it in their courses.

Assertion #3: Student responses to the implementation of the SCTIL approach influenced participants' attitude towards the inquiry article instructional format and their plans for incorporating the instructional approach into their future practice.

Based on interview data from this study and the belief systems model, participants who implemented a SCTIL inquiry article lab received responses from their students that contributed to a change or maintenance of their attitudes towards the instructional format. Participants who entered the SCTIL program with positive attitudes toward the inquiry article format reported positive environmental responses to their implementation, which contributed to maintaining their positive attitudes. Their students found this approach more interesting than cookbook labs and they enjoyed taking on more ownership of their investigations. While all participants reported that their students had difficulty with the writing aspect of the inquiry article approach, those participants with positive incoming attitudes were able to provide necessary encouragement and guidance for their students to push through their difficulties. Those with incoming neutral attitudes reported negative environmental responses to their implementation, which contributed to their change in attitude towards the inquiry article format from neutral to negative. In the following sections, I describe the participants' environmental responses and connect them with participants' attitudes towards the SCTIL instructional format.

Positive Student Responses to Implementing the SCTIL Approach

Professors Brinkley, Garrett, and Wilson received positive responses from their students during the implementation of their inquiry articles. Professors Brinkley and Garrett described their students' initial responses to the SCTIL approach as hesitant because of their desire to have more concrete assignments with clean, clear-cut answers. They anticipated resistance from their students when introducing a new approach to lab teaching. During the implementation, students surprised the faculty with their overall success with the inquiry articles even though the faculty had to modify their expectations. Professor Brinkley's students had difficulty with the journal writing requirements and, in the end, were required to do less than a full inquiry article write-up. The students enjoyed the process of the inquiry article lab and became more comfortable with it by the end of the lesson. Professor Garrett's students also had difficulties with writing, as well as a lack of Excel and microscope skills. After giving additional feedback and more time for the process, she felt the students enjoyed the lab and were overall successful with it. Professor Wilson, having prior experience in implementing the inquiry article format, prepared her students for the change in format from their typical lab approach by talking about her expectations and the design of the lab before her implementation. She felt that they were open to something new, stating that they were not "adversely opposed to it" (Interview 2, Professor Wilson). In her final interview, she stated that she was surprised by their willingness to start or contribute to a class discussion about their investigations. They had lengthy conversations, hearing from different students about varied findings and interpretations. She thought they enjoyed the variety in the lab and was pleased with their response. Professor Wilson credited her informative approach to preparing them for inquiry articles as well as their upper-level status as science majors for receiving positive feedback from their experience.

In addition to positive student responses, both Professors Brinkley and Garrett discussed having administrators, particularly their department chairs, who were supportive of their participation in the SCTIL program. Their administrators were aware of their participation in the program and encouraged them to improve their students' learning.

Overall, participants who reported having overall positive environmental responses to their SCTIL lab implementations tended to maintain their positive attitudes towards the instructional approach.

Negative Student Responses to Implementing the SCTIL Approach

Professor Rogers was the only participant who implemented an inquiry article lab and received negative student responses. Prior to his implementation, he reported a concern about how his students would respond. He felt that he would easily be able to teach the lab, but his students would most likely have difficulty getting the "conceptual connections" (Professor Rogers, Interview 2). As Professor Rogers anticipated, he reported in his third interview that his students had problems learning the concepts of resistance in his lab. He stated:

> I THOUGHT that they would intuitively understand that a thicker wire would have less resistance . . . I expected more of them to be able to get it on at least a gut level that the resistance would drop when it was thicker. (Professor Rogers, Interview 2).

Professor Rogers was frustrated with his students' lack of intuition in learning physics and was unable to explain why they responded in this way. When discussing his perspective on the inquiry article format, he noted, "There's still enough material that we need to cover that I don't think we can do this very often" (Professor Rogers, Interview 3). For Professor Rogers, having the support of a fellow physics colleague did not outweigh his perception of his students' negative response to his SCTIL implementation. The negative student responses contributed to a shift in his attitude towards the inquiry article approach from neutral to negative.

Overall, participants' student responses played an influential role in their belief systems as they shaped participants' attitudes towards the SCTIL inquiry article format. Those who received positive student responses maintained positive attitudes towards the instructional approach while those with negative student responses developed more negative attitudes towards the approach.

Assertion #4: The summer institute was essential for participants to gain knowledge about the inquiry article format; however, the implementation component within their own context was essential in changing their beliefs about inquiry-based teaching.

The belief systems model is designed to be interactive with components influencing each other, as well as the overall belief system being influenced by an implemented practice. While the first three assertions focus on change within components of the model, this assertion focuses on the interactive nature and influence that the SCTIL program components had on the participants' knowledge and beliefs.

The design of the SCTIL program included a 3-day summer institute, ongoing support from SCTIL staff during participants' implementation of inquiry-based labs, and a follow-up reflection meeting at the end of the school year. Based on interviews with the participants who implemented a lab (Professors Brinkley, Garrett, Rogers, and Wilson), the summer institute was instrumental in contributing to participants' knowledge about the SCTIL inquiry-based instructional approach. During the 3-day event, participants learned about the essential features of classroom inquiry (NRC, 1996) and what inquiry would look like in a college science lab environment with the SCTIL format. They also learned that classroom inquiry was not limited to independent student research projects, but could incorporate a range of possibilities in design. Participants used this knowledge as they designed SCTIL labs for their own courses and gained feedback from peers and CUES staff members. Therefore, this concentrated amount of time and support contributed to participants' new knowledge about inquiry teaching.

The SCTIL program also required participants to design and implement two inquiry-based SCTIL labs in their classrooms during the following school year. While their knowledge was primarily gained during the summer institute, their beliefs were impacted through the implementation component of the program. The act of implementing the SCTIL labs they had designed themselves and thinking about their own context and course goals allowed them to apply their knowledge to their classrooms. For example, Professor Rogers explained how his context of non-science majors influenced his decision to modify his SCTIL lab to fit his goals for their learning. Professor Wilson discussed how her upper level science majors benefited from this type of learning approach even though the original design of the SCTIL inquiry article was targeted for non-science major labs. Therefore, the implementation component was an essential piece of the SCTIL faculty development program that impacted participants' beliefs about inquiry-based teaching.

CHAPTER SIX: CONCLUSIONS AND IMPLICATIONS

The purpose of this study was to understand college science teachers' belief systems about inquiry-based teaching and investigate how they changed, if at all, within the context of the SCTIL professional development program. The following research questions guided this study: 1) In what ways, if any, do participants' beliefs and knowledge about inquiry-based teaching and learning change through the SCTIL program; 2) What components of participants' belief systems have the greatest impact on their decision of whether or not to incorporate the SCTIL inquiry article format into their future instructional practice; 3) How do environmental responses to participants' SCTIL lab implementation influence change in their belief systems about inquiry-based teaching and their future plans for incorporating the instructional approach into their practice, if at all; and 4) What components of the SCTIL program were the most supportive for changing the participants' beliefs and knowledge about inquiry-based teaching?

This chapter includes a summary of the findings, a discussion of the findings in relation to the research literature discussed in Chapter Two, a discussion about the belief systems model, an explanation of what can be concluded from this study, implications for faculty development and policy, and recommendations for future research.

Summary of Findings

The first research question focused on the ways participants' beliefs and knowledge about inquiry-based teaching and learning changed within the SCTIL program. Based on my interviews, I assert that they developed knowledge and beliefs about classroom inquiry and began to value a more student-directed approach to inquiry-based instruction. The participants were research scientists entering the faculty development program with experience in research laboratories. Learning about the SCTIL inquiry-based instructional format for laboratory teaching expanded their knowledge about classroom inquiry and how to implement inquiry-based methods in their classrooms. Of those who implemented an inquiry article lab (Professors Brinkley, Garrett, Rogers, and Wilson), their knowledge of inquiry and inquiry-based teaching contributed to a change in their value of student-directed learning. Although they came in to the program with a more teacher-directed practice in their laboratory teaching, they learned how to give students more ownership in their own learning experience.

The second research question examined what components of the belief systems model had the greatest influence on participants' decisions to include the inquiry article instructional format in their future practice. Drawing from my interview data, I claim that the participants' attitudes and motivations were the most influential components in this decision-making process. Participants' incoming attitudes towards the inquiry article instructional format and their implementation of it were either neutral (Professors Rogers and Propes) or positive (Professors Brinkley, Garrett, and Wilson). Of the four participants who implemented (Professors Brinkley, Garrett, Rogers, and Wilson), Professors Brinkley, Garrett, and Wilson maintained their positive attitudes following their implementation and planned to incorporate the approach in their future practice. Professor Rogers described a more negative attitude following his implementation and did not express a desire to incorporate the approach into his practice.

Motivations also played an important role in this decision process. Participants who described primarily internal motivations for participating in the SCTIL program (i.e., wanting to increase their pedagogical knowledge, network with colleagues, or improve their students' learning experience) planned to incorporate the SCTIL format into their future practice. These participants were Professors Brinkley, Garrett, and Wilson. Professor Rogers described primarily external motivations for participating in the program (i.e., joining at the request of a colleague and wanting to improve his teaching practices for tenure) and did not express a desire to incorporate the instructional approach in his future practice.

The third research question focused on the impact of environmental responses on participants' belief systems following implementation. Based on my data, I assert that students' responses to the participants' inquiry article implementation influenced participants' attitudes towards the instructional approach as well as their plans for incorporating it into their future practice. Participants with incoming positive attitudes reported their students responded positively to the new approach, which contributed to their maintained positive attitudes. The participants' attitude was important as they encouraged students and provided them with support as they engaged in inquiry-based learning. The participant who entered the program with a neutral attitude and implemented an inquiry article lab received negative student responses that contributed to the participant's more negative attitude towards the instructional approach. These responses also played a role in influencing participants' decisions about incorporating the inquiry article format into their future practice. Positive student responses to their implementation contributed to participants' decision to include the inquiry article design, while negative student response contributed to a lack of interest in including the design in future practice.

The final research question investigated the supportive role of the SCTIL program components on changing participants' knowledge and beliefs. The findings from the study show that the summer institute contributed to their gained knowledge about inquiry and inquiry-based teaching and learning while their implementation in the following school year played a critical role in refining their knowledge and changing their beliefs about inquiry-based teaching. An important design component of the SCTIL program was the experience of implementing their inquiry article labs in their own contexts.

The overall findings from this study present a new perspective on teacher learning through faculty development as well as insight into their learning process. Therefore, I posit that faculty development can make a significant impact on teachers' belief systems about an instructional approach as well as their future practice if teachers enter the experience with positive attitudes and primarily internal motivations for participating.

Discussion

The following discussion is organized according to the research questions. I use the literature reviewed in Chapter Two as a point of comparison with the findings of this study. The purpose of this section is to understand how the findings help to fill gaps in the literature, support the current literature, or provide an alternative perspective. I conclude this chapter by discussing the use of the Sociocultural Belief Systems Model (Jones & Carter, 2007) as a theoretical framework for this study.

Change in College Science Teachers' Beliefs and Knowledge

The participants in this study gained new knowledge about classroom inquiry through the SCTIL summer institute and described a change in their beliefs about inquiry-based teaching and learning following their implementation of the inquiry article approach. During the SCTIL program, their beliefs shifted to include more value on student-directed learning and classroom inquiry.

In 2002, Harwood, Reiff, and Phillipson reported that college science teachers' beliefs about scientific inquiry were reflective of their experience as scientists, characterizing scientific inquiry as fueled by questions, used in problem-solving, focused on the process not the product, and connecting the known to the unknown. Brown et al. (2006) extended this research by investigating college science teachers' beliefs about inquiry in the classroom. They reported that college science teachers viewed inquiry-based instruction as student-directed, independent research. Incorporating inquiry into their teaching practice meant conducting scientific investigations as they would in their own labs. As a result of their findings, Brown et al. proposed an inquiry continuum to identify a possible range in inquiry-based teaching between student-directed and teacher-directed learning, as well as describing partial to full inquiry (see Figure 2). The authors' purpose was to support college science teachers' understanding that inquiry-based teaching was not limited to full inquiry and student-direction, but could include many possible approaches. This inquiry continuum was used as part of the SCTIL research-based content on inquiry teaching. The participants in this study found the continuum useful in helping them understand the variation possible in inquiry-based instructional design.

The findings from this study support two key features of faculty development presented by Loucks-Horsley et al. (2003), which included the importance of designing research-based programs that engage teachers in their own learning and are "driven by a well-defined image of effective classroom learning and teaching" (p. 44). The SCTIL program was based on research about classroom inquiry (i.e., the inquiry continuum). These findings support the limited literature based on inquiry in college science teaching by providing insight into teachers' incoming beliefs and knowledge about inquiry-based teaching and how that changed through their learning experience.

This study also contributes to the research strand about how science teachers' beliefs and knowledge about classroom inquiry change after learning about inquiry and related pedagogical strategies through a professional development program. Previous studies on secondary science teacher learning through inquiry-based professional development have shown that teachers' gain knowledge about inquiry-based instruction but experience little change in their beliefs or practice (Lotter et al., 2006; Wee et al., 2007). This study contributes a new perspective for college science teacher learning through professional development in which the program design influenced knowledge and beliefs, as well as plans for their future practice. The participants in this study who implemented the inquiry article labs described their incoming beliefs about inquiry-based teaching as being more closely aligned with full inquiry and student-direction, similar to the previous research findings (Brown et al., 2006). They described their prior laboratory instructional practice, however, as being primarily teacher-directed due to their hesitancy in giving students more ownership of their own learning. Professors Brinkley, Rogers, Garrett, and Wilson described their practice as including some features of inquiry prior to the program, such as asking and answering questions as scientists would; however, they tended to implement these features with a teacher-directed approach. Their experience as science researchers instilled a desire to include inquiry in their classroom yet they seemed to have difficulty in knowing how to implement inquiry in their instruction. The inquiry article format provided them a structured teaching strategy to align their practice with their beliefs. Therefore, this study contributes new knowledge about the importance of inquiry-based faculty development in order to incorporate more inquiry into college science classrooms. Adding to the teacher learning literature, these findings contribute a deeper understanding about how college science teachers learn—through research-based, authentic experiences that are implemented in their practice.

Impact of Belief System Components on Decision to Include Inquiry Articles in Future Practice

Attitudes and beliefs were the most prominent belief system components that influenced participants' intention of including the SCTIL inquiry-based format in their future practice. Participants' attitudes towards the inquiry article format and their attitudes towards implementing it both contributed to this decision process as well as their motivations for participating in the SCTIL program.

Research on teachers' attitudes towards instructional strategies shows that learning how to use a strategy helps teachers develop a more positive attitude towards the strategy (Bratt, 1977; Butts & Raun, 1969; Kennedy, 1973). In the context of this study, participants learned about inquiry and inquiry-based teaching through the SCTIL program. While not all participants' attitudes changed, the findings from this study showed the importance of participants' incoming attitudes in their learning experience and their plans for incorporating the strategy in their future practice. Participants with incoming positive attitudes maintained their positive attitudes through the program and expressed interest in using the inquiry article format in the future; however, participants with incoming neutral attitudes towards implementing the approach developed negative attitudes towards implementation, which contributed to their lack of interest in incorporating the SCTIL inquiry article format in their practice. These findings about attitudes contribute a more specific perspective to the faculty development and teacher learning literature on the importance of teachers' incoming attitudes towards learning and implementing new instructional strategies.

In addition to attitudes, motivations were another key component of the belief systems model that influenced the participants' decision to incorporate the inquiry article approach in their practice. In the adult learning literature, Knowles (1980) presented the assumption that "the most potent motivations are internal rather than external" (p. 101). The limited research on college teachers' motivations for participating in faculty development indicates that college teachers tend to be internally motivated. Three examples of internal motivators presented in the literature are the drive to improve teaching skills, quality of work, and research skill (MacKinnon, 2003). Extending this literature base on college teachers' motivations, the findings from this study identify teachers' internal and external motivations for participating in the SCTIL program. Internal motivations included the drive to learn and use an inquiry-based instructional approach, an interest in linking the inquiry article format to their own research for publications, and an interest in networking with other science colleagues to get ideas and feedback through the program. External motivations included working toward tenure and participating to please a fellow department colleague who was also participating in the program. Participants giving primarily internal motivators planned to incorporate the inquiry-based approach into their future practice while participants giving primarily external motivators did not express a desire to include it in their practice.

Building on the teacher learning research about self-directed learners being internally motivated (Weimer, 2002), these findings extend this strand to focus on the influence of motivations on teachers' decision-making process by showing that faculty members who participate in programs with a self-directed, internally motivated nature are more likely to carry the new instructional approach into their future practice.

Role of Student Responses

Teachers tend to view the effectiveness of faculty development by the success of their implementation based on students' responses (Guskey, 1986). A study by Friedrichsen and Dana (2005) found that secondary science teachers' orientations, or their knowledge and beliefs about teaching science, were strongly influenced by their students' feedback to their daily instructional practice. They noted that if teachers believed their students were bored or dissatisfied with an instructional approach, they would make modifications to their practice with the intention of improving their students' learning experience. In this study, participants' implementation of a single instructional approach, the inquiry article format, resulted in either perceived positive or negative responses from their students. The student response fed back into the teachers' belief systems influencing their attitudes towards the inquiry article format as well as their future plans for incorporating the instructional approach into their practice. A literature search on student responses to college teachers' implementation following faculty development resulted in no publications. The majority of college faculty development literature is descriptive rather than empirical, which explains this significant gap in understanding the influence of student response on college teacher learning during implementation. Therefore, the findings from this study on student responses contribute to this gap by providing a picture of how college teacher learning is influenced by students' responses. In light of the belief systems model, students' responses serve as a filter to college teachers' belief systems about an instructional practice.

Supportive SCTIL Components that Changed Participants' Beliefs and Knowledge

The design of the SCTIL program included multiple faculty development strategies to support change in the participants' beliefs and knowledge about inquiry-based teaching. These strategies included a 3-day collaborative summer institute, follow-up support during the participants' implementation in their courses, and a reflection meeting at the end of the school year. A review of the literature on faculty development models shows that current models have a collaborative nature (i.e., Koch, et al., 2002; Pittas, 2000; Stevenson, Duran, Barrett, & Colarulli, 2005). Professors Brinkley, Garrett, Rogers, Propes, and Wilson all participated in the 3-day summer institute in which they gained new knowledge about the SCTIL inquiry article instructional approach through the collaborative design of the sessions. Professors Brinkley, Garrett, Propes, and Wilson discussed their appreciation of working with peers and meeting other faculty members who would be attempting to use the same instructional approach. Collaboration played an important role in their learning environment.

