THE EFFECTS OF INTERACTIVE DISCOURSE, THE SOCRATIC METHOD, AND ACTIVE LEARNING LABS ON STUDENT ACHIEVEMENT AT THE UNIVERSITY LEVEL – A COMPARATIVE APPROACH

A Dissertation

by

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ABSTRACT

The primary purpose of this study was to examine and provide an observational analysis for a non-traditional, undergraduate biology classroom at a research I university in the southern United States. This study employed a mixed methods design. The researcher collected qualitative data associated with the design of the non-traditional classroom, input from the professor (Dr. X) whose class was being analyzed, input from her teaching assistants as well as student perceptions of these biology courses. The main research question guiding this study was: What are the unique characteristics of Dr. X's biology classes and what impact do they have on students' learning outcomes and experiences?

The results of this study were as follows:

1) The scope, sequence, and desired student outcomes of Dr. X's biology courses deviate radically from the traditional biology courses at the same university.

2) Dr. X's students felt that Dr. X's teaching style was discussion based and that it was their job to make sense of the in-class material and outside readings.

3) The majority of Dr. X's students reported that Dr. X instructed them to develop life-long learning skills and be passionately curious about the knowledge of biology.

4) T-Test and ANCOVA statistical analysis showed three statistically significant student achievement outcomes. Dr. X's students' grades were statistically significantly higher at the Biology 111 and Biology 112 levels when compared to students taking Biology 111 and 112 in the traditional biology class formats. Students taking Biology 111 and 112 in the traditional biology class formats attained significantly higher grades within Biology

213 – the next biology course taken by biology majors after Biology 111 and Biology 112.

The future of STEM education resides within the science education community's ability to assess new strategies, validate preexisting strategies, and to be accountable for the teaching methodologies used by science educators. Dr. X represents a new strategy of teaching biology at the undergraduate level. Her strategy is a break from traditional science teaching that is often times teacher-centered and lacks any semblance of creativity, collaborative elaboration, engagement or connectedness.

DEDICATION

This dissertation is dedicated to my parents, Dr. Terry William Lee, Fightin' Texas Aggie class of 1970, and my loving mother, Mrs. Georgianne Marie Lee. My mother taught me how to stand my ground and how to get things done correctly and in a timely manner. I am still amazed even to this day at everything she has accomplished. Her best days are ahead of her and I am excited to be a part of her life moving forward. Words cannot begin to convey how much I love my parents and how much I value being a person born sliding into home plate while others struggled to get to first base. The love I have for my parents, my aunts and uncles, my cousins, my grandparents and my sister makes me luckier than most and I acknowledge that.

My dad passed away in January of 2013 and he will not get to see my dissertation or my Ph.D. He taught me how to hunt and fish and how to embrace the transcendent beauty of nature He taught me how to play baseball and what it means to be an Aggie. He taught me how to sing the "Aggie War Hymn," how to sing "Whiskey River" by Willie Nelson and most importantly, my dad taught me how to think. I am his son and I miss him dearly.

In addition, I would like to especially dedicate this dissertation to my beautiful wife, Caley Lynn Lee, Fightin' Texas Aggie class of 1993 and to my two sons, Braden Alexander Lee and Ryan James Lee. You three are the greatest things that ever happened to knucklehead like me. I love you three more than I can say.

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INTRODUCTION

Many science research agencies – including The National Research Council, The National Science Foundation and The Geophysical Union – have recently cited the need to promote and improve scientific literacy within the United States (McConnell, Steer & Owens, 2003). Science educators have consistently ranked the quality of students' Science, Technology, Engineering, and Mathematics (STEM) learning experiences and their intellectual development as a means of promoting scientific literacy (Angelo & Cross, 1993; Trice & Dey, 1997). To help increase the STEM workforce in the US as well as to promote scientific literacy, the quality of the students' learning experiences at the collegiate level should be improved.

To facilitate that improvement, new interventions and learning strategies within the field of STEM education have been implemented and analyzed. National Research Council (2012) named these interventions and learning strategies that are proved to be effective in formal education as "evidence based pedagogies." Some examples of the evidence-based pedagogies are active learning, cooperative learning, peer-led team learning, peer instruction, problem-based learning, project based learning, inquiry-based learning, and challenge-based learning all of which are student-centered and/or learner-oriented strategies (Froyd, Borrego, Cutler, Prince, & Henderson, 2013).

Studies by Chickering and Gamson (1987), Tobias (1990), Angelo (1993) and Astin (1993) point out that science instructors must incorporate three fundamental elements into their science teaching. These three elements are: (a) the science content must be relevant, (b) science instruction must increase student-student interaction and, (c) science teaching must engage the students so as to encourage student understanding. An ideal learning environment requires the content to be relevant to the students' daily life experiences and the context to be dialogical and cognitively engaging for the students (Bransford, Brown, & Cocking 2000).

Problem Statement

Seminal studies within science education have indicated that unmotivated students and passive learning are the two major obstacles connected to poor student performance in collegiate biology courses (Weimar, 2002). Traditional lecture formats are capable of disseminating a wide array of information to many students at once. But these traditional formats often times merely promote superficial learning (Armbruster, Patel, Johnson, & Weiss, 2009) and fail to cultivate life-long learning and critical thinking skills. An unintended consequence of the large lecture formats is that students are not prepared to succeed outside of college. Students attaining science degrees are not equipped to develop deep understanding, analyze, and solve real world issues and problems (American Association for the Advancement of Science, 1989; Boyer, 1998; The National Research Council, 1999, 2003, 2007; Handelsman et al., 2004, Handelsman, J., Miller, S., and Pfund, C., 2007; Rauckhorst, W. H., Czaja, J.A. & Baxter, M.M., 2001). These studies have advocated for different methods to promote the understanding of science and scientific concepts by students enrolled in higher education.

Many factors affect a student's success in university-level biology courses (Moore, 2007; Rumberger, 2001). One factor is the corollary between absenteeism and a student's academic success. There is a nexus between a student's attendance record and her academic engagement, which can then be related to the student's grade in the course. Romer (1993) reported that absenteeism was rampant because students feel that attending class is optional. As students miss the class meetings, they tend to study the biology topics from the textbooks or similar supplementary materials. Not attending the class sessions and not discussing the topics with their peers and the course instructor lead to rote-memorization and passive learning. Students do not delve into and analyze the issues existing in STEM fields and miss the opportunities to engage in meaningful discussions to generate solutions. Over time, students develop negative attitudes towards STEM subjects. They lose their interest to further study in the field. This adds to existing deficiencies in STEM workforce pipeline in the US.

One potential reason students often times feel disinclined to attend a collegiate level biology class is the incongruence between the class' lab and the class' lecture. Many biology instructors and students alike often feel there is an inherent disconnect between biology lab and biology lecture. Chin and Malhotra (2002) and Hodson (1998) have theorized that if science labs could introduce and refine science process skills that the lab experience would be more meaningful within the overall framework of the class. Burrows and Nazario (1998) noted that if students are able to develop scientific process skills in lab that the distance between biology lab and lecture may be bridged due to a perception of lab material being applied in the laboratory setting. While biology instructors may try with varying success to connect lab and lecture, many obstacles must be overcome to achieve closure in this perceived gap. As noted by Burrows and Nazario (1998) the limitations associated with connecting lab and lecture are: different lab and lecture textbook authors, resource limitations, the inherent disconnect between the lab and lecture syllabi, and infrastructure limitations.

Science instructors should be concerned with the way that their students perceive their class and the lab associated with that class. At the pre-college level, researchers have been able to demonstrate that a student's attitude towards the class plays a major role in the academic success of the student (Gottfried, Hoots, Creek, Tamppari, Lord & Sines, 1993; Greenfield, 1997). Lawson, Banks, and Logvin (2007) have shown that there is a significant interaction between a student's self-efficacy and her reasoning ability, which then translated into greater college biology student achievement. Students' self-efficacy and their reasoning ability could be improved only if they are given the opportunities to actively participate in class (Bandura, 1993). Researchers have encouraged their introductory biology students to participate meaningfully in lab and lecture by asking causal questions. Causal questions may then be followed by several valid answers which can be tested in lab or re-examined by lecturers at a later date. Question-asking and question-answering strategies promote deliberate and mindful extraction. A cognitive bridge between the lectures and the labs can be established through engaging students in open-ended discussions in lectures and more practical applications in labs. However, because of the large class sizes, the majority of the lower level undergraduate biology courses in Research I universities lack the opportunity to engage the students in any form of conversation or dialogical practices.