In addition, a current theme in the literature on faculty development models shows the importance of situating the content in a teacher's context (i.e., Abell, 2005; Cook, Wright, & O'Neal, 2007). Four of the five participants (Professors Brinkley, Garrett, Rogers, and Wilson) implemented their SCTIL inquiry article format in the contexts of their own classrooms. This design, according to the belief systems model, allowed the participants to gather student responses during implementation which would influence their belief systems. The act of implementing played a critical role in influencing change in the participants' belief systems. The participants' descriptions of inquiry-based teaching became contextual as they could discuss examples from their experience as well as their expanded beliefs about classroom inquiry. In the teacher learning literature, one perspective for learning is situated cognition. As reviewed in Chapter Two, this means that what an individual learns is specific to the situation in which it is learned (i.e., Lave & Wenger, 1991; Putnam & Borko, 2000). Putnam and Borko (2000) describe the importance of interaction in learning. In this context, participants learned about inquiry and an inquiry-based teaching approach while interacting with colleagues and modifying their own labs, then implementing their work in their classrooms. This sociocultural view of learning shows the importance of incorporating interaction and implementation in science faculty development.

Use of the Sociocultural Embedded Belief System Model

I used Jones and Carter's (2007) Sociocultural Embedded Belief Systems Model, based on secondary science teacher literature, as a conceptual framework for this study on college science teachers (see Figure 1). Due to the model's recent publication, this study may be the first to empirically test the usefulness of the model. In this section, I discuss helpful and problematic components of the model, then provide a revised model based on this study.

As I first read Jones and Carter's (2007) description of their belief systems model, I felt it was an appropriate match for investigating teachers' belief systems within faculty development. My previous research on faculty development focused on teachers' knowledge and beliefs, as well as their departmental social norms (Hutchins &

Friedrichsen, 2007). I had not taken into consideration teachers' attitudes, motivations, or self-efficacy. This model was useful in that it provided an expanded view of the influential components of a teacher's learning experience.

Through my design and data collection process, I encountered two main issues in applying the model to the context of this study. First, in considering teachers' epistemological beliefs about science, science learning, and science teaching, my interest was more specific and required participants to respond accordingly. I resolved this issue by interpreting the model using the specific epistemological components of beliefs about science as inquiry, science learning through inquiry, and inquiry-based teaching. Developing contextual questions for inquiry-based teaching and learning contributed to the richness of the study.

The second issue that arose was the skills component of the model. If I were to observe their skills through classroom observations, I would have no point of comparison due to the lack of standardized skills needed for teaching with the inquiry article format. More importantly, I did not want to evaluate the participants' skills due to the constructivist tradition used in the study. Through the interviews, I allowed my participants to construct their own belief system components. I found that if I asked participants to evaluate themselves, their limited pedagogical knowledge about inquiry-based teaching hindered their ability to assess their own skills.

While I tried to adhere to the language of this model while explaining my interpretation of the components for this context, the participants' responses about their beliefs were not limited to their epistemological beliefs, or their beliefs about how knowledge is constructed. Participants focused on their changing values when discussing their beliefs, as seen in Assertion #1. For example, Professor Wilson talked about the value of giving students more ownership in the lab after seeing how successful her students were using the inquiry articles. Researchers have discussed values as related to beliefs since the 1950s (i.e., Kluckhohn, 1951; Rokeach, 1968). Rokeach defined values as “abstract ideals, positive or negative, not tied to any specific object or situation, representing a person’s beliefs about modes of conduct and ideal terminal goals” (1968, p. 160). Values, therefore, may play a role in belief systems as part of teachers’ beliefs about teaching and learning.

As an outcome of this study, I present a new belief system model in Figure 10 that is specific for college science teachers’ learning about inquiry teaching. This model draws from the framework of the Sociocultural Model of Embedded Belief Systems (Jones & Carter, 2007). Rather than limiting the beliefs component to epistemological beliefs, I expand this section to include beliefs and values, while adding “course goals” as a sub-component. The participants in this study discussed their goals for their course content when describing their context of implementing inquiry articles. Their beliefs and values about their course curriculum influenced their design of their inquiry articles.

In thinking about the influence of participants’ implementation on their belief system, I felt that reflection was an important component that was missing from the Jones and Carter (2007) model. Critical reflection of one’s teaching can help teachers see their instruction through their students’ viewpoint and allow teachers to see themselves as constantly evolving and growing (Brookfield, 1995). The participants in this study reflected on their implementation during their third interviews as they responded to questions about their beliefs, motivations, reactions, etc. It is critical for teachers to think

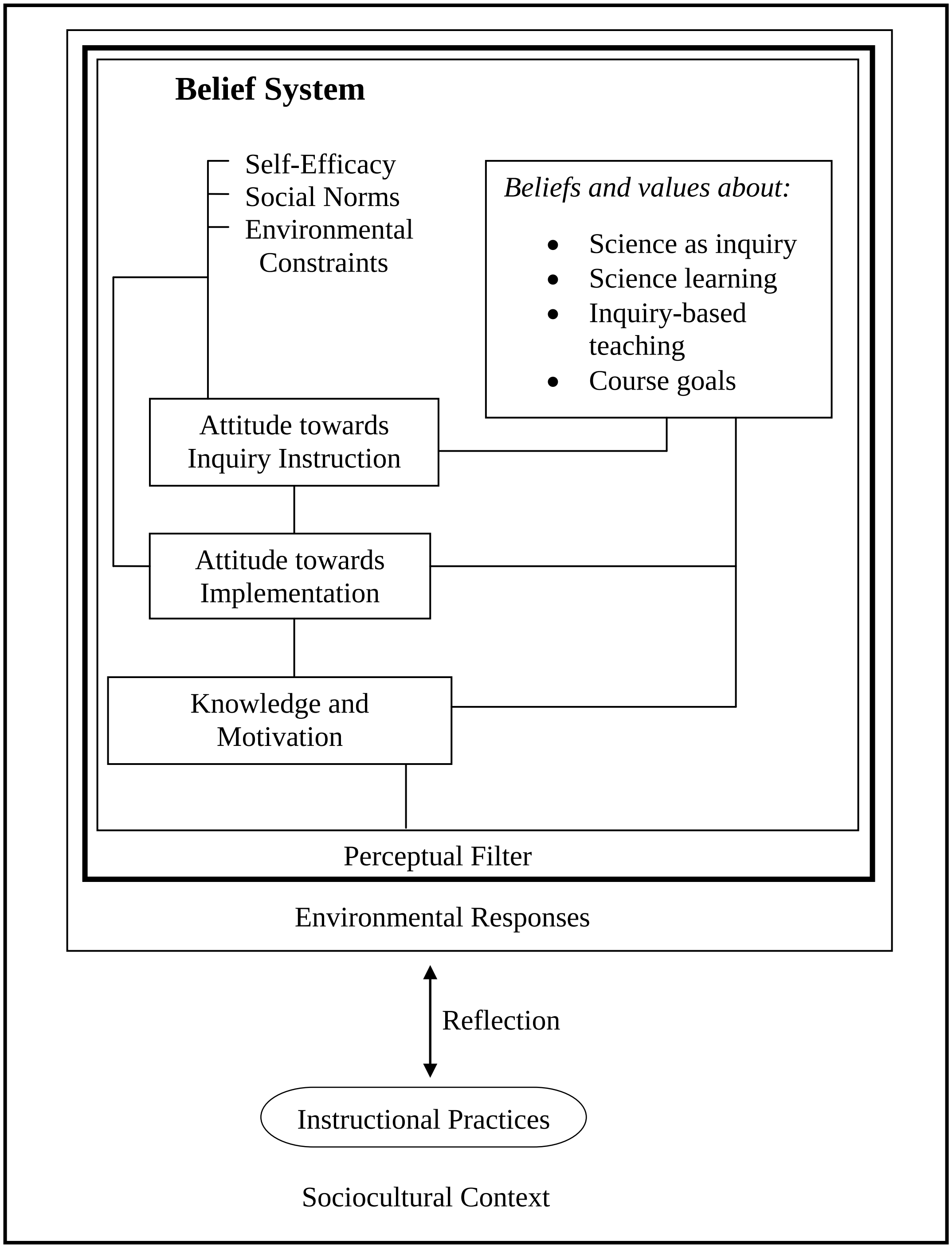


Figure 10. Inquiry Belief System Model for College Science Teachers

about their teaching to help make sense of what they learn and consider how it influences their belief system.

Conclusions

The overarching research question asked: In what ways, if any, do college science teachers' beliefs systems about inquiry-based teaching change within the context of the SCTIL professional development program? Based on the findings from this study, participants experienced varied levels of change in their beliefs about inquiry and inquiry-based teaching, their knowledge about the inquiry article format, and their attitudes towards the instructional approach and its implementation. Depending on their students' responses to their implementation, the teachers' beliefs and attitudes were impacted. Following this faculty development experience, participants discussed their plans of using the inquiry article format in their future practice. These plans were influenced primarily by the participants' attitudes and their students' responses. Therefore, the college science teachers' learning was supported through research-based, authentic experience with classroom inquiry that could be carried into their practice. We learn from these findings that the components of college science teachers' belief systems play an interactive role in influencing each other throughout the learning experience. While some components (e.g. knowledge and skills) could be influenced by faculty developers, other components (e.g., attitudes and beliefs) may be difficult to impact.

This study contributes significant findings to the fields of teacher learning, faculty development, and inquiry in college science education. For the teacher learning literature base, these findings present a deeper understanding of how college science teachers learn through science-specific faculty development and gives evidence of the importance of contextual experiences in implementing what they learn. For faculty development research, this study provides one of the first empirical studies looking at the influence of student responses to implementation following participation in a faculty development program. This is also a rare empirical study on a faculty development model that shows the value of collaboration and situated context in the design of the model. To extend the research strand on college science teachers' beliefs and knowledge about inquiry in the classroom, this study presents a perspective on how these components change through learning about inquiry and applying it within a science faculty development program. Overall, this study makes significant contributions to the field of college science teacher learning through faculty development.

Significance of the Study

In reflecting on the significance of this study on college science education, it is important to consider why this research makes an impact on the field. Without improving students' learning experience in college STEM courses by improving STEM instruction, we would continue to lose students who choose to move to other majors. Ultimately, this would result in a decline in future scientists that would contribute to our knowledge of science. Therefore, these findings give us new insight into improving college science education for both teachers and students.

Implications

In order to address the national shortage of STEM majors and the fact that students are leaving the pipeline of science-related fields, we must focus on more effective science faculty development and appropriate policies to support college teacher learning during their doctoral studies. Therefore, this study provides implications for faculty development and policy.

For Faculty Development

While the purpose of this study was not to evaluate the SCTIL faculty development program, the findings present aspects of the program that were beneficial to teacher learning and would inform faculty developers in designing programs for college teachers.

First, faculty development programs need to include collaboration and situated learning experiences that are individualized for the participants' contexts. Learning about teaching within the framework of their own students, classroom, and curriculum allows teachers to use what they learn in a meaningful way.

Second, developers need to be aware of the affective components involved in their participants' incoming belief systems. What is their motivation for participating? How does this contribute to their attitude toward the learning experience? Faculty developers would likely benefit from knowing this information about their attendees before the program begins. The ideal program would attract internally motivated college science teachers with incoming positive attitudes towards learning the content.

Third, students' responses to teachers' implementation plays a critical role in influencing teachers' belief systems about an instructional strategy. Faculty developers need to continue their support for teachers through implementation to support teachers as they reflect on their students' responses. This could include one-on-one debriefing meetings to help the teachers make sense of what they learned through teaching, a peer support group to talk about issues during implementation, or encouraging teachers to share their experience and thoughts through university teaching seminars, which would support time for reflection.

Finally, the long-term nature of the SCTIL program was key to giving teachers time to process what they learned through the summer institute and incorporate it into their classrooms. It encouraged participants to think about inquiry-based teaching over a year-long period, which extends beyond the typical one-day workshop approach. Faculty development design needs to extend beyond short-term designs (e.g., one-day workshops) by supporting a change in teachers' beliefs through implementation into teachers' practice.

For Policy

The college science teachers in this study did not have strong educational components in their own graduate programs prior to becoming faculty members. If faculty members had more pedagogical coursework, this may have contributed to stronger belief systems about reform-oriented instruction, enhancing their learning experience in the SCTIL program. Therefore, there is a need for research-based, reform-oriented education experiences in graduate programs for future college teachers. Most graduate programs tend to focus on developing research skills and knowledge, failing to require education courses and meaningful teaching experiences (Austin, 2002). In many science graduate programs, students gain experiences as teaching assistants in laboratory courses; however, students are asked to follow a prescribed curriculum in their teaching. Future college science teachers need to become familiar with the science education literature on effective teaching and student learning. They also need to gain experience in implementing reform-oriented, inquiry-based teaching strategies in the classroom. To enhance their learning experience, graduate students could keep reflective journals as a strategy for thinking about their teaching practice. Therefore, an implication for policy is to ensure that research universities embed meaningful graduate student development experiences that include pedagogy courses as well as teaching practice as a required part of graduate education. Other components may include mentorship programs, teaching assistantships with reform-oriented teachers, or required science education discussion groups/workshops in which graduate students collaborate in their reading of science education literature or reflect on teaching experiences. Pedagogy courses should be science-specific to develop future college teachers' pedagogical content knowledge for science teaching.

For practicing college science teachers, the value of teaching at research institutions tends to be low. The guidelines for promotion and tenure focus on research with little attention on teaching. Universities need to encourage the improvement of college science education by placing higher value on teaching through their tenure guidelines. Administrators can also demonstrate the value they place on teaching by supporting faculty development opportunities. Based on this study, it is important for teachers to enter faculty development with positive attitudes and internal motivations. In order to recruit more teachers into faculty development, administrators need to first encourage those with positive attitudes towards learning and using new pedagogy, then highlight those individuals to their peers. Administrators could also support the use of inquiry-based teaching by assigning teachers to the same courses for several years in order to give them the opportunity to refine and improve their instructional designs.

Recommendations for Future Research

This section presents recommendations to extend the findings from this study in future research in the fields of teacher learning, faculty development, and the belief system model.

Based on the timeline of this study, I followed participants through their first implementation of an inquiry article lab. To better understand how teachers' belief systems change, a longer longitudinal study of their participation and implementation would be informative. This research, whether it be conducted on future SCTIL programs or similar formats, needs to extend beyond one implementation into teachers' ongoing practice for several years in order to see additional changes in belief systems components and the teachers' learning.

For some institutions, it may be difficult to attract internally motivated teachers with positive attitudes towards learning new instructional strategies through faculty development. Faculty developers may design excellent programs but make little impact on teachers who enter with negative attitudes or primarily external motivations. Therefore, future research needs to be conducted to understand influences on college teachers' incoming attitudes and motivations before they participate in faculty development. These findings would contribute to faculty developers' knowledge about these affective domains prior to recruitment. If faculty developers understood their future participants' belief systems in a holistic way (e.g., attitudes, motivations, beliefs, etc.), they could design more individualized programs to support a change in teachers' beliefs.

This study focused on new and junior faculty members. Experienced faculty members have different motivations for participating in faculty development. They do not have the pressure of tenure and may be more internally motivated to improve their teaching practice. Further research needs to be conducted on experienced faculty to understand their attitudes, motivations, and change in knowledge and beliefs.

Based on my discussion of the Sociocultural Embedded Belief Systems model (Jones & Carter, 2007), I recommend further research to test the usefulness of this model with college science teachers by incorporating values as a component and excluding skills. Applying this model as a framework in future faculty development research studies would add to these findings and contribute a deeper understanding about science teacher learning through faculty development experiences. In addition, there is a need for more empirical studies to test the usefulness of this model as a framework

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APPENDIX A

EXAMPLE OF INQUIRY ARTICLE LAB

Journal of Honors Lab Investigations 2(1): 20 - 25, 2002
Effects of Osmosis on Blood Cell Volume
Suzy E. Otto and Dr. Frank Schmidt

Abstract: Because osmotic pressure affects living cells dramatically, we wanted to understand the effect that variation of solute concentration has on osmosis. We placed human blood cells in various concentrations of aqueous salt (NaCl), glucose, and urea solutions, expecting that as solute concentration increased, blood cell volume would decrease systematically. Differences in blood cell volume were observed by centifuging cells and measuring their volume and by viewing cells under a microscope for signs of osmotic effects. We found that blood cells placed in NaCl and glucose solutions with concentrations greater than 1% and 4% (weight/volume) respectively, decreased in volume and appeared "shriveled" under a microscope. Cells placed in distilled water and in NaCl and glucose solutions less than 0.1% and 0.4% (w/v), respectively, apparently drew in enough water to cause their rupture, leading to the loss of cell mass on centrifugation, and the disappearance of intact cells under the microscope. Cells placed in solutions with intermediate concentrations yielded intermediate volumes of blood cells and cells appeared rounded and uniform under microscopic examination. Cells placed in all concentrations of urea solution we tested were apparently destroyed, resulting in an inability to separate them from the aqueous portion of their solution by centrifuging. This is interesting because urea is a wasteproduct of cell metabolism that increases in high protein diets (like the Atkins diet). The behavior of cells in these and other solutions should be explored in more depth to gain a better understanding of the critical levels of normal blood solutes.

Introduction:

Osmosis is a natural process in which water moves across a semi-permeable membrane from areas of low solute (molecules that are dissolved) concentration to those of high solute concentration. The direction of water movement can be predicted by comparing the solute concentrations or "tonicity" in aqueous solutions on either side of a membrane. Solutions that contain higher concentrations of solute are called "hypertonic" and are diluted by osmosis when water molecules move into them. "Hypotonic" solutions have lower solute concentrations and will lose water in the osmosis process. Two solutions with the same concentration are called "isotonic" and will show no net exchange of water when placed on opposite sides of a membrane. (Bowen, 2000). Note that the designation of a solution as hypo- or hypertonic must be done relative to another solution. For example, a 0.1 molar NaCl solution would be considered hypotonic to a 0.5 molar solution, but the same 0.1 molar NaCl solution is hypertonic relative to distilled water.

The relative volume of blood cells in a solution can be estimated by measuring the volume of centrifuged cells. Separation of cells from solvent should be clearly seen by formation of distinct clear and red liquid layers in the centrifuge tube. Changes in the cell volume caused by osmosis of water into or out of individual cells can then be measured as a change in the overall volume of the compacted cell layer in the tube tip.

Our goal was to determine the effect of various concentrations of NaCl, Glucose, and Urea solutions on red blood cell volume. We selected these solutes because they occur naturally in the blood at varying levels (Kimball 2001).We expected that the blood cell plasma membrane would serve as a semi-permeable membrane and facilitate osmosis. We expected that cells exposed to hypotonic solutions, such as distilled water and low-level solute concentrations, would expand in volume as water entered them. If water influx were great enough, some cells could actually rupture. In higher solute concentration solutions, we expected the direction of osmosis to reverse, drawing water out of the cells and into the hypertonic solution surrounding them. In this case, the volume of the blood cells should decrease.

Materials and Methods:

A sample of human blood was obtained from Prof. Mark Milanick of the University of Missouri Physiology Department. The blood had been heparanized and refrigerated to keep it fresh for our experiment. When working with human blood, it is necessary to follow biosafety procedures. Precautions used during our experiment included wearing rubber gloves when handling blood, the use of mechanical micropipettes for dispensing blood, properly disposing of contaminated materials, and avoiding contamination of stock solutions.

We used 0.4 mL microcentrifuge tubes to mix our test solutions with the blood. We used total volumes of 250 µL (micro liters) or 0.25 mL in order to avoid spillage from overfilled tubes and to give space in the tube to facilitate mixing. We obtained pre-mixed stock solutions containing 5% NaCl, 5% urea, and 20% glucose (by weight) which we diluted to six different concentration levels for our experiment. We calculated volumes of stock solution, distilled water, and blood needed to yield 250 μL of each specified solution concentration. Table 1 shows the concentrations and volumes mixed for the experiment using NaCl solutions. Similar tables were prepared for other solutions.

Once all volumes were calculated, solutions were mixed directly in the centrifuge tubes. We set up a row of six tubes for the NaCl dilutions in a test tube rack. In order to keep track of the various solution concentrations, we planned to increase the NaCl concentration as we worked from left to right.

First we placed distilled water volumes in the tubes by using a micropipette and adjusting the wheel to deliver the desired volume in μL(microliters). The NaCl volumes were added next, again using the micropipette to deliver a pre-determined volume. Finally, 50 μL of blood was added to each tube. The tubes were tightly capped and then rotated and gently tapped/shaken to facilitate mixing. Micropipette tips were changed between solutions to avoid contamination. Similar procedures were followed to set up six dilution levels for glucose and urea solutions.

Table 1: NaCl Solution Specifications. Volumes of stock solution, water, and blood were calculated to provide 250 μL (.25 mL) of total solution at the specified concentration. The table below shows the calculations for the NaCl solution. Similar calculations were made for Urea (trials 1-6) and Glucose (trials 13-18). All trials used the same volume of blood (50 L) so that comparison of compacted cell layers indicated differences in cell volumes rather than initial blood volumes.

Trial Number:	7	8	9	10	11	12
NaCl Conc. (wt.%):	0%	0.1%	0.5%	1%	2%	4%
Component Vol. (μL)						
5% NaCl stock solution	0	5	25	50	100	200
distilled water	200	195	175	150	100	0
blood	50	50	50	50	50	50
Total Vol. (μL)	250	250	250	250	250	250

The concentration (Cx, trial solution , where x = NaCl, glucose, or urea) of the solution in a given trial was calculated as follows:

$$C_{x,\ \text{trial solution}} = \frac{(C_{x,\ \text{stock solution}}) \times (\text{volume of stock solution})}{(\text{volume stock solution} + \text{volume water} + \text{volume blood})}$$

For example, using NaCl trial solution #9:

$$C_{NaCl,\,9} = \frac{(0.05) \times (25\ \mu L)}{(25 + 175 + 50)\mu L} = 0.005 \text{ g NaCl/gH2O} = 0.5 \text{ wt \% NaCl}$$

After mixing, the tubes were returned to the rack and allowed to stand for approximately 10 minutes to allow osmosis to occur. Trial numbers were written on the lids of tubes to ensure easy identification after centrifuging.

Just prior to centrifuging, we removed 5μL of solution from each centrifuge tube and placed it on microscope slides (two per slide). Care was taken to change the micropipette tip between solution types. Cover slips were placed over the solution droplets and slides were labeled with appropriate trial numbers. The cells were viewed under a microscope at 100X magnification to see if there were any visible differences in cells that had been exposed to various solutions.

Then the tubes were placed in a centrifuge and spun. Equal numbers of tubes were placed on both sides of the centrifuge to ensure proper balance. The centrifuge speed was set at 2000 rpms and the tubes were spun for 1 minute. After centrifuging, the tubes were returned to the racks and examined.

We measured the height of the red compacted cell layer by placing a ruler (marked in mm) against the sloped tip of the tube and estimating the height of cells present. This height measurement was converted to a cell volume estimate through a calibration process. Calibration was accomplished by placing a range of known distilled water volumes (25, 50, 75, 100, 150, and 200 μL) in tubes and centrifuging them in the same manner as the experimental trials (to remove air and pack water in the tip). The height of each water volume was then measured in mm with the ruler. In this way, we developed a scale that allowed us to convert our liquid height measurement to a liquid volume. Table 2 gives the calibration for mm and volume.

Table 2. Relationship between solution height and solution volume in a 0.4 mL centrifuge tube.

solution height in mm	6	6.5	7	7.5	8
solution volume in L	25	30	40	45	50

Results:

Table 3 lists the measured height of the compacted cell layer and the estimated cell volume, based on the calibration scale described in the Materials and Methods section in Table 2. Many of the solutions did not exhibit the expected two phase (clear and red) pattern, but instead remained red throughout. We took this to be an indication that the cells were no longer intact, but that they had ruptured and their cell fragments did not have significant mass to be forced to the tip of the centrifuge tube.

Table 3: Volume of Compacted Cells in Various Solution Concentrations. Cell layer height was measured directly with a ruler. Cell volume was estimated through comparison to known water volumes as given in Table 2.

<u>**Urea Solutions:**</u>						
Urea Conc. wt%	0%	0.1%	0.5%	1%	2%	4%
Height of Red Layer (mm)	all red	all red	all red	all red	all red	all red
Vol. Compacted Cells (μL)	n/a	n/a	n/a	n/a	n/a	n/a
<u>**NaCl Solutions:**</u>						
NaCl Conc. wt%	0%	0.1%	0.5%	1%	2%	4%
Height of Red Layer (mm)	all red	all red	8	6.5	6	6.5
Vol. Compacted Cells (μL)	n/a	n/a	50	30	25	30
<u>**Glucose Solutions:**</u>						
Glucose Conc. wt%	0%	0.4%	2%	4%	8%	16%
Height of Red Layer (mm)	all red	all red	7.5	7	6.5	6
Vol. Compacted Cells (μL)	n/a	n/a	45	40	30	25

The rupture of cells in very low NaCl and glucose solution concentrations matches our expectation that water would osmotically move into a cell that is hypertonic to its surroundings, possibly to the point of rupturing the cell. The observation that cells ruptured in all concentrations of urea solutions was unexpected, and will be addressed in the Discussion section.

Figure 1 shows a plot of NaCl and glucose solution concentrations versus the estimated volume of compacted cells. Note that these data, in general, demonstrate that as solution concentration increases, the volume of compacted cells decreases. This trend matches expectations since immersion of a cell in a hypertonic solution would osmotically draw water out of the cell, thus shrinking cells and reducing their volume. The degree to which osmosis drew water out of the cells varied significantly between the NaCl and Glucose solutions, as can be seen by the large difference in the slopes of the two curves on the plot.

We only examined glucose trials #13 - #18 for microscopic changes in blood cells due to osmosis. We could not see any evidence of cells in Trials 13 and 14, which used the least concentrated glucose solutions. This observation is consistent with the hypothesis that cells in hypotonic solutions may draw in so much water that they rupture. Trials 15 and 16 used intermediate concentration solutions. Microscopic examination showed numerous small, black bodies we believed to be red blood cells (no red color was seen). These cells were uniformly round in shape, apparently plump, but not ruptured. Cells were also apparent in the high concentration trials (#17 & #18), but they did not exhibit the uniform round shape previously seen. We concluded that the irregular shape we saw instead was the result of cells "shriveling" in hypertonic solutions.

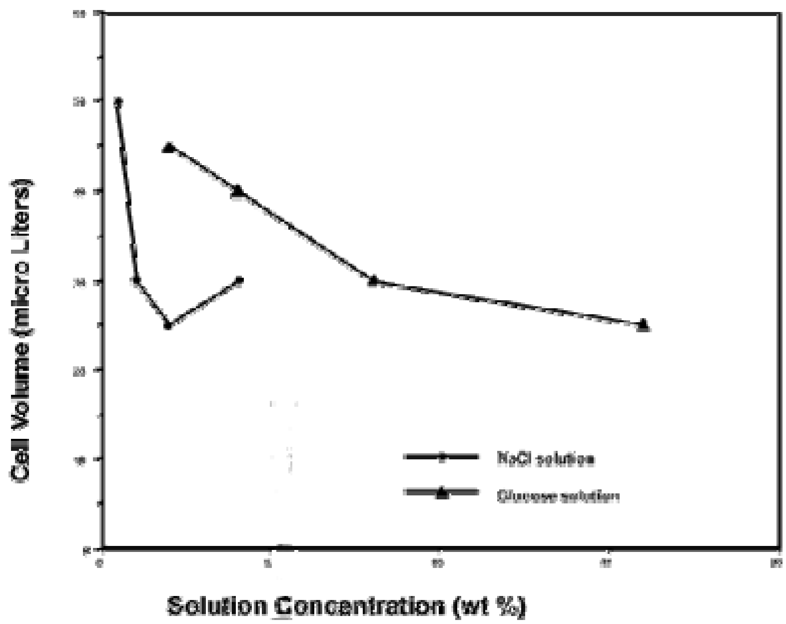

Figure 1: Plot of NaCl and Glucose solution concentrations versus the blood cell volume estimated. Lower concentrations resulted in rupture of blood cells and are not included.

Discussion:

The experiment we performed gave us a visual indication that osmosis affects human blood cells and that the concentration of surrounding molecules or ions can cause variations in blood cell volume and physical condition. Although the trends seen in the glucose and NaCl solutions were as expected (blood cell volume decreased with increasing hypertonicity), the difference in the degree of cell volume decrease between NaCl and glucose solutions was not expected. The NaCl solution showed a more severe cell volume decrease than was observed in similar concentrations of glucose. Upon further examination, this may be explained with the knowledge that NaCl is a salt and dissociates readily into Na+ and Cl- ions in aqueous solution. Therefore, although the NaCl stock solution contained 5%(weight/volume) NaCl, ionization would create a solution with twice as many ions as were predicted by the formula weight of the NaCl originally present. In other words, the ionic presence would effectively double the driving force for osmosis, since the ionic concentration is twice the "molecular" concentration. Since glucose does not disassociate in water, its osmotic driving force is unaffected by ionization effects. Using this explanation, one could rationalize that the osmotic strength of a NaCl solution would be higher than that of a similar concentration of glucose, as seen in Figure 1.

The other surprising result that we need to address is the lack of intact cells in any concentration of urea solution tested. Osmosis alone cannot explain the destruction of the blood cells in high urea concentrations since the osmotic pressure is independent of the type of solute present. If the effect of urea were the same as that of NaCl or glucose, high concentrations of urea should pull water out of the cell, causing cells to become smaller rather than to rupture. Urea is capable of destroying the structure of proteins, which are a component of biological membranes (Voet and Voet, 1990). Therefore, the destruction of cells in urea solution likely has little to do with osmotic effects, but instead results from a biochemical attack of urea on the structure of the cell itself. This observation helps to explain the critical function of the kidneys, which are responsible for the removal of urea waste products in the human body. Urea is produced naturally through metabolic breakdown of amino acids, and must be excreted from the body to prevent potentially fatal health effects (Kimball, 2001).

Significantly increased amounts of Blood Urea Nitrogen (BUN) 2 +/- 4 mg/L, have been found in people on high protein diets like the Atkins diet (Westman *et al*. 2002) so there may be potential public health consequences if large numbers of people get on these diets.

Sources of potential error in our experiment arose primarily from the small volumes of solutions that were used. When working with such small volumes, even a small error in measurement could have profound effects on the solution concentration and ultimate results. Also, measurement of the blood cell volume was subject to measurement errors since the range of variation was so small (a few mm) and the measurement relied on judgment to determine the liquid level and read the ruler. Measurement errors could be minimized through the use of multiple trials and through independent measurements by several different observers. Alternatively, we could have used calibrated centrifuge tubes or the capillary tubes used in diagnostic laboratories for similar measurements.

The results of this experiment have raised several other questions it may be interesting to investigate. 1) Do blood cells show similar osmotic behavior in other types of solutions (such as sucrose or KCl)? 2) Do mixtures of solutes change osmotic behavior? and 3) Is it possible to estimate what concentration is iso-osmotic to blood cells by determining the concentration at which no volume change of red blood cells occurs?

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APPENDIX B

CONSENT FORM

Participant Consent Form

August __, 2007

Dear Participant,

This letter seeks permission for your participation in a non-funded dissertation project entitled, "Examining college science teachers' belief systems about inquiry-oriented teaching in the context of a professional development program." This letter outlines the purpose, procedures, duration, benefits and risks of your participation with this project, as well as addressing the issues of confidentiality, voluntary participation and the approval for studying human subjects.

Purpose of Research

For my study I am interviewing and observing college science teachers who are participating in the SCTIL professional development program. My purpose is to understand how your ideas about inquiry-oriented teaching change, if at all, as part of participating in this program. As a future professional developer, I hope to better understand college science teachers' perspectives, as well as how professional development can guide your learning about effective teaching.

Specific Procedures to be Used for the Entire Study

I will collect the following data from your participation: 1) three individual teacher interviews – one before the SCTIL summer workshop, one before implementation of the revised lesson, and one after implementation of the revised lesson; 2) observation field notes from the SCTIL summer workshop and the implementation of one of your lessons. Each interview will be scheduled at the convenience of the participants and will last approximately one hour.

Duration of Participation

August 2007 to January 2008 for data collection.

Benefits to the Individual

Using the various interviewing techniques will require you to reflect about your understanding of teaching as well as your planning and implementation of the lesson. This type of reflective practice is often encouraged, but rarely carried out due to other responsibilities by college faculty, so a benefit of this study is that it will provide you with the time to be reflective about your teaching.

Risks to the Individual

For all teacher participants, I perceive no risks to you, and no judgments or evaluation will be made on your classroom instruction for the purpose of review by the institution of the University of Missouri – Columbia.

Confidentiality

Regarding the collection of observational data, a pseudonym will be assigned to any data originating from you; thus your personal identity will be held confidential. You will not be included by name in any future report resulting from this study, unless you wish otherwise.

Voluntary Nature of Participation
You do not have to participate in this research project. If you do agree to participate you can withdraw your participation at any time without penalty.

Human Subject Statement
This project has been reviewed and approved by the University of Missouri-Columbia Human Subjects Review Board. The Board believes the research procedures adequately safeguard your privacy, welfare, civil liberties, and rights. If you have any questions, you may reach me at (573) 882-5485, my dissertation advisor, Dr. Patricia Friedrichsen at (573) 882-6828. For additional information regarding human subjects participation in research, please contact the University of Missouri-Columbia IRB office at (573) 882-9585.

If you are willing to participate in this project, please complete the consent form below.

Sincerely,

Kristen L. Hutchins
Doctoral Candidate
Principal Investigator

Consent Form

I, ________________________________ agree to participate in the research project entitled "Examining college science teachers' belief systems about inquiry-oriented teaching in the context of a professional development program" conducted by Kristen L. Hutchins, a doctoral candidate in the College of Education, Department of Curriculum and Instruction of the University of Missouri – Columbia.

I understand that:

- My participation is voluntary and that I must be 18 years of age to participate.
- My identity will be kept confidential.
- I understand that all interviews will be audiotape.

I have read the letter above and am aware that I may contact Kristen Hutchins with any questions or concerns.

I agree to participate in this project and realize that I may withdraw without penalty at any time.

______________________________ ______________________
Participant's Signature Date

____
Participant's Name

APPENDIX C

INTERVIEW PROTOCOLS

Teacher Interview Protocol—Pre-Workshop

Primary source for sub-question #1: What is the nature of the participants' belief systems about inquiry-oriented teaching before participating in the SCTIL professional development program?

Rationale: The reason for interviewing participants prior to the SCTIL summer workshop is to get a baseline understanding of what makes up their belief systems.

Before turning on the recorder to record the interview explain that I will be asking the teacher to acknowledge on tape that this interview is being recorded. Explain that I will begin by stating my name, the date and the name of the interviewee.

<Begin recording>

1. *Teaching Background*—probes:
    a. How long have you been teaching at the college level?
    b. Do you have other teaching experience? If yes, please describe. (if grad school, describe specific role as teacher.)
    c. Describe any training/coursework you've had in college teaching. (such as education courses, mentors, TA training, workshops . . .) What did you learn from that experience?
    d. What is your normal teaching load? What courses have you taught? What courses will you teach in the coming year? If you're teaching a course you've taught before, will anything be different this year?
    e. Think about a course that you've recently taught. What is the format of the course (Lab, lecture, etc.)? Describe a typical lecture period in this course. Describe a typical lab period. What informed your decision to teach this way?