There are reports published documenting the effectiveness of interactive and dialogical classroom context, discussion based teaching, and active learning (von Glaserfeld, 1989; Vygotsky, 1978). However, the researcher did not locate a single study discussing the impact of a small-size, lower level, undergraduate biology class on students’ learning experiences and outcomes that have been systematically assessed using both quantitative and qualitative research methods. Is there a difference between a small size classroom where interactive discourse, the Socratic Method, and active learning are the norms of the class context and a large size classroom where the lectures are didactic and teacher-oriented in the same department at a Research I university in the U.S.? The aim of this study is to answer to this question. This research project is an observational analysis to examine potential differences associated with non-traditional biology teaching at the university level. The observational analysis intends to elucidate meaningful differences. If identified, these meaningful differences could be applied to other biology programs found at other Research I universities. This observational analysis intends to assess and evaluate one particular university-level biology program to provide for more meaningful learning experiences for students involved in the program. The researcher located a small size class where one professor among many in the same department at a Research I university teaches lower level undergraduate biology courses through interactive discourse, the Socratic Method, and active learning approaches.

Exploring the teaching approaches implemented in the small size class and documenting the short term and long terms effects of these practices on students' learning outcomes and their experiences is timely. The findings of this study will shed light on the barriers and deficiencies of the large size lower level biology classrooms and the negative outcomes of passive learning and non-dialogical teaching practices. The researcher explores a unique case, a biology college instructor's class, with particular interest in her teaching context, students' learning outcomes and experiences, and students' attitudes towards the implemented instruction.

In the next Chapter, I discuss the relevant literature. This chapter comprises two parts. In part I of the review of literature the key terminology and concepts are defined and the frameworks that are foundational for evidence-based pedagogies are addressed. Among these concepts and frameworks are constructivist learning, transfer of knowledge, adaptive expertise, and *How People Learn* framework (Bransford, Brown, & Cocking 2000). After reviewing these concepts and frameworks, the reader will better understand the differences between interactive and discussion based instructions as opposed to those instructional settings that are didactic and exclude any dialogical conversations in class. Then, in Part II, evidence-based pedagogies in post-secondary and college level biology education are reviewed. Chapter II ends with an overview of a STEM education perspective for a desired change.

In Chapter III, I state the research questions; discuss the study design; and outline the proposed study's research methods. I employed a mixed methods study design utilizing both quantitative and qualitative research approaches. In the study design section, I convey my philosophical orientation to explain why I have chosen the mixed methods approach as my study design. In Chapter III, I also describe the characteristics of the study participants, the research instruments, and the analyses I conducted.

In Chapter IV, I present the study findings. This chapter has three parts. In part I, I discuss the findings emerged from the interviews with Dr. X and his teaching assistants and my observations in Dr. X classes. In Part II, I present the themes emerged from the analysis of the data collected from Dr. X's students. In Part III, the results of the statistical analyses comparing Dr. X and other instructors' students' learning outcomes are presented.

In Chapter V, I summarize the findings, state the conclusion, and discuss the implications for future research.

CHAPTER II

REVIEW OF LITERATURE

Part I: Evidence-Based Pedagogies

Emerging research within the fields of cognitive psychology, neurology, and education have allowed the scientific and education communities an opportunity to analyze and discover strategies and interventions that promote not only student success on assessments, but the long-term retention of information by students as well. The last 15 years of cognitive psychology and education research has allowed these two fields to compare ideas in an effort to elucidate foundational principles through which the human brain and human behavior can be assessed. The assimilation of metacognitive principles and constructivist learning techniques have underscored the inherent need within education to make sure that cognitive science is at the forefront of how both teachers and students adapt to modern learning environments, technologies, and school district needs. There is an inherent need to make sure that traditional models of education are being assessed so that learners may reach their potential and that the science of learning may be put into practice (Bransford, Brown, & Cocking 2000). In this review of literature, I focus on what the National Science Foundation would refer to as evidence based pedagogies (National Research Council, 2012). Evidence based pedagogies represent a theoretical framework within which many components of science, technology, engineering, and mathematics education (STEM) can be critiqued and evaluated.

Figure 1 (next page) presents a conceptual map of the key terms and concepts discussed in this review of literature. The premise conveyed in Figure 1 is that evidence-based pedagogies are based upon the constructivism; the use of evidence-based pedagogies in teaching will help enhance human cognition; and instructors implementing such pedagogies utilize pedagogical content knowledge that will be defined later in this chapter.