2. *Knowledge and Beliefs about Inquiry*:
    a. The SCTIL project focuses on inquiry.. People define inquiry in many different ways. What does the term " inquiry" mean to you?
    b. What does inquiry-oriented teaching mean to you? What do you think it would look like? What do teachers do? Students? How do you think this is different from how you are teaching in [your course]?
    c. Let's say you are doing a peer review for a colleague who has a reputation for their inquiry-oriented teaching. What would you expect to see the teacher do in the classroom? How is this different from typical classes? What about the students…what would they be doing?
    PROBE: Do you feel that you're an expert in inquiry-oriented teaching? What do you think it would take to become an expert?

3. *Beliefs about Inquiry-Oriented Teaching*: Do you currently use inquiry in your teaching? Why or why not? What is the most difficult/least difficult thing about teaching with inquiry?

4. *Beliefs about Inquiry Learning*:
    a. How do you think students best learn science?
    b. What are some strategies/tips that you share with students for learning science in your courses?
    c. From a student perspective, what do you see as the advantages of inquiry teaching? Disadvantages?

5. *Environmental Constraints*: What do you think might influence your ability to teach using inquiry? Any supports or constraints? (probes: What about in your department, among your colleagues, physical classroom, students in your courses?) PROMPTS:
    a. How do you think your students will respond to inquiry teaching?
    b. How do you think colleagues might respond?

6. *Social Norms*: Departments vary considerably from one institution to another. It would be helpful to me if you would describe the culture of your department.
    a. Is teaching valued in your department? By the chair? By colleagues? In what ways is teaching valued/not valued?
    b. How often do you discuss teaching with your department colleagues? What type of teaching advice have gotten from your colleagues? Your chair?
    c. How would you describe your department's expectations for teaching?
    d. How would you describe the typical teaching methods in your department? How common is inquiry teaching in your department? In what ways is this sort of teaching supported or rewarded?

7. *Efficacy*: How do you feel about your current skills to teach using an inquiry-oriented approach? What concern do you have about implementing this in your teaching?

8. *Attitudes*: Let's say that your department chair asks you to use include some inquiry in your courses. How would you feel about that? Why?

9. *Motivation*: Why did you decide to participate in the SCTIL program? (Prompts: Were you encouraged to participate by someone in your department?)
   What do you hope to gain from the summer institute?

Conclude the interview: Are there other things that are going through your mind that you'd like to share with me?

Thank the interviewee for their time in participating in this interview.

Teacher Interview Protocol—Pre-Implementation

<Begin recording>

1. *Knowledge and Beliefs about Inquiry and Inquiry Learning*:
    a. What did you gain from participating in the summer workshop? Did it cause you to think differently about inquiry? How? Did it cause you to think differently about TEACHING with inquiry? In what ways?
    b. What does the term "inquiry" mean to you? How does the mini-journal fit into your definition of inquiry?
    c. How do you think students learn from the mini-journal teaching approach? How do you think this is different from learning through other teaching approaches?

2. *Design*:
    a. Talk me through your lab that you're using this week. [show them a copy of their journal.]
        i. What changes have you made since the summer workshop?
        ii. What is your role in each of the sections? What are the students doing in each of the sections?
        iii. Where do you think this lab fits on the inquiry continuum? [show graph] Why?
    b. What are your goals for this inquiry lab?

3. *Attitude towards Instruction/Implementation*: How do you feel about the quality of the lab you created? What do you think will go well? What concerns do you have about implementing this lab?

4. *Environmental Constraints*:
    a. Do you anticipate any problems or constraints…. with this group of students? …with the physical classroom? …with colleagues or the department?
    b. Are there any other constraints you anticipate?

5. *Environmental Response*: How do you think your students will react to this new form of teaching? What difficulties do you think they will have?

6. *Efficacy*: How confident do you feel about teaching this particular lesson? Compare this to how you felt about a lesson you taught last week. Compare this to your feeling last summer when we talked during the first interview.

7. *Motivation*: Do you plan on doing more mini-journals in your classroom? Why or why not?

Conclude the interview: *Ask if there is anything else they would like to add. Thank the interviewee for their time in participating in this interview*

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Teacher Interview Protocol—Post-Implementation

Primary source for sub-question #3: In what ways do the participants' belief systems change as a result of implementing a revised inquiry-oriented lesson in their undergraduate science lab course?

Before turning on the recorder to record the interview explain that I will be asking the teacher to acknowledge on tape that this interview is being recorded. Explain that I will begin by stating my name, the date and the name of the interviewee.

<Begin recording>

1. *Knowledge and Beliefs about Inquiry and Inquiry Learning*:
    a. [Draw from their responses from the pre-implementation interview for this section of questions. Build on their responses.]
    b. You said before that you think students learn……. , has your view about this changed?
    c. Did implementing your inquiry lab cause you to think differently about inquiry, in general? How?
    d. Did it cause you to think differently about TEACHING with inquiry? In what ways?

2. *Design*:
    a. Did you make any changes to your lab during class? Tell me about that. Why did you make those changes?

3. *Beliefs about Inquiry and Inquiry-Oriented Teaching*:
    a. Where would you put this lab on the inquiry continuum if you had to pick a point? [show them the continuum]. Why?
    b. To what extent did this mini-journal align with your intended goals for the lab?

4. *Attitude towards Instruction/Implementation*: How do you feel about the quality of the lab you created? What do you think went well? Where did you see problems with the lab?

5. *Environmental Constraints*: Were there any problems or constraints with this group of students? …with the physical classroom? …with colleagues or the department? Were there any other constraints?

6. *Environmental Responses*:
    a. How did your students respond to this teaching approach?
    b. What sort of feedback did you receive on your inquiry articles (from colleagues, department chair, SCTIL staff…)? How did that feedback influence your thinking about the use of mini-journals?

7. *Motivation*: Would you continue to use this approach in your science teaching? Why or why not?

8. *Reflection*: Would you use this particular inquiry article again in your class? Why or why not? Would you change anything about it? If you adapted additional lessons into the inquiry article format, what would you change about how you designed or implemented your lesson?

9. *Efficacy*: How confident do you feel about your ability to teach this inquiry article format? What about teaching with an inquiry-based approach, in general?

Conclude the interview: *Ask if there is anything else they would like to add. Thank the interviewee for their time in participating in this interview.*

Teacher Interview Protocol—Non-Implementation version

<Begin recording>

1. *Knowledge and Beliefs about Inquiry and Inquiry Learning*:
    a. What did you gain from participating in the summer workshop? Did it cause you to think differently about inquiry? How? Did it cause you to think differently about TEACHING with inquiry? In what ways?
    b. What does the term "inquiry" mean to you? How does the inquiry article format fit into your definition of inquiry?
    c. How do you think students learn from the inquiry article teaching approach? How do you think this is different from learning through other teaching approaches?

2. *Design*:
    a. Talk me through your lab that you developed during the summer workshop.
        i. What problems did you have with developing this lab?
        ii. What is your role in each of the sections? What are the students doing in each of the sections?
        iii. Where do you think this lab fits on the inquiry continuum? [show graph] Why?
        iv. What are your plans for future use of this lab?
        v. What are your goals for this inquiry lab? (student learning, instruction…) What difficulties do you expect your students to have?

3. What sort of feedback did you receive on your inquiry articles (from colleagues, department chair, SCTIL staff…)? How did that feedback influence your thinking about the use of inquiry articles?

4. *Attitude towards Instruction/Implementation*: How do you feel about the quality of the lab you created? What do you think will go well? What concerns do you have about implementing this lab?

5. *Environmental Constraints*:
    a. In terms of implementing the lab, do you anticipate any problems or constraints…. with this group of students? …with the physical classroom? …with colleagues or the department?
    b. Are there any other constraints you anticipate?

6. *Efficacy*: How confident do you feel about teaching this particular lesson? (compared to other lessons you've taught).

7. *Motivation*: Do you plan on doing more inquiry articles in your classroom? Why or why not?

Conclude the interview: *Ask if there is anything else they would like to add. Thank the interviewee for their time in participating in this interview.*

Teacher Interview Protocol—Non-Implementation version Follow-up

<Begin recording>

1. Change of Plans—so I understand that you've decided not to implement your SCTIL lab this semester. What was your reason? What other constraints were in place that made this difficult to implement?

2. *Design*:
    a. Talk me through the final version of the lab that you developed during the summer workshop.
        i. How was this different from your original plan? What changes did you make?
        ii. Where do you think this lab fits on the inquiry continuum? [show graph] Why?
        iii. What are your goals for this inquiry lab? (student learning, instruction…) What difficulties do you expect your students to have?

3. *Environmental Responses*:
    a. What support did you receive in developing this lab? (Megan, Kristy, SCTIL staff, colleagues…)
    b. Did the students do any part of the lab? If so, what was their response?

4. *Efficacy*: How confident do you feel about this particular lesson? (compared to other lessons you've taught).

5. *Motivation*: What are your plans for future use of this lab? Do you plan on doing any other inquiry article labs in the future? Why or why not?

Conclude the interview: *Ask if there is anything else they would like to add. Thank the interviewee for their time in participating in this interview.*

APPENDIX D

PROFESSOR BRINKLEY'S INQUIRY ARTICLES

Version 1

Journal of Aquaculture Society: **Vol. 1, No. 1, pp. 1–x.**

*Estimating the abundance (and biomass) of a population of aquatic plants (*Lemna minor*, duckweed)*

Abstract: Soil, air and water pollution can have serious impacts upon the biotic component of ecosystems, including human health and wellbeing. In the investigation reported here, we examine population abundance of duckweed (*Lemna minor*) within two pond ecosystems located on the Florissant Valley campus of SLCC. Our broad goal was to assess the potential of duckweed to serve as a biological indicator of chemical contamination of freshwater aquatic ecosystems. To this end, we estimated the population abundance of two separate populations of duckweed that are assumed to experience different levels of chemical contamination due to surface runoff. We predicted that the pond closest to the parking lot pollution source would support duckweed populations at a lower abundance that duckweed populations within less contaminated ponds. Field sampling was used to collect data for calculating estimates of population abundance based on frond counts. Our results indicate that the pond closest to the parking lot supports a less abundant population than the other pond. Future studies using duckweed as a biological indicator for ecotoxicological investigations are suggested.

Introduction

Linkages between human actions and **environmental inputs** arising from those actions have effects upon health, survival, and population growth or decline. Rapid growth of human populations combined with uncontrolled industrial growth, urban expansion and agricultural land conversion has led to **serious impacts** upon the environment and human quality of life (McMichael 1993; Meyer and Turner 1992; Molner & Molner 1999; Wellburn 1988). Despite governmental regulations and oversight (f.ex.: the EPA), environmental activism and involvement from industry (chemical, industrial, agricultural) to reduce pollution, the release of harmful chemicals into the environment continues (Worldwatch Institute 2007).

An especially significant environmental impact from human actions is **fresh water pollution**. The Worldwatch Institute, a non-partisan and independent, interdisciplinary research organization, reports that eighty one percent of our nations community water is dependent upon ground water sources, and that fifty three percent of the population relies upon ground water as the source of drinking water (Worldwatch Institute 2007). Fresh water resources such as this are critical for populations- ninety five percent of all fresh water on earth exists as groundwater (Gleick 1993; 2002).

The major **sources** of fresh water pollution can be classified as municipal, industrial, and agricultural (Worldwatch Institute 2007). Fresh water contamination may occur by numerous **routes** from these sources, such as surface runoff, liquid spills, wastewater discharges, eutrophication, littering, leaching to groundwater, leaking underground storage tanks and municipal landfills (Sampat and Peterson 2000; Worldwatch Institute 2007). Among the most significant **chemical contaminants** are hydrocarbons, heavy metals, herbicides, pesticides and chlorinated hydrocarbons.

A knowledge and understanding of the **biological responses** of individual organisms, populations and communities to environmental changes resulting from fresh water pollution can be used to assess the intensity of pollution and other disturbances (Adams et al. 1989; Almar et al. 1998). These **biological indicators** can be used for encouraging the ecologically sensitive management of freshwaters in the face of the conflicting demands of today`s society.

The duckweeds (Family *Lemnacea*) are useful biological indicators for conducting bioassay experiments with water samples because you can measure their growth rate by counting how many new fronds develop over a five-day period. By measuring the number of new fronds on duckweed plants growing in a test solution and comparing that to the number of new fronds in a control solution, you can test the sensitivity of duckweed to different compounds, or various concentrations of a single compound. **Our objective** was to estimate the abundance of duckweed populations within two ponds on the campus of [redacted]. **We predicted** that the pond that was closer to the parking lot would experience more surface pollutant runoff leading to contamination of the pond that would reduce population abundance of duckweed compared to the population in the pond that is more removed from the parking lot. Sartor et al. (1974) reported similar contamination effects from street runoff.

Materials and Methods

Study Site: The study site is located on the [redacted] campus of [redacted]. Situated in the northeastern corner of the campus property are two ponds that were the focus of this investigation (see figure 1). These ponds are filled primarily by runoff coming from the areas around the pond that drain rainwater into the ponds. As the water flows into the ponds it picks up minerals and soil particles. The type of rock and soil through which the water filling these ponds runs through determines the type of minerals present in the water. Rocks exposed in this part of [redacted] are usually limestone, made primarily of calcium carbonate. It is of significance to note that the northernmost pond is situated at a higher elevation and a further distance away from the large parking lot that the southernmost pond is next to.

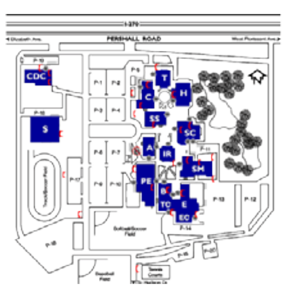


Figure 1. Map of [redacted] campus. Pond 1 is southernmost and at lowest elevation, pond 2 is westernmost and at highest elevation.

Study Species: The duckweeds (Family *Lemnacea*) are a small and cosmopolitan group, found from the sub-polar regions to the tropics. They all prefer ditches, ponds, lakes and slow-flowing rivers. There are only 22 species in the world and most are very widespread. All have a few flattened, often rounded, disc-like leaves (they are really leaf-like stems or thalli) floating on the surface. New leaves bud off from these as the plant grows. Once there are half a dozen leaves the plants break apart. Often there is an unbranched rootlet hanging below the leaves. Some of these rootlets are photosynthetic.

Elias Landolt did extensive investigations of duckweed ecology. He found that duckweeds grow under a wide variety of conditions. However, he did find some generalities. Duckweeds generally are not found in oligotrophic water (water in which nutrients are in low supply). They also are rare on lakes drained by granitic soils and limestone and on very old soils that are poor in most nutrients. Exceptions are waters heavily contaminated by waste water.

Overall procedure: For equipment, we obtained plastic tea strainers, white plastic trays, wax pencils, tape measures and balances. We measured the surface area of the tea strainer the surface area of ponds 1 and 2. **We collected 12 samples from each pond** by lowering the tea strainer carefully into the pond, allowing duckweed to distribute itself evenly above it. We then raised the tea strainer and allowed water to drain, and we removed the duckweed attached to the *outside* of the tea strainer.

Biomass: We scraped plants from the interior of the tea strainer into weighing boats, blotting the plants dry before weighing fresh mass.

Abundance: We marked the base of a shallow plastic tray (culture tray) with a wax pencil to create a grid of squares 5 cm x 5 cm. We then flooded the tray with at least 1 cm depth of tap water and emptied the contents of the tea strainer into the tray and spread the duckweed out evenly. When counting fronds, it is the accepted procedure to count **every visible frond**, even the tips of small new fronds that are just beginning to emerge from the pocket of the mother frond. We used a dissecting microscope for frond counts by placing a square-ruled sheet of paper beneath the culture tray (matching the wax grid outline) to help reduce counting errors. We counted the number of plants over 10 squares and then calculated the total number in the tray.

We calculated the average population abundance (i.e. number of leaves) and biomass of duckweed in the two ponds using the following calculations:

1. The total number of plants (N) collected in each tea-strainer sample = the number of plants counted in the sampled area(s) of the tray (n) x (total area of tray ÷ area of tray sampled)

2. Mean fresh mass (M) of single duckweed plant = mass of strainer sample ÷ N

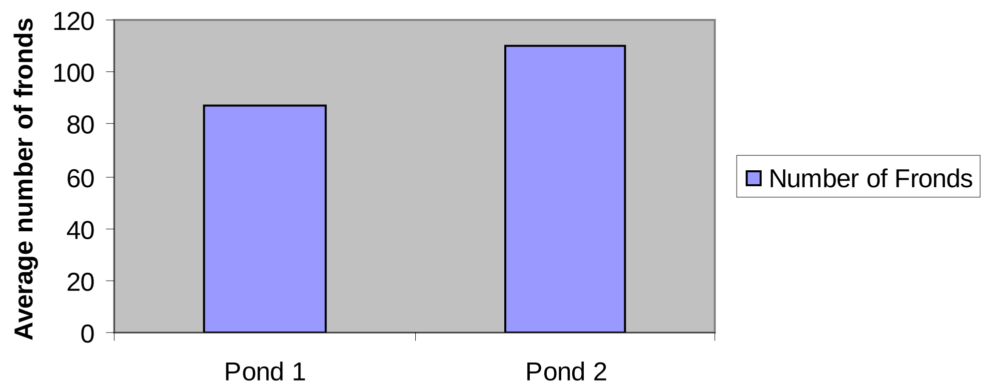
3. The number of plants (P) on the pond = N x (area of pond ÷ area of the tea-strainer)

4. Total biomass of duckweed on pond = P x M g (if you give the mass in grams)

Results

Figure 2 illustrates the results obtained from the two ponds on the [redacted] campus sampled in May 2007. Pond 1, which is located closer to the parking lot (see figure 1), was predicted to exhibit lower abundance of duckweed due to assumed greater surface runoff of pollutants from the nearby parking lot. This was supported by the data gathered in May of 2007.

Figure 2. Average abundance of duckweed within the two ponds located on the [redacted] campus.



Discussion: Our investigation has confirmed that there is a difference in the population abundances of duckweed within the two ponds located on the [redacted] campus. The data supports our hypothesis that potentially elevated chemical contamination levels in the lower pond due to surface runoff from the parking lot have negatively impacted the duckweed populations in the lower pond compared to the higher elevation pond.

The assumption that higher levels of chemical pollution are responsible for the decreased abundance of duckweed in the lower pond needs to be assessed. Further investigations into the mechanisms responsible for the observed differences in abundance are warranted.

Of broader significance and potential application would be investigations into the uses of duckweed as a **biological indicator** for the intensity of pollution and other disturbances on aquatic ecosystems. Pollutants (such as copper ions) in the pond water are known to affect the growth and biochemistry of duckweed. The inhibitory effects on growth are reflected in a reduced concentration of photosynthetic pigments (such as chlorophyll) and an increase in activity of antioxidant enzymes (such catalase and peroxidase), within the leaves. Responses to substances such as copper sulphate in the water are measurable within as little as 24 hours (peroxidase), and effects on population growth of fronds will be detected within a week.

Methods for quantitative measurements of photosynthetic pigments (such as chlorophylls and carotenoids), and for secondary compounds such as anthocyanins, can be found on OSMOWEB. Using these methods, you could carry out investigations into enzyme levels (such as the peroxidase enzyme), pigments or growth rate. Possible investigations include:

- The effects of different concentrations of pollutants (such as copper sulphate or detergents)
- The effects of eutrophication, simulated by adding different concentrations of fertilizers to the water
- The relationship between enzyme levels, pigments and growth rate during cultivation of duckweed
- The effects of disturbance (water movement) on growth

Research such as described above will continue to shed light on the linkages between human actions and environmental inputs and the consequences those actions and inputs have upon health, survival, and population growth or decline. Armed with such knowledge we may be better able to develop wise, sustainable, ecologically sensitive interactions with and management of the world's freshwaters.

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Journal of SLCC Environmental Society: **Vol. 1, No. 1, pp. 1–5.**

Estimating the abundance of a population of aquatic plants (*Lemna minor*, duckweed)

Abstract: Soil, air and water pollution can have serious impacts upon the biotic component of ecosystems, including effects upon human health and wellbeing. In the investigation reported here, I examine population abundance of duckweed (*Lemna minor*) within two pond ecosystems located on the . I estimated the population abundance of two separate populations of duckweed that are assumed to experience different levels of chemical contamination due to parking lot surface runoff. I hypothesized that the pond closest to the pollution source would experience negative impacts upon population dynamics. I predicted that the pond closest to the parking lot would support duckweed populations at a lower abundance than duckweed populations within ponds further from the parking lot. I conducted field sampling using tea strainers to collect data for calculating estimates of population abundance based on frond counts. The results support the hypothesis and indicate that the pond closest to the parking lot supports a less abundant population than the pond furthest from the parking lot. Future studies investigating the effects of various compounds and compound concentrations upon the overall life cycle and population processes of aquatic species and communities would be useful for improving our understanding of the ecotoxicological interactions caused by human behavior, as well as providing a sound empirical foundation for developing recommendations and strategies for sustainable interactions with the biosphere.

Introduction

Linkages between human actions and **environmental inputs** arising from those actions have effects upon health, survival, and population growth or decline (Campbell, Reece and Simon, 2007). Rapid growth of human populations combined with uncontrolled industrial growth, urban expansion and agricultural land conversion has led to **serious impacts** upon the environment and human quality of life (McMichael 1993; Molner & Molner 1999). Despite governmental regulations and oversight (for example the EPA or USDA), environmental activism and involvement from industry (chemical, industrial, agricultural) to reduce pollution, the release of harmful chemicals into the environment continues (Worldwatch Institute 2007).

An especially significant environmental impact from human actions is **fresh water pollution**. The Worldwatch Institute, a non-partisan and independent, interdisciplinary research organization, reports that eighty one percent of our nations' community water is dependent upon ground water sources, and that fifty three percent of the population relies upon ground water as the source of drinking water (Worldwatch Institute 2007). Fresh water resources such as this are critical for populations- ninety five percent of all fresh water on earth exists as groundwater. It is imperative that we understand sources of pollution and the effects in order to develop recommendations and strategies for management, restoration, such as through bioremediation, reduction and prevention of pollution, as well as protection of freshwater resources.

The major **sources** of fresh water pollution can be classified as municipal, industrial, and agricultural. Fresh water contamination may occur by numerous **routes** from these sources, such as surface runoff, liquid spills, wastewater discharges, littering, leaching to groundwater, leaking underground storage tanks and municipal landfills. Among the most significant **chemical contaminants** are hydrocarbons, heavy metals, herbicides, pesticides and chlorinated hydrocarbons.

A knowledge and understanding of the **biological responses** of individual organisms, populations and communities to environmental changes resulting from fresh water pollution can be used to assess the intensity of pollution and other disturbances (Almar et al. 1998). These **biological indicators** can be used for encouraging the ecologically sensitive management of freshwaters in the face of the conflicting demands of today`s society.

My objective was to estimate the abundance of duckweed populations within two ponds on the campus o[redacted]. I **hypothesized** that duckweed population dynamics would be negatively impacted by surface runoff pollution, such as from roads and parking lots. To test this hypothesis, I estimated population abundance of duckweed within two ponds, one adjacent to a large parking lot and the other isolated from the parking lot by both distance and elevation (see figure 1). **I predicted** that the pond that was adjacent to the parking lot would experience more surface pollutant runoff leading to contamination of the pond that would reduce population abundance of duckweed compared to the population in the pond that is more removed from the parking lot.

Materials and Methods

Study Site: The study site is located on the[redacted]. Situated in the northeastern corner of the campus property are two ponds that were the focus of this investigation (see figure 1). These ponds are filled primarily by runoff coming from the areas around the pond that drain rainwater into the ponds. As the water flows into the ponds it picks up minerals and soil particles. The type of rock and soil through which the water filling these ponds runs through determines the type of minerals present in the water. Rocks exposed in this part of St. Louis County are usually limestone, made primarily of calcium carbonate. It is of significance to note that the northernmost pond is situated at a higher elevation and a further distance away from the large parking lot that the southernmost pond is next to.

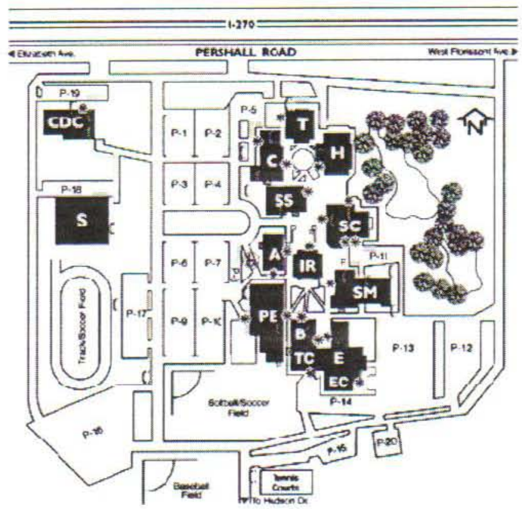

Figure 1. Map of [redacted]. Pond 1 is southernmost and at lowest elevation, pond 2 is westernmost and at highest elevation.

Study Species: The duckweeds (Family *Lemnacea*) are a widely distributed group of 22 species found from the sub-polar regions to the tropics. They are typically found within ponds, lakes, slow-moving streams and rivers, and ditches. The typical body structure consists of a few flattened, disc-like fronds or thalli that float on the surface. Reproduction is by budding, where new individuals grow from and break off of the 'parent' plant, usually after there are about 6 new fronds.

Overall procedure: For equipment, I obtained plastic tea strainers, white plastic trays, wax pencils, tape measures and balances. I measured the surface area of the tea strainer and the surface area of ponds 1 and 2. **I collected 12 samples from each pond** by lowering the tea strainer carefully into the pond, allowing duckweed to redistribute itself once again. I then raised the tea strainer and allowed water to drain, and removed the duckweed attached to the *outside* of the tea strainer and returned them to the pond.

In order to calculate abundance, I marked the bottom of a shallow, rectangular plastic culture tray with a wax pencil to create a grid of squares 5 cm x 5 cm. I filled the tray with approximately 1 cm depth of water and emptied the fronds from the tea strainer into the tray. I used the standardized procedure of counting every visible frond. This included any tips of small new fronds that are just beginning to emerge from the pocket of the mother frond. I used a dissecting microscope (10x) for frond counts. I counted the number of fronds over 10 grid squares. To calculate the average population abundance (i.e. number of fronds) of duckweed in the two ponds I used the following calculations:

1. The total estimated number of plants (N) collected in each tea-strainer **sample**: (the average number of plants counted in a grid square of the tray) x (total number of squares)

2. The estimated number of plants (P) on the pond = average N x (area of pond ÷ area of the tea-strainer)

Results: Figure 2 illustrates the results obtained from the two ponds on [redacted] Valley campus sampled in May 2007. Pond 1, which is located closer to the parking lot (see figure 1), was predicted to exhibit lower abundance of duckweed due to assumed greater surface runoff of pollutants from the nearby parking lot. This was supported by the data gathered in May of 2007.

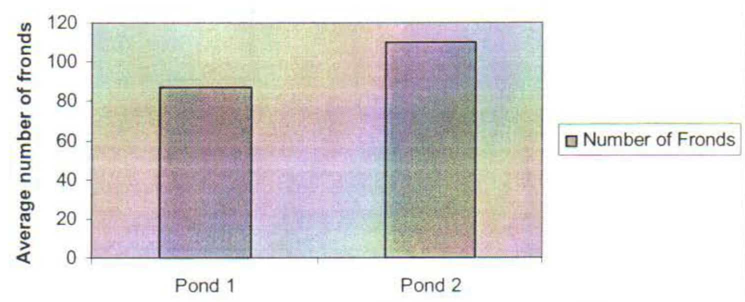

Figure 2. Average abundance of duckweed within the two ponds located on the [redacted] Valley campus.

Discussion: The results of this investigation indicate that there is a difference in the population abundances of duckweed within the two ponds located on the [redacted] Valley campus. The data supports my hypothesis that potentially elevated chemical contamination levels in the lower pond due to surface runoff from the parking lot have negatively impacted the duckweed populations in the lower pond compared to the higher elevation pond.

The assumption that higher levels of chemical pollution are responsible for the decreased abundance of duckweed in the lower pond needs to be assessed. Further investigations into the mechanisms responsible for the observed differences in abundance are warranted.

Of broader significance and potential application would be investigations into the uses of duckweed as a **biological indicator** for the intensity of pollution on aquatic ecosystems. Duckweeds are excellent model organisms for **conducting investigations into the toxic effects of pollution** upon the ecology of organisms due to the fact that you can measure their growth rate by counting how many new fronds develop over a five-day period. Experiments can be designed where the sensitivity of duckweed (reflected by changes in growth rate) to various compounds can be tested in various test solutions. Possible investigations include: the effects of different chemical pollutants (such as oil, gasoline, copper sulphate, various pesticides, herbicides, and insecticides, various fertilizers, etc.). Research such as this will continue to shed light on the linkages between human actions and environmental inputs as well as the consequences those actions and inputs have upon health, survival, and population growth or decline. Armed with such knowledge we may be better able to develop wise, sustainable, ecologically sensitive interactions with and management of the world's freshwaters.

Citations

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Worldwatch. http://www.worldwatch.org/taxonomy/term/109; cited August 2007.

Journal of SLCC Scientific Society: Vol. 1, No. 1, pp. 1–5.

Title of your investigation- possibly the research statement

[redacted]

Abstract:

9+ well written sentences (~100-200 words)

- What? Broadly speaking
  Broad subject area within which your research investigation topic falls; refer to textbook/lecture, library databases, google, etc.
- What? More specifically speaking
  Lead into the specific sub-discipline you are investigating
- What? Very specifically speaking
  Research question you are seeking to answer (gap in knowledge within this sub-discipline you are seeking to fill- what is not known that you are attempting to answer)
- Why?
  Why this research question is meaningful or relevant- why it is important or useful for us to 'fill this gap in knowledge'
- H & P
  Your hypotheses and predictions (and possibly a brief explanation of them)
- Methods
  How you will test your hypotheses/predictions- your main methods briefly `mentioned or outlined (such as your experimental design)
- Main Results
  Just what the main results were, briefly
- Interpretation
  Again, just one brief sentence or two
- Broad Relevance
  Relate your results and conclusions back to the knowledge gap and broad subject area of your research topic

1) Read and identify above in an abstract
2) Write an abstract for lab 1 experiment

Experimental Design Set-Up sheet

1) What are you asking?	
2) Why is it *interesting*- connect to the research report article?	
3) What do you think will happen (sketch a graph)?	
4) How many variables will you look at?	
5) How will you proceed- write out your procedures in your lab manual; how many replicates?	
6) Prepare data *collection* and data analysis tables; include any necessary calculations.	
7) Try out your set-up.	

Abstract Peer Review Sheet **Name**______________________________

Abstract reviewed:____

5 = excellent (A+); 4 = very well-written (A); 3 = above average (B); 2 = average (C); 1 = below average; 0 = failing

Review Criteria	Reviewer Comments
1. **Abstract** Does the abstract ***clearly*** describe the overall study?	
2. **Question** Is the research question presented? Is there both a broad context given for the research topic as well as a specific or narrow context?	
3. **Significance** Is it made clear why this research question is meaningful or relevant- why it is important or useful for us to 'fill any gap in our knowledge base relevant to this research topic? Is the study tied to real life phenomena?	
4. **Objectives; Hypothesis & Prediction(s)** Are the research objectives clear? Is the hypothesis presented? Are predictions stated?	
5. **Methods** Is it clear how the hypotheses/predictions will be tested? Are the main methods briefly `mentioned or outlined- is the experimental design described? Are data collection and analysis methods clear?	
6. **Results & Discussion** Are the main results reported? Are there interpretations/explanations given? Were explanations tied to the research objectives?	
7. **Follow-up Questions & Broad Picture** Are the follow-up questions reasonable and feasible? Are the results and conclusions related back to the knowledge gap and broad subject area of the research topic?	

Research Report Grade sheet

Name______________

Topic______________

Grade_____

Elements to consider for a well written report:

Abstract	Introduction	Methods	Results	Discussion	Citations	Format	Quality
Question	Context of question	A narrative written in your own words	Table	Question, hypothesis and results restated	Research paper (peer reviewed)	approved	Coherent
Why it matters	What is known (background)	Adequate detail	Graph (properly labeled)	Hypothesis supported or unsupported?	Textbook chapters		Thoughtful
Hypothesis and/or predictions	What is not known and why it matters		Written narrative tied to tables and graphs	What does it mean?	Approved websites		Grammar
Methods	Hypothesis and predictions		Calculations	Further questions	Scientific literature		Unique
Results							
Interpretation							
Broad relevance							

Grade Scale:

4 (excellent) = All elements present, including elements in 'Quality' column

3 (above average) = Most elements present; additionally, at least one element in each column present

2 (average) = Missing a few elements

1 (below average) = missing several elements

0

4 = 100% x 30 pts = 30 pts

3 = 85% x 30 pts = 25 pts

2 = 70% x 30 pts = 21 pts

1 = 50% x 30 pts = 15 pts

APPENDIX E

PROFESSOR GARRETT'S INQUIRY ARTICLES

Version 1

SCTIL Laboratory Instruction Template

Instructor		
[redacted]		
Course Name		
Genetics		
Laboratory Title		
Effect of Colchicine on the Cell Cycle (First Draft August 14, 2007)		
Number of Students		
20		
Student Background		
Year	**Major**	**Prerequisites**
Second Year	Biology	Intro Biology – 1 semester

Key Pre-Knowledge (check all appropriate)			
☐ Mathematics	☐ Reading	☐ Problem Solving	☐ More specific:
☐ Scientific	☐ Writing	☐ Decision Making	
☐ Experimental	☐ Communication	☐ Interpreting	

Learning Goals		
For All Students	**For Most Students**	**For Top Students**
Use of microscope Distinguish Interphase from M Phase; Characterization of various stages of mitosis Graphing in Excel Fundamentals of Experimental Design (controls, treatment groups, sample size, data collection and analysis, interpretation)	Role of microtubules in mitosis Animal cells vs. plant cells Cell growth vs. cell division Use of model systems in biology	Integrating information across disciplines. Use of statistical tools in data analysis
Potential Difficulties of Instruction \		
Pre-Lab Preparation	**Lab Approach**	**Post-Lab Assessment**
Working with Excel: calculations and graphing	Student difficulty in making squash preparations - issue of method validation and knowledge of root	How data are presented and analyzed Connecting concepts

	structure. Inconsistent characterization of stage of cell cycle – observation of prepared slides to familiarize students with visual assessment	

Mini Journal Format

Abstract

Colchicine has been shown to disrupt the cell cycle in various vertebrate cells and has been used in the treatment of gout and certain tumors. Development of a plant model system to study the effects of colchicine could provide an alternate to working with animal models. This preliminary study was designed to evaluate the use of the Allium meristem in the study of colchicine effects on the cell cycle. Allium bulbs were sprouted in water for three days and randomly assigned to one of two treatments (control or colchicine). After brief treatment (60 minutes), the tip of the meristem was cut from three samples and fixed in 70% ethanol prior to processing. Squash preparations were made after sequential treatment with HCl, Carnoy fixative and toluidine blue. Slides were examined with a light microscope and scored to classify cell cycle stage. Cell cycle distribution for control vs. colchince treated mertistem cells was 40 v. 55% Interphase, 32 v. 41% Prophase, 11 v. 1% Metaphase, 5 v 1% Anaphase and 10 v 0% Telophase. These data suggest that colchicine treatment changes the distribution of cells throughout the cell cycle, disrupting the progression of cells from prophase to metaphase. Further characterization of this system is needed to determine if Allium meristem would provide an appropriate alternate model to vertebrate systems and to characterize the mechanism of this effect.

Introduction

Normal growth of an organism is controlled by coordinated regulation of the cell cycle, composed of two dominant phases known as interphase (cell growth and DNA synthesis) and M phase (the phase of active cell division including both nuclear division and cytoplasmic division)(Pierce, 2006). During certain stages of development rapid proliferation of cells is essential. In contrast, uncontrolled proliferation of various cell types can lead to tumor formation (Marte et al., 2004). The onion root is one potential model organism that could be used to study regulation of the cell cycle . Newly developing apical meristem undergoes rapid proliferation and cell growth as the onion root seeks out a source of nutrients. This produces a tissue where various stage of the cell cycle can be readily observed (Feldman, 1984).

The drug colchicine has been used in the treatment of gout (Ahren et al., 1987) and for the management of various cancers (Sartorelli and Creassey, 1969). It has been suggested that the drug acts by disrupting the cell cycle in vertebrate cells (Behnke, O. 1965). The purpose of this experiment is to examine effect of colchicine on the cell cycle of an Allium root. We hypothesize that colchicine will disrupt the cell cycle as previously observed in vertebrate cells. These data would then provide the basis for further development of a plant model system to characterize factors affecting the cell cycle.

Methods

Onion bulbs were grown in tap water for 3 days prior to the start of the experiment to establish roots and were subsequently transferred to one of two treatments, control or colchicine (.1% w/v). Samples (4 – 6 cm)of the root tip were taken 60 minutes after the start of the treatment. Each sample was transferred to 70% ethanol until squash preparations were made and scored.

Preparation of root tip squashes Root tip samples are treated for 4 minutes in HCl, followed by 4 minute treatment with Carnoy fixative. The terminal 1 – 2 mm of the root tip was transferred to a slide, and stained with toluidine blue for 1 – 2 minutes. The dye was removed by blotting and the root tip washed with diSCTILled water before making the final squash.

Data Collection Each cell was examined by bright field microscopy (40 – 100X). and assigned to one of five stages of the cell cycle (Interphase, Prophase, Metaphase, Anaphase, Telophase) using previously published criteria (Pierce, 2006). A minimum of 100 cells for each root tip were scored. Three root tips for each group (control and colchicine) were evaluated.

Results

Assessment of Cell Cycle Stage. Tabulated data for cell counts (Table 1) were used to determine the proportion of cells in each stage of cell cycle (Figure 1). In response to 60 minute exposure to colchicine there was an apparent decrease in the number of cells observed in Metaphase, Anaphase and Telophase with an associated apparent increase in the number of cells observed in Interphase and Prophase.

Table 1. Cell counts obtained from Allium meristem treated with water (control) or colchicine.

Treatment	Interphase	Prophase	Metaphase	Anaphase	Telophase	Undetermined	Total
Control	38	34	10	8	10	0	100
Control	48	40	2	4	6	0	100
Control	32	22	24	4	12	18	112
Colchicine	44	54	2	0	0	0	100
Colchicine	70	28	0	4	0	0	102
Colchicine	54	44	2	0	0	0	100

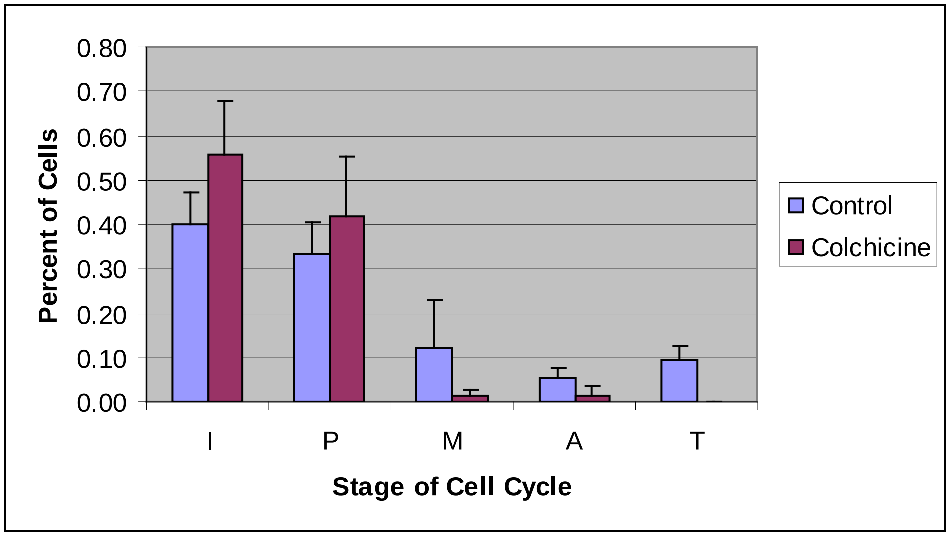

Figure 1. Change in cell cycle in response to colchicine in onion root tip cells (mean +/ SD).
(I: Interphase, P: Prophase, M: Metaphase, A: Anaphase, T: Telophase)

Discussion

Onion meristem provides a simple system for the study of the cell cycle, where the major stages of mitosis (prophase, metaphase, anaphase and telophase) can be identified by light microscopy. These data suggest that in a rapidly growing meristem, 60% of cells are in mitosis with 51% (32/60) identified in prophase. In contrast, only 45% of the cells exposed to colchicine were identified as being in mitosis and the majority of cells (91%; 41/45) were in prophase. Collectively the data suggest that there may be an effect of colchicine on rapidly dividing onion meristem that restricts the progression from prophase to metaphase, although these studies do not identify a specific mechanism of action. These preliminary observations support the hypothesis that colchicine disrupts the cell cycle. Further studies are needed to more fully characterize the effect of colchicine. Characterization of other compounds with known effects on tumor growth or with structural similarity to colchicines may be useful in extending this initial observation.

Follow-up Questions

1. Do the data presented support the conclusions drawn by these authors? Why or why not?
2. Where in the cell cycle is disruption most likely occurring? How did you make this determination? What are the unique features of this stage of the cell cycle?
3. Is it likely that colchicine impacts animal cells in a similar manner as seen with onion meristem? What elements of the cell cycle are similar or different between plant and animal cells? Do you think other plant tissue would respond in a similar manner? Why or why not?
4. What other factors could have influenced the author's results?
5. What is colchicine (structure/ class of compound)? What other common compounds are similar to colchicines?

6. Do you think colchicine is a good drug for the treatment of gout and or tumors? Why or why not?
7. What additional information might be useful in assessing the usefulness of this model in studying the effects of colchicine on the cell cycle?
8. What additional information would you need to effectively repeat this experiment?

Ahren et al., Aust N Z J Med. 1987 Jun;17(3):301-4.
Behnke, O. (1965) The effect of colchicines and sodium cacodylate on the spindle of dividing vertebrate cells. J. Ultrastruct. Res 12, 241-242.
Feldman LJ. The Development and Dynamics of the Root Apical Meristem. American Journal of Botany, Vol. 71, No. 9 (Oct., 1984), pp. 1308-1314.
Goode, MD. (1967). Kinetics of microtubule .assembly after cold disaggregation of the mitotic apparatus. J. Cell Biol. 35,47A.
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Pierce BA. 2006. Genetics: A conceptual approach. WHFreeman and Company, New York.
Sartorelli AC, Creasey WA., 1969. Annu Rev Pharmacol. 9:51-72.

Version 2

Mini Journal Format

Abstract

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Methods

Onion bulbs were grown in tap water for 3 days prior to the start of the experiment to establish roots and were subsequently transferred to one of two treatments, control or colchicine (.1% w/v). Samples (4 – 6 cm)of the root tip were taken 60 minutes after the start of the treatment. Each sample was transferred to 70% ethanol until squash preparations were made and scored.

Preparation of root tip squashes Root tip samples are treated for 4 minutes in HCl, followed by 4 minute treatment with Carnoy fixative. The terminal 1 – 2 mm of the root tip was transferred to a slide, and stained with toluidine blue for 1 – 2 minutes. The dye was removed by blotting and the root tip washed with distilled water before making the final squash.

Data Collection Each cell was examined by bright field microscopy (40 – 100X). and assigned to one of five stages of the cell cycle (Interphase, Prophase, Metaphase, Anaphase, Telophase) using previously published criteria (Pierce, 2006). A minimum of 100 cells for each root tip were scored. Three root tips for each group (control and colchicine) were evaluated.

Results

Assessment of Cell Cycle Stage. Tabulated data for cell counts (Table 1) were used to determine the proportion of cells in each stage of cell cycle (Figure 1). In response to 60 minute exposure to colchicine there was an apparent decrease in the number of cells observed in Metaphase, Anaphase and Telophase with an associated apparent increase in the number of cells observed in Interphase and Prophase.

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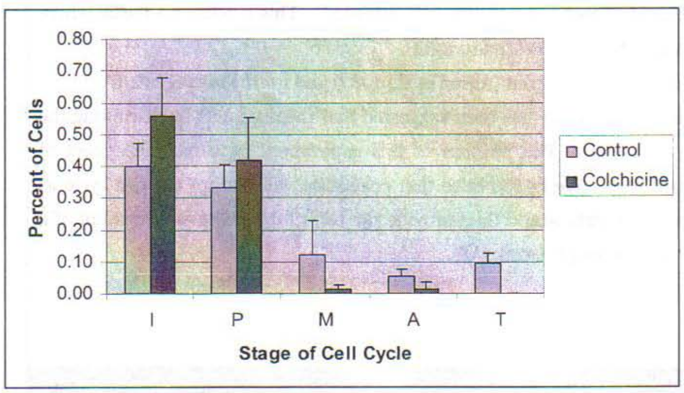

Figure 1. Change in cell cycle in response to colchicine in onion root tip cells (mean +/ SD).
(I: Interphase, P: Prophase, M: Metaphase, A: Anaphase, T: Telophase)

Discussion

Onion meristem provides a simple system for the study of the cell cycle, where the major stages of mitosis (prophase, metaphase, anaphase and telophase) can be identified by light microscopy. These data suggest that in a rapidly growing meristem, 60% of cells are in mitosis with 51% (32/60) identified in prophase. In contrast, only 45% of the cells exposed to colchicine were identified as being in mitosis and the majority of cells (91%; 41/45) were in prophase. Collectively the data suggest that there may be an effect of colchicine on rapidly dividing onion meristem that restricts the progression from prophase to metaphase, although these studies do not identify a specific mechanism of action. These preliminary observations support the hypothesis that colchicine disrupts the cell cycle. Further studies are needed to more fully characterize the effect of colchicine. Characterization of other compounds with known effects on tumor growth or with structural similarity to colchicines may be useful in extending this initial observation.

Follow-up Questions

1. Do the data presented support the conclusions drawn by these authors? Why or why not?
2. Where in the cell cycle is disruption most likely occurring? How did you make this determination? What are the unique features of this stage of the cell cycle?
3. Is it likely that colchicine impacts animal cells in a similar manner as seen with onion meristem? What elements of the cell cycle are similar or different between plant and animal cells? Do you think other plant tissue would respond in a similar manner? Why or why not?
4. What other factors could have influenced the author's results?
5. What is colchicine (structure/ class of compound)? What other common compounds are similar to colchicines?
6. Do you think colchicine is a good drug for the treatment of gout and or tumors? Why or why not?
7. What additional information might be useful in assessing the usefulness of this model in studying the effects of colchicine on the cell cycle?
8. Would this model be useful in studying other types of chemicals? Why or why not?
9. What additional information would you need to effectively repeat this experiment?

Ahren et al., Aust N Z J Med. 1987 Jun;17(3):301-4.

Behnke, O. (1965) The effect of colchicines and sodium cacodylate on the spindle of dividing vertebrate cells. J. Ultrastruct. Res 12, 241-242.

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Sartorelli AC, Creasey WA., 1969. Annu Rev Pharmacol. 9:51-72.

APPENDIX F

PROFESSOR PROPES'S MINI-JOURNAL

Version 1

SCTIL Laboratory Instruction Template

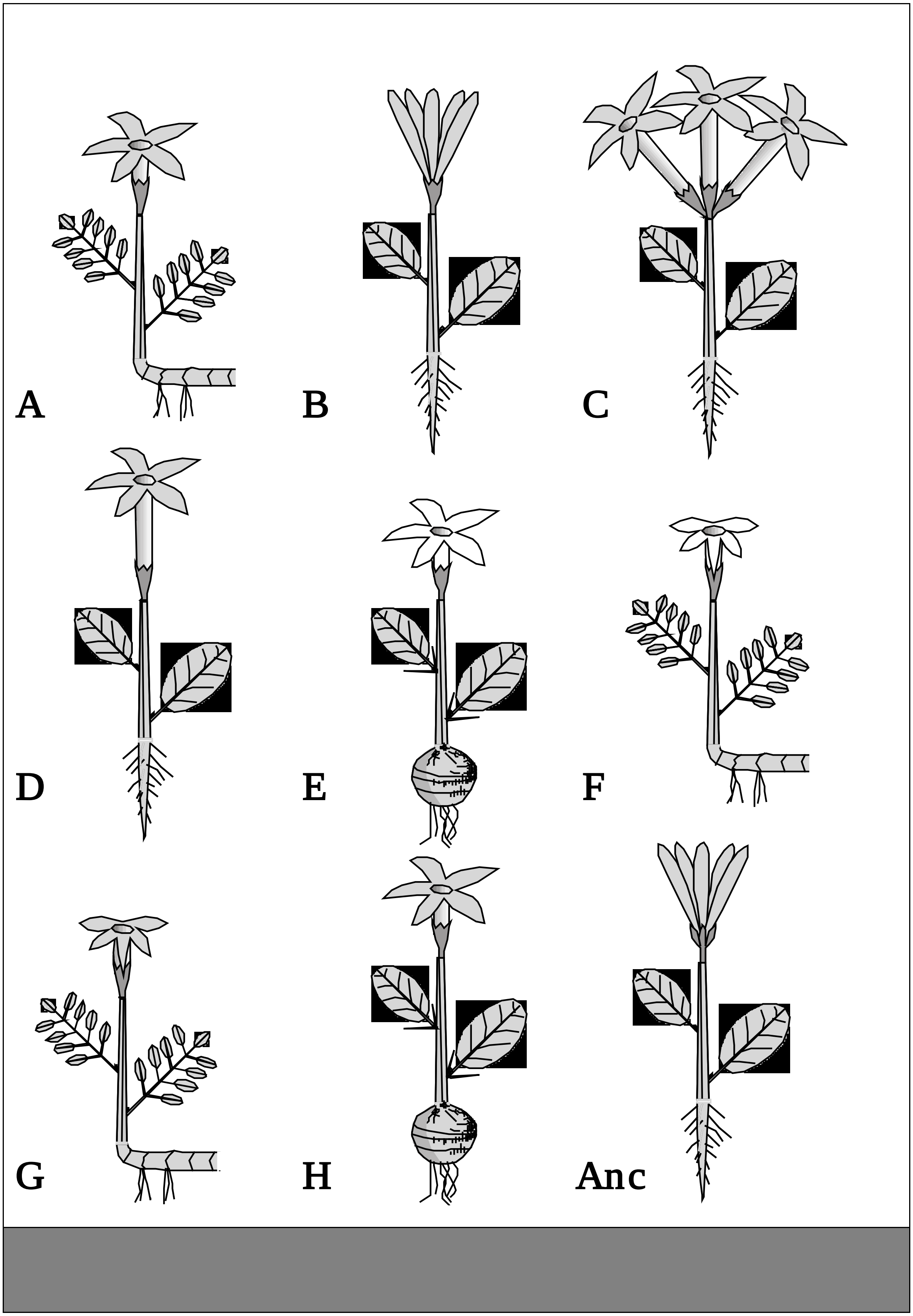
<table>
<tr><th colspan="3">Instructor</th></tr>
<tr><td colspan="3">[redacted]</td></tr>
<tr><th colspan="3">Course Name</th></tr>
<tr><td colspan="3">Plant Systematics</td></tr>
<tr><th colspan="3">Laboratory Title</th></tr>
<tr><td colspan="3">Phylogeny of Hypothetical Plants</td></tr>
<tr><th colspan="3">Number of Students</th></tr>
<tr><td colspan="3">40</td></tr>
<tr><th colspan="3">Student Background</th></tr>
<tr><th>Year</th><th>Major</th><th>Prerequisites</th></tr>
<tr><td>Sophomore to Senior</td><td>Biology, Fish and Wildlife, or Education</td><td>None/Intro Bio</td></tr>
<tr><th colspan="3">Key Pre-Knowledge (check all appropriate)</th></tr>
<tr><td colspan="3">☐ Mathematics
☐ Scientific
☐ Experimental
☐ Reading
☐ Writing
☐ Communication
☐ Problem Solving
☐ Decision Making
☐ Interpreting
☐ More specific:</td></tr>
<tr><th colspan="3">Learning Goals</th></tr>
<tr><th>For All Students</th><th>For Most Students</th><th>For Top Students</th></tr>
<tr><td>How can we group organisms?
Distinguish phenetic (overall similarity) versus cladistic methods (see below).</td><td>Can phylogenetic trees vary in their representation but have same meaning?
Yes, only topology of tree matters (branches can swivel at a node but mean the same thing).</td><td>Do all characters tell the same evolutionary story?
No, there is homoplasy (reversals, convergence)</td></tr>
<tr><th colspan="3">Potential Difficulties of Instruction</th></tr>
<tr><th>Pre-Lab Preparation</th><th>Lab Approach</th><th>Post-Lab Assessment</th></tr>
<tr><td>Students familiarization with concepts:
Homology, inherited characters.
Phenetics: use of all</td><td>Classifying qualitative characters as bimodal characters (+ and –, or 0 and 1) is easier than coding characters as multistate.</td><td>Can students transfer skills to a new set of organisms (another set of hypothetical organisms or real</td></tr>
</table>

variable data to make evolutionary trees based on overall similarity. Cladistics: use of only synapomorphies (shared derived characters) to make evolutionary trees. Distinguish trees from keys.	For example, categorize flowers long or flowers short, or flowers white and flowers colored.	organisms) or with new types of data (molecules/DNA sequences versus just morphological characters).

Mini-Journal Format

Abstract

Phylogenetic relationships within evolutionary biology are explored by a tree-building exercise from a given set of hypothetical plants. This is an introductory exercise that would precede a more elaborate lab (which would be more conducive to the mini-journal format with a meaningful abstract. Hypothetical plants given to students to put into groups and then to construct phylogenetic trees for:


A
B
C
D
E
F
G
H
Anc

Introduction
Evolutionary biology often focuses on Darwinian concepts like natural selection, fitness and adaptation. However, Darwin's only illustration in his Origin of Species (1859) was a tree of life that conveyed the importance of another idea, "descent with modification." Darwin's phylogenetic tree (or phylogeny) illuastrated how he conceived species changing over time. Phylogenetic trees serve as visual representations of possible historical relationships among species where taxa at the tips/ends of trees represent species, genera or other taxa. These taxa can include both living or extinct organisms. Branches of the trees then represent ancestral populations of species through time, and nodes designate points where on species splits into two descendant populations (that are then sister taxa). Rooted trees identify the origin of the lineage and by inference ancestral character states. The combined image of tips, branches and nodes illustrates Darwin's concept of "descent with modificati0n" and a plausible hypothesis for relationships among organisms. [Introduction can also include a primer on phenetic and cladistic methodologies, the concept of shared derived characters, monophyly, and parsimony, see Burks and Boles 2007 for examples and activity that makes phylogeny from chocolate bar wrappers].

Methods
1. Given illustrations of hypothetical organisms (plants above), ask students to discuss above: - how do the taxa differ from one another morphologically? - what are different ways to group taxa? (use all characters? Some characters? Prioritize?) - why group taxa? (Grouping for identification/taxonomic keys or to reflect evolutionary relationships?) - develop a grouping system for the taxa and explain the relationships between and within groups you developed. How do you make grouping method explicit? - how can you represent groupings? (alternatives to phylogenetic trees?) - based on these living taxa, what do you think the "most ancestral" organism or progenitor to these taxa looked like? (this hypothetical plants exercise gives the ancestral organism, other exercises do not) 2. Construct a data matrix with species A-H, and ancestor (Anc) in first column, and then morphological characteristics in following columns. Assume the ancestor has the ancestral character state for all characters (so put a 0 for all characters in the matrix). Variations from that are derived character states (1). For example, Anc and species B have petals separate (0) and all the other species have petals fused (1). 3. Draw a parsimonious tree with all the species (Anc, and A-H) at the tips and character state changes indicated on the branches.

Results
The data matrix table. The phylogeny with character state changes.

Discussion
Answers to question in methods above....other ideas? Discuss characters in conflict (homoplasy)? Discuss follow-up questions below?
Follow-up Questions
To further develop your grouping system, what additional information would you like to have? (phenotypic data given...other types of data? More living or fossil species?). Can your grouping system methodology incorporate new taxa? How would you deal with character conflict (homoplasy, ncongruence) within a dataset? What if the incongruence had a biological basis (e.g., morphology versus molecules?)? How add fossil data? Practical problems: are all trees dichotomously branching? H How represent unresolved nodes or ambiguity? How representing reticulate evolution (hybrids) or gene duplication?
Citation
Burks R.L, and L.C. Boles. 2007. Evolution of the chocolate bar: a creative approach to teaching phylogenetic relationships within evolutionary biology. The American Biology Teacher 69: 229-237. Darwin, C. 1859. Origin of Species.

APPENDIX G

PROFESSOR ROGERS'S INQUIRY ARTICLES

Version 1

SCTIL Laboratory Instruction Template

Instructor
[redacted]
Course Name
Exploring the Principles of Physics
Laboratory Title
The Resistance of Different Wires
Number of Students
20-30

Student Background		
Year	**Major**	**Prerequisites**
Sophomore	Education	none

Key Pre-Knowledge (check all appropriate)			
☐ Mathematics	☐ Reading	☐ Problem Solving	☐ More specific:
☐ Scientific	☐ Writing	☐ Decision Making	
☐ Experimental	☐ Communication	☐ Interpreting	

Learning Goals		
For All Students	**For Most Students**	**For Top Students**
Thicker wires have less resistance	Thicker wire allows more paths for current to flow	Longer wires = series resistors, but thicker wires = parallel resistors, -> parallel resistors have lower resistance.

Potential Difficulties of Instruction		
Pre-Lab Preparation	**Lab Approach**	**Post-Lab Assessment**
Easy	Getting students to think of new things to try, making sure they're measuring resistance correctly (especially in regards to contact points)	If they thought of something that didn't affect the resistance, or got a result which didn't make any sense, how do you grade it?

Mini-Journal Format
Abstract
The electrical resistance of circuit elements is critical to how circuits operate. The resistances of four wires of the same material and length but with various thicknesses were measured in order to investigate how wire thickness affects the resistance of a length of wire. Because longer wires have more resistance, we expected that an increase in the amount of wire material for thicker wires would lead to higher resistance. However, we found that the resistance actually decreases as wire thickness increases. The thinest wire, with a 0.006 inch diameter, had a resistance of 73.3 Ω, while the thickest wire, with a 0.018 inch diameter, had a resistance of only 5.1 Ω. The resistance of a wire is therefore not solely dependent upon the amount of material in the wire: the form is critical as well. This may be an important consideration in choosing wires for applications such as extension cords or home lighting.
Introduction
They will have done length dependence of resistance and series resistance circuits already. They also know that increased resistance means less current (which they observe from brightness of lightbulb).
Methods
4 different guage wires of the same material and same length, measure the resistance with a multimeter.
Results
Thicker wires have less resistance.
Discussion
The amount of resistive material isn't the only factor which affects the resistance. The shape it takes makes a difference as well: adding material by making wire longer increases resistance while adding material to make wire thicker lowers resistance.
Follow-up Questions
How about varying both thickness and length? What about only varying one cross-sectional dimension? Do curves matter? Maybe use aluminum foil, then they can make lots of length/width variations.
Citation
This is the tough part: Ohm's original papers might be a good citation, but they're in German and I can't find a translation.

Version 2

The Effects of Wire Thickness on Electrical Resistance

Abstract

The electrical resistance of circuit elements is critical to how circuits operate. The resistances of a wire of constant diameter was measured as a function of the length of the wire segment measured in order to investigate how the length of a conductor affects its resistance. Because the electrical current encounters more resistive material for a longer conductor, we expected the resistance to increase as length increased. We found that the wire had a resistance proportional to the length, with every centimeter of wire contributing approximately 0.98 Ohms. While the particular constant of proportionality should vary for different conductors, the linear dependence of the resistance on length should be common to all conductors. This may be an important consideration in choosing wires for applications such as extension cords or home lighting.

Introduction

The amount of current which flows through a circuit depends upon the resistance of the circuit[1]. Previous experiments have shown that when multiple resistors are placed in series, the total resistance of the circuit is equal to the sum of the individual resistors. In a simple battery and lightbulb circuit, the lightbulb is often the primary resistor of interest, but the connecting wires are actually resistors as well. If the resistance from the wires is large, the amount of current flowing through the circuit will decrease. This can have a negative impact on the performance of a circuit (for example, decreased light output from a lightbulb) or even, in extreme cases, lead to disaster, such as fires caused by faulty wiring inside a home[2]. Understanding the factors which affect the resistance of wires is therefore important to understanding how to design safe and effective circuits. The length of wires used in circuits is a commonly encountered variable, and is even something which consumers adjust using extension cords for electrical appliances. We therefore decided to investigate how the resistance varied with the length of a conductor.

We expect that increasing the length of a conductor will increase its resistance in the same manner that adding additional resistors to a series circuit increases resistance. We can consider each unit length of a wire to be like a resistor, and when we lengthen the wire, we are connecting these pieces in series. If this model is correct, then the resistance of the wire should be directly proportional to the length of the wire.

Materials and Methods

We used a single steel wire 0.004 inches in diameter[3] to perform our resistance tests. The wire was strung between two posts on a wooden board. We connected our multimeter to our wire using the alligator clip leads. The leads were clipped to the wire at fixed distances apart (measuring from the inside distance between the leads), from 2 to 20 cm separation every 2 cm. The multimeter was used to measure resistance directly. To test the resistance of the multimeter leads, we attached the leads directly to each other without the wire and recorded the measured resistance.

Results

Figure 1 shows the resistance as a function of wire length. As expected, the resistance of the wire increased with increasing wire length. To test our prediction that the resistance should be proportional to the wire length, we performed a least-squares fit of our data to the form $R = c*L + R_0$, where R is the resistance of the wire, L is the length of the wire, c is the constant of proportionality, and R_0 should be the resistance of the rest of the circuit. The fitted parameters were c = 0.98 Ω/cm and R_0 = 0.86 Ω. The measured resistance of the multimeter alligator clip leads was only 0.2 Ω.

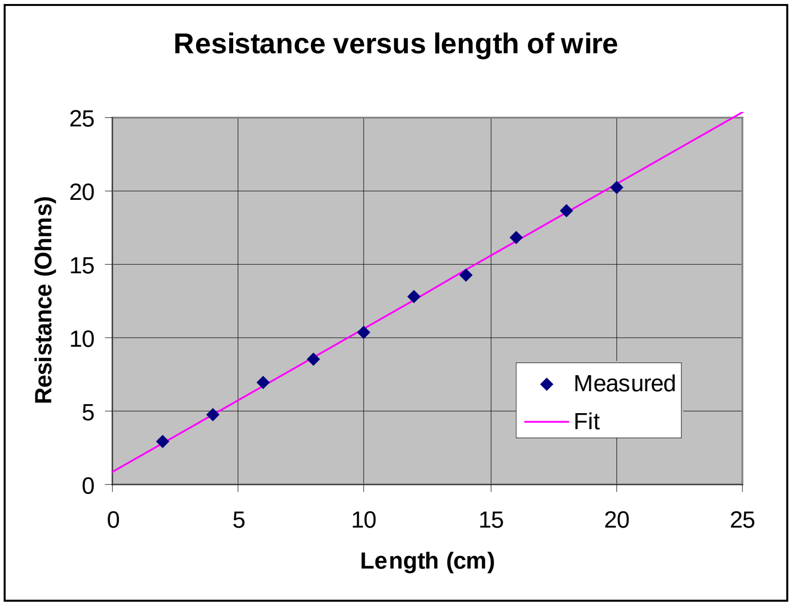


Figure 1: Resistance as a function of wire length for 0.004 inch diameter steel wire. Symbols indicate measured values. The solid line indicates a least-squares linear fit to our data, as discussed in the text.

Discussion

Increasing wire length increases resistance, as we expected. Furthermore, as the length of the wire was varied, the resistance did indeed appear to vary linearly, indicating that the resistance of the wire was approximately 0.98 Ω/cm. However, our fit results also imply that at zero wire length, we should SCTILl have a resistance of 0.86 Ω. This is significantly larger than the resistance of the multimeter leads themselves. We suspect that the alligator clips may have formed poor contact with the wire, since the wire was so thin that the alligator clips did not grasp it firmly. That could create extra resistance at the contact points, which would account for our fit results.

Assuming we are correct about the origin of the larger-than-expected residual resistance, our model for why the resistance increases with the length of the wire appears to be correct. As the wire length increases, electrons have to pass through more resistive material, and so the resistance increases. A similar linear dependence of the resistivity on length has also been observed in graphite rods[4], suggesting that this behavior is not peculiar to our wire but is a general property of uniform-thickness conductors.

The length of a conductor is not the only geometric parameter which might affect resistance, however. For example, wires come in different thicknesses. What effect does changing the cross section (the area perpendicular to the length of the wire) have on the resistance? Adding more resistive material by lengthening the wire increases the total resistance, but would adding more resistive material in a different configuration always increase the resistance? In the case of varying the length, we have an analogue with series circuits to guide us, but this model may not be applicable to the case of varying the cross section, and so we do not know if resistance should increase or decrease in such a case.

References

1) M. Chandrasekhar and R. Litherland, "Exploring Physics: Workbook for Physics 2330", 2006.

2) U.S. Fire Administration, "On the Safety Circuit: A Factsheet on Home Electrical Fire Prevention," accessed online 8/14/2007 at http://www.usfa.dhs.gov/downloads/pdf/fswy5.pdf

3) Wire gauge conversion chart accessed online 8/14/2007 at http://www.sizes.com/materls/wire.htm

4) O. P. Vajk, unpublished lab report, Physics 2330, September 2006.

APPENDIX H

PROFESSOR WILSON'S INQUIRY ARTICLES

Version 1

Use of Indicators, pH and spectrophotometry to visualize the principles of the Henderson Hasselbalch equation

[redacted]

Abstract

We will work on how to write this in class ~200 words:
What was known, what you tried, what you found.

Introduction

pH is a log scale of the measurement of hydrogen ions in a solution, typically measured with a pH meter. The H^+ ions are generated when weak acids or bases only partially dissociate in solution until the point that equilibrium is established. pKa is the measurement of constant rate of disassociation of a substance. The relationship between pH and pKa is demonstrated by the Henderson Hasselbalch equation. This equation correlates the disassociation rate of weak acids (or weak bases) with the pH and the concentration of the products of the disassociation.

Indicators (including phenol red) are weak acids which can be used to monitor changes in pH. Removal of protons from the acidic form results in conversion to the basic form and a corresponding color change. This color change can be monitored via spectrophotometry which works on the principle that substances in solution absorb light of one wavelength and transmit other wavelengths in proportion to the concentration. Beer's law relates the concentration of a sample, the Absorbance of the sample and molar absorptivity; if two values are known the third can be determined. Together these laws can be mathematically applied to correlate the absorbance, disassociation constants, the concentration of the acid and base forms and the pH.

The experiment performed here required familiarity with the pH meter and the spectrophotometer. The absorbance of a solution containing an indicator was determined under acid and alkaline pH conditions to identify the wavelength of maximum absorbance for each form. The absorbance of a variety of solutions of different pH, all containing indicator, was determined. The pH of the solution and absorbance allowed experimental determination if the pKa using the Henderson Hasselbalch equation. This experiment allowed a visual appreciation of pKa and provided a better understanding of the role of a buffer and application of the Henderson Hasselbalch equation.

Methods

Phenol Red : The stock of phenol red was provided. From this, a working stock was generated consisting of 16 mls of a 1:10 dilution in water and mixed well by inverting the tube several times to ensure the solution was uniform. The 16 ml volume ensured there would be enough of the working stock to perform all exercises in this laboratory experiment.

The working stock of phenol red was diluted 1/10 to make 10 mls each of HIn^+ and In^- by adding 1 ml of the working stock of phenol red to 9mls of 0.1 M Na_2HPO_4 or 1/10 in 0.1 M NH_4OH (made fresh). These tubes were mixed well to ensure they were completely uniform.

Cuvettes : Three cuvettes were obtained and rinsed with dH_2O to ensure they were clean. Each cuvette was filled with dH_2O and the absorbance of each tube was checked at 600nm 400nm, picking one cuvette to use as the blank. This ensured the cuvettes were sufficiently 'matched' to ensure the absorbance obtained was due to the solution contained within and not differences in the cuvette.

The 3 cuvettes were filled with either the Na_2HPO_4 solution, the NH_4OH solution or water for the blank. Using the Spec20, the absorbance of the 2 solutions was taken every 10nm at wavelengths from 400 to 600 nm, using the blank to zero the machine at each new wavelength. Data are shown in Table 1 below.

Once collected the data were examined to ensure they were within the acceptable range for accuracy. The wavelength which yielded the maximum absorbance for the HIn^+ and the In^- forms as well as the isobestic point were determined from the data. (graphs shown in Figure 1, below)

pH of phosphate buffered solutions : Test tubes were labeled according to the target pH as indicated in Table 1. A range of pH solutions were generated, pipeting samples as indicated in Table 1. After each solution was made, it was mixed well and 1 ml was removed from each tube, leaving 9 mls in each. One ml of the working stock of phenol red was added to each tube, bringing the volume back to 10 mls. This was mixed well to ensure it was homogeneous.

Estimated pH	mL 0.1 M Na_2HPO_4	mL 0.1 M NaH_2PO_4
4.5	0.0	10.0
5.0	0.10	9.9
5.5	0.40	9.6
6.0	1.4	8.6
6.5	2.7	7.3
7.0	6.6	3.4
7.3	8.1	1.9
7.5	8.9	1.1
7.8	9.3	0.70
8.0	9.6	0.40
8.5	9.9	0.10
9.0	10.0	0.0

The pH of each sample was measured via pH meter and recorded as the 'actual' pH of the solution. The absorbance of each solution was measured at the wavelength determined to yield maximum absorbance of the HIn^+ and In^- forms.

Results

Determine maximum absorbance of HIn^+ and In^- Phenol red was diluted 1:10 in water to generate the working stock. This working stock of phenol red was further diluted 1/10 in either 0.1M NaH_2PO_4 or 0.1M NH_4OH to generate the HIn^+ and In^- forms and determine maximal absorbance of each. The absorbance readings from 600 to 400 nm (at 10 nm intervals) were taken on a Spec 20 spectrophotometer. The data are shown in the chart in Figure 1 and plotted together on the Graph in Figure 1. The two forms have clear and maximal absorbance readings at distinct wavelengths.

Use of a range of buffered solutions to calculate the equilibrium constant A series of buffered solutions predicted to have a variety of different pHs were prepared as indicated in Table 1 (Methods). One ml of the working stock of phenol red was added to 9 mls of buffered solution. The phenol red displayed an obvious color change in the various tubes of different pH; the solution ranged from red through orange to yellow. These solutions were used to determine both the actual pH of the solution (measured with a pH meter) and the absorbance of each phenol red solution at the maximal absorbance wavelength for the HIn^+ and In^- forms (as determined in the section above) Figure 2 complies the data in a chart showing the actual pH and the absorbance at the two wavelengths resulting in maximum absorption plus the isobestic point. The wavelength for HIn+ was 430 nm; which In^- absorbed maximally at 550 nm. The absorbance of each sample at the isosbestic point, 480 nm was also determined. The data are complied in Figure 2. From these data, the acid concentration, base concentration, molar absorptivity and the pKa of phenol red were calculated for each sample. An average value calculated from these. Sample calculations are shown in Figure 3.

Conclusions

This part should be a running narrative telling what you learned and how the data indicated things you did or did not expect. If your readings were not as expected (you saw a VERY red tube where you would have expected a yellow samples) provide reasons why the data may have turned out like this (forgot to pipet one of the reagents, spilled some before adding phenol red, etc).
Use this section to answer the questions provided in the handout. Be sure to use full sentences and whenever possible, work the answer into the flow of the text. You need not answer the questions in the order in which they appear in the handout, but do make sure you address all of the questions.

If your experiment lead you to wonder "what would happen if…" put it here.

This write up is the starting point for **YOUR** experiment this week – I have provided you with the data from the original protocol. Based on these data and the protocol and what you have leared by reading your background material for this week, how would you go about VARYING this protocol to learn more about the fundamental principles involved?
What are the variables?
How could we test them?
What would we learn form the answers we obtain?

Figure 1 Determination of the maximum absorbance of the HIn+ and In- forms of phenol red. Absorbance of phenol red solutions in NH_4OH (NH_4) or in HNa_2PO_4 (PO4) was measured at the wavelengths indicated (in nm). The graph shows the two data sets superimposed to allow determination of absorbance maximum of the HIn+ and the In- forms as well as the isobestic point (~470 nm).

Data 1/15/07

Wavelength (nm)	NH4 (Abs)	PO4 (Abs)
600	0.04	0
590	0.1	0.005
580	0.23	0
570	0.41	0
560	0.6	0
550	0.62	0
540	0.56	0.01
530	0.45	0.01
520	0.37	0.02
510	0.3	0.025
500	0.24	0.05
490	0.19	0.07
480	0.14	0.12
470	0.1	0.15
460	0.08	0.2
450	0.06	0.24
440	0.04	0.25
430	0.035	0.27
420	0.025	0.26
410	0.02	0.24
400	0.02	0.22

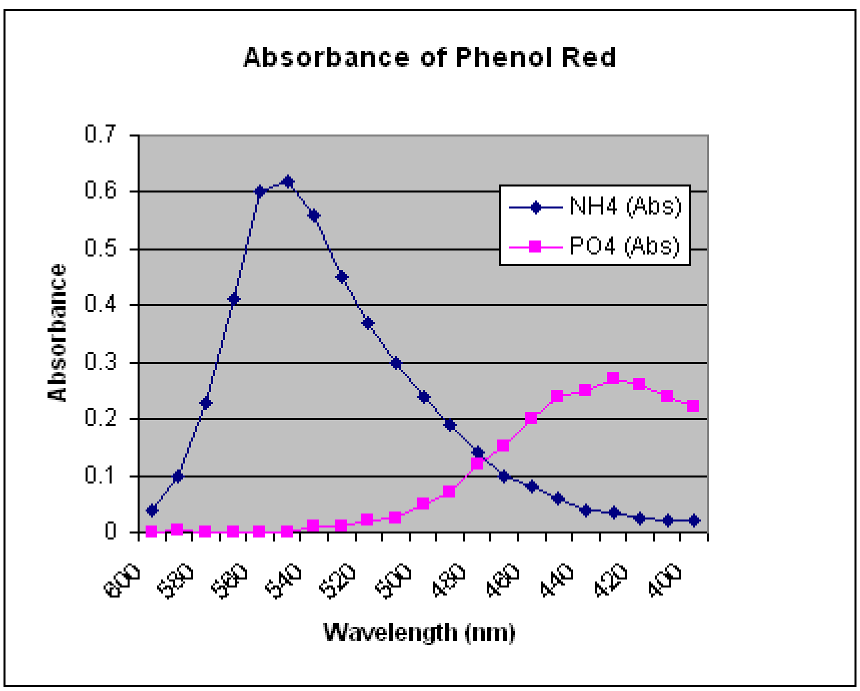


Figure 2 Absorbance of phenol red in different pH solutions at wavelengths of maximum absorbance for HIn+ and In- forms. Solutions of approximate pH as indicaeted were generated. The exact pH was determined by pH meter and the absorbance of each solution at the three wavelengths indicated were measured on the Spec 20. (the calculations here were not completed but were started to help you figure it out yourself – on YOUR report, make sure your tables are FULLY completed.)

At base form maximum, acid from does not absorb

pH estimate	pH determined	A 430 (acid)	A 480 (ip)	A 550 (base)	bace conc (M)	acid conc	pKa
4.5	4.79	0.3	0.13	0.01			
5	5.25	0.3	0.13	0.01			
5.5	5.37	0.3	0.14	0.02			
6	5.9	0.3	0.135	0.02			
6.5	6.32	0.3	0.14	0.03			
7	7	0.26	0.14	0.11	1.96 x10-6	8.04 X10-6	7.61
7.3	7.37	0.23	0.14	0.21	3.7 x10-6		
7.5	7.65	0.185	0.14	0.3	5.3 x10-6		
7.8	7.85	0.15	0.14	0.39			
8	8.13	0.11	0.15	0.47			
8.5	8.63	0.06	0.15	0.58			
9	9.16	0.04	0.15	0.62			

E = 47,863

Figure 3 Sample calculations The values in Figure 2 were used to calculate the base concentration, acid concentration and pKa of phenol red, as indicated in Figure 2. The molar absorbtivity was calculated from these values, using method A as shown below.

Calculations: Method "A"

At Base Form Maximum, Acid form does not absorb

Use Beer – Lambert to determine Molar absorptivity

$\lambda = \underset{\text{BaseMax}}{540}$ $A = 0.56$

$A = \varepsilon b c$

$0.56 = \varepsilon\,(1.17\,\text{cm})\left(c\ \frac{\text{mol}}{L}\right)$ → $\frac{0.1\,g}{250\,ml} = \frac{0.4\,g}{1\,L}\left[\frac{376\,g}{L}\right]$ (the MW)

↓ so APPROX 1 mM STOCK $= 1\times10^{-3}\,\frac{\text{mol}}{L}$ → Did 1/10 then 1/10 for Abs

↓ TOTAL Conc. $= 1\times10^{-5}$

$\varepsilon = \frac{0.56}{(1.17\,\text{cm})(1\times10^{-5}\,\frac{\text{mol}}{L})}$

$\varepsilon = 47{,}863\ M^{-1}\,cm^{-1}$

Now: with ε can use ε and Abs At EACH pH to calculate BASE conc

→ then [Acid] + [Base] = 1×10^{-5}

figure out Base ↓ into HH

$\frac{A}{\varepsilon b} = c$

$\frac{0.11}{47{,}863(1.17)} = 1.964\times10^{-6}$

Version 2

Use of Indicators, pH and spectrophotometry to visualize the principles of the Henderson Hasselbalch equation

Abstract

The pH is a measure of the H+ ions present in a solution. Indicators are compounds that can be added to solutions to monitor changes in pH, usually via a colorimetric change. Spectrophotometry can be used to accurately measure these colorimetric changes. The absorbance of the acid form and the base form of the indicator (phenol red) was determined across a spectrum to determine the wavelength of maximum absorbance of each form. A series of buffered solutions each containing the indicator was generated. The pH and the absorbance of the indicator (at the maximum wavelength of each form) was determined for each solution. These data were applied Applying the Henderson Hasselbalch equation allowed an experimental determination of the pKa of a 0.1 M solution of phosphate containing phenol red, determined here to be 7.61.

Introduction

pH is a log scale of the measurement of hydrogen ions in a solution, typically measured with pH meter. The H^+ ions are generated when weak acids or bases only partially dissociate in solution until the point that equilibrium is established. pKa is the measurement of constant rate of disassociation of a substance. The relationship between pH and pKa is demonstrated by the Henderson Hasselbalch equation. This equation correlates the disassociation rate of weak acids (or weak bases) with the pH and the concentration of the products of the disassociation.

Indicators (including phenol red) are weak acids which can be used to monitor changes in pH. Removal of protons from the acidic form results in conversion to the basic form and a corresponding color change. This color change can be monitored via spectrophotometry which works on the principle that substances in solution absorb light of one wavelength and transmit other wavelengths in proportion to the concentration. Beer's law relates the concentration of a sample, the Absorbance of the sample and molar absorptivity; if two values are known the third can be determined. Together these laws can be mathematically applied to correlate the absorbance, disassociation constants, the concentration of the acid and base forms and the pH.

The experiment performed here required familiarity with the pH meter and the spectrophotometer. The absorbance of a solution containing an indicator was determined under acid and alkaline pH conditions to identify the wavelength of maximum absorbance for each form. The absorbance of a variety of solutions of different pH, all containing indicator, was determined. The pH of the solution and absorbance allowed experimental determination if the pKa using the Henderson Hasselbalch equation. This experiment allowed a visual appreciation of pKa and provided a better understanding of the role of a buffer and application of the Henderson Hasselbalch equation.

Methods

Phenol Red : The stock of phenol red was provided. From this, a “working stock” was generated consisting of a total of 16 mls at a 1:10 dilution in water (1.6 mls phenol red plus 14.4 mls diSCTILled water). This solution is mixed very well by inverting the tube several times (with parafilm on the end) to ensure the solution was uniform. The 16 ml volume ensured there would be enough of the working stock to perform all exercises in this laboratory experiment.

The working stock of phenol red was then diluted 1/10 to make 10 mls each of HIn^+ and In^-. This occurred when 1 ml of the working stock of phenol red was added to 9mls of 0.1 M Na_2HPO_4 or in a separate tube, 1 ml of the working stock of phenol red was added to 9 mls of 0.1 M NH_4OH (diluted freshly in water from a 10X stock of the 1M NH_4OH stored in the fume hood). These tubes were mixed well to ensure they were completely uniform.

Cuvettes : Three cuvettes were obtained and rinsed with dH_2O to ensure they were clean. Each of the 3 cuvettes was filled with dH_2O and the absorbance of each tube was checked at 600nm 400nm. This was done by randomly selecting one cuvette to use as the blank. The Spec20 was ‘zeroed’ with this cuvette filled with water and the other cuvettes, filled with water, were measured to determine their absorbances. When both cuvettes gave identical readings, the cuvettes were deemed to be a sufficiently ‘matched’ to ensure the absorbance obtained was due to the solution contained within and not differences between the cuvettes.

The 3 cuvettes were filled with either the Na_2HPO_4 plus indicator solution, the NH_4OH plus indicator solution or water (for the blank). Using the Spec20, the absorbance of the 2 solutions was taken every 10nm at wavelengths from 400 to 600 nm, using the blank to zero the machine at each new wavelength. Data were collected and assembled into the Table in Figure 1, below.

Once collected, the data were examined to ensure they were within the acceptable range for accuracy, determined by the limits of the spectrophotometer. The wavelength which yielded the maximum absorbance for the HIn^+ and the In^- forms as well as the isosbestic point were determined from the data. (graphs shown in Figure 1, below)

pH of phosphate buffered solutions : Test tubes were labeled according to the target (estimated) pH as indicated in Table 1. A range of pH solutions were generated, pipeting samples in the ratios as indicated in Table 1. After each solution was made, it was mixed well and 1 ml was removed from each tube, leaving 9 mls in each. One ml of the working stock of phenol red was added to each tube, bringing the volume back to 10 mls, yielding a 1:10 dilution of the phenol red in the desired buffer. This combination of solutions was mixed well to ensure it was homogeneous.

Table 1 : Estimated pH	**mL 0.1 M Na_2HPO_4**	**mL 0.1 M NaH_2PO_4**
4.5	0.0	10.0
5.0	0.10	9.9
5.5	0.40	9.6
6.0	1.4	8.6
6.5	2.7	7.3
7.0	6.6	3.4
7.3	8.1	1.9
7.5	8.9	1.1
7.8	9.3	0.70
8.0	9.6	0.40
8.5	9.9	0.10
9.0	10.0	0.0

The pH of each sample was measured via pH meter and recorded as the 'actual' pH of the solution. The absorbance of each solution was measured at the wavelengths determined to yield maximum absorbance of the HIn^+ form, the In^- form and the isosbestic wavelength. All data were recorded in Table in Figure 2

Results

Determine maximum absorbance of HIn^+ and In^- Phenol red was diluted 1:10 in water to generate the working stock. This working stock of phenol red was further diluted 1/10 in either 0.1M NaH_2PO_4 or 0.1M NH_4OH to generate the HIn^+ and In^- forms and determine maximal absorbance of each. The absorbance readings from 600 to 400 nm (at 10 nm intervals) were taken on a Spec 20 spectrophotometer. The data are shown in the chart in Figure 1 and plotted together on the graph in Figure 1. The two forms have clear and maximal absorbance readings at distinct wavelengths.

Use of a range of buffered solutions to calculate the equilibrium constant A series of buffered solutions predicted to have a variety of different pHs were prepared as indicated in Table 1 (Methods). One ml of the working stock of phenol red was added to 9 mls of buffered solution. The phenol red displayed an obvious color change in the various tubes of different pH; the solution ranged from red through orange to yellow. These solutions were used to determine both the actual pH of the solution (measured with a pH meter) and the absorbance of each phenol red solution at the maximal absorbance wavelength for the HIn^+ form, the In^- form and at the isosbestic point (as determined in the section above). Figure 2 compiles these data in a chart showing the actual pH and the absorbance at the three wavelengths resulting in maximum absorption plus the isobestic point. The maximal absorbance wavelength for HIn+ was 430 nm; the In^- absorbed maximally at 550 nm. The absorbance of each sample at the isosbestic point, 480 nm, was also determined. From these data, the acid concentration, base concentration, molar
absorptivity and the pKa of phenol red were calculated for each sample. An average value calculated from these. Sample calculations are shown in Figure 3.

Conclusions

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Data 1/15/07

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450	0.06	0.24
440	0.04	0.25
430	0.035	0.27
420	0.025	0.26
410	0.02	0.24
400	0.02	0.22

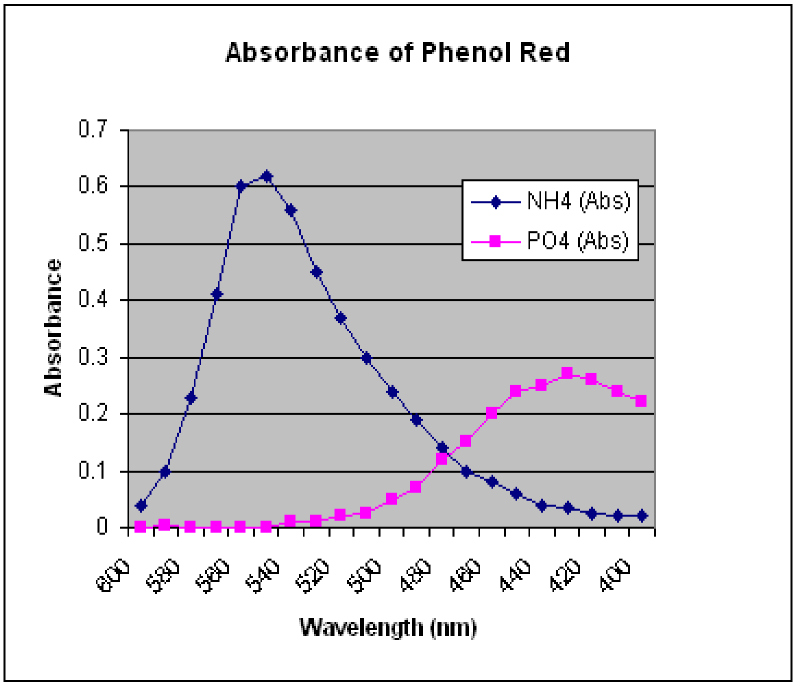

Figure 2 Absorbance of phenol red in different pH solutions at wavelengths of maximum absorbance for HIn+ and In- forms. Solutions of approximate pH as indicaeted were generated. The exact pH was determined by pH meter and the absorbance of each solution at the three wavelengths indicated were measured on the Spec 20. (the calculations here were not completed but were started to help you figure it out yourself – on YOUR report, make sure your tables are FULLY completed.)

At base form maximum, acid from does not absorb

pH estimate	pH determined	A 430 (acid)	A 480 (ip)	A 550 (base)	bace conc (M)	acid conc	pKa
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5.5	5.37	0.3	0.14	0.02			
6	5.9	0.3	0.135	0.02			
6.5	6.32	0.3	0.14	0.03			
7	7	0.26	0.14	0.11	1.96 x10-6	8.04 X10-6	7.61
7.3	7.37	0.23	0.14	0.21	3.7 x10-6		
7.5	7.65	0.185	0.14	0.3	5.3 x10-6		
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E = 47,863

Figure 3 Sample calculations The values in Figure 2 were used to calculate the base concentration, acid concentration and pKa of phenol red, as indicated in Figure 2. The molar absorbtivity was calculated from these values, using method A as shown below.

Calculations: Method "A"

At Base Form Maximum, Acid form does not absorb

Use Beer – Lambert to determine Molar absorptivity

$\lambda = \underset{\text{BaseMax}}{540} \quad A = 0.56$

$A = \varepsilon b c$

$0.56 = \varepsilon\,(1.17\,\text{cm})\,(c\ \tfrac{\text{mol}}{L}) \longrightarrow \dfrac{0.1\,g}{250\,ml} = \dfrac{0.4\,g}{1\,L}\left[\dfrac{376\,g}{L}\right]$ (the MW)

↓ so APPROX 1 mM STOCK

$= 1\times10^{-3}\,\frac{\text{mol}}{L} \rightarrow$ Did 1/10 then 1/10 for Abs

↓

TOTAL Conc. $= 1\times10^{-5}$

$\varepsilon = \dfrac{0.56}{(1.17\,\text{cm})(1\times10^{-5}\,\frac{\text{mol}}{L})}$

$\varepsilon = 47{,}863\ M^{-1}\,cm^{-1}$

Now: with E can use E and Abs At EACH pH to calculate BASE conc

$\dfrac{A}{\varepsilon b} = c$ → then [Acid] + [Base] = 1×10^{-5}

$\dfrac{0.11}{47{,}863(1.17)} = 1.964\times10^{-6}$

figure out Base ↓ into HH

VITA

Kristen L. Hutchins grew up in Arkadelphia, Arkansas where she completed her primary and secondary education. She received a Bachelor of Arts degree in Biology from Ouachita Baptist University in Arkadelphia and then moved to Fayetteville, Arkansas to begin her graduate studies. She completed a Master of Science degree in Kinesiology from the University of Arkansas at Fayetteville (U of A). During her time at the U of A, she taught several undergraduate courses in the Kinesiology department and was appointed by the dean as a physical education instructor for grades K-5 at a local elementary school.

Kristen completed her doctoral degree program in Science Education from the University of Missouri (MU) in Columbia, Missouri. During her doctoral program, she served as Project Coordinator for a state-funded professional development evaluation grant. She also taught an undergraduate Biodiversity lab course at a neighboring university, Westminster College, and served as a teaching assistant for a large-lecture introductory Biology course at MU. Dr. Patricia M. Friedrichsen was her program advisor and dissertation chair.

In August of 2008, Kristen moved to Brownwood, Texas to begin a faculty position in the Biological Sciences department at Howard Payne University. She teaches primarily biology and physiology courses. Outside of work, Kristen spends her free time with her husband of seven years, Dalton Hutchins, and their 6-month-old son, Blake.