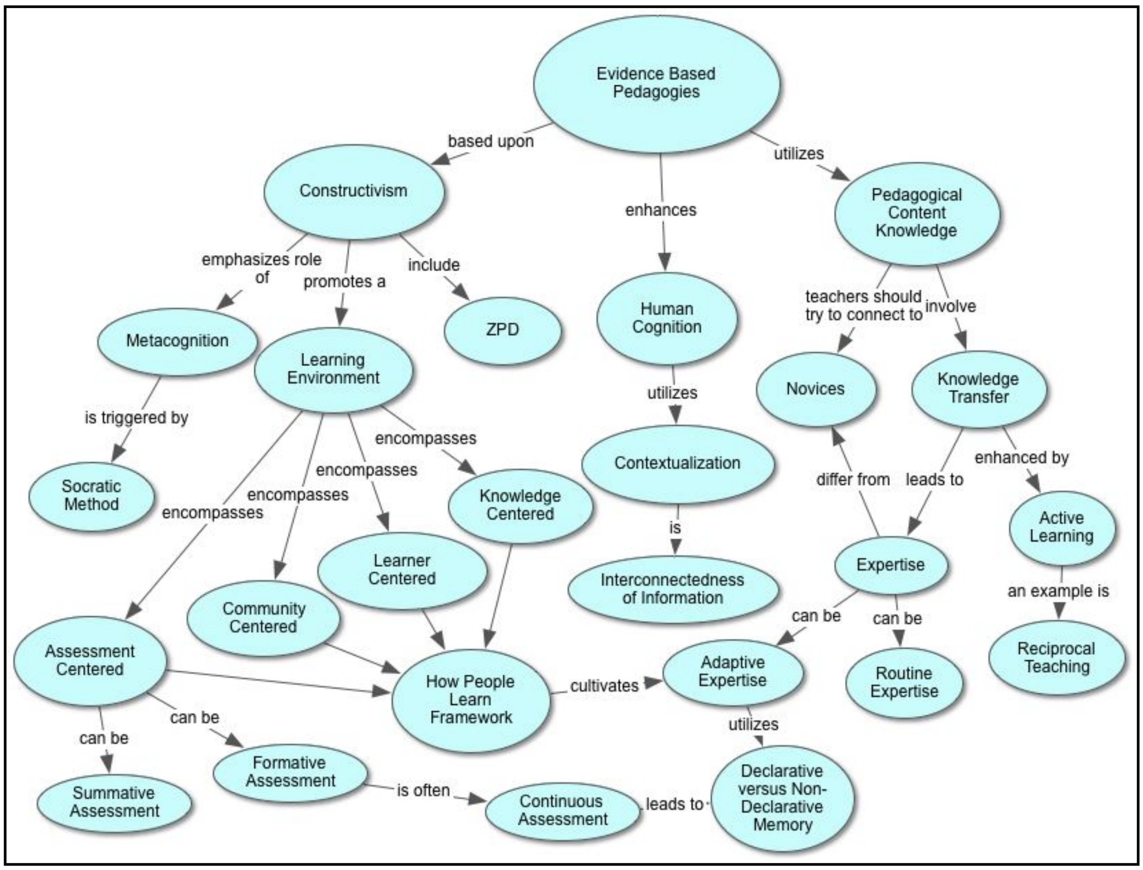

Figure 1. The Concept Map of the key terms and concepts discussed in this review of literature.

Constructivist Learning

Cognitive science has undergone a significant change since the 1950s. The education community now knows that social contexts and cultural parameters matter vis-à-vis the learning environment and how students tend to construct knowledge (Bransford, Brown, & Cocking 2000; Donovan & Bransford, 2005). Constructivist learning – the learning modality that postulates learners construct new learning based on what they already know - is the prevailing paradigm in terms of modern cognitive science (Cobern, 1991; Driver, 1986; Mintzes & Wandersee, 2004; Yager, 2000). Modern constructivist tenets suggest that students being exposed to facts *is* an important component of the process. Yet more important is that students be exposed to usable knowledge and also be allowed to organize material in their own way so as to promote recall and applicability. Students should be cognizant about their own learning and instructors should facilitate this process. How might an instructor facilitate such student enlightenment? In a word, the answer is *metacognition*. Metacognition is one's ability to know what they do and do not fully understand with assessment playing a critical role in the aforementioned (Mintzes & Wandersee, 2004; Flavell, 1979; Gilbert, 2005; Osborne, 1985). Students should be encouraged to ascertain their own fundamental understanding of a subject as assessment and accountability are encouraged within any particular learning environment. Why do sports teams play pre-season games? These games are played to allow teams an opportunity to assess their own strengths and weaknesses. Students must be able to embrace this course of action in terms of their own abilities to integrate and process information – with the application of knowledge and problem solving being the goals for the student *and* the instructor (Bransford, Brown, & Cocking, 2000).

What students bring *to* the classroom (e.g., preconceptions) matters in their learning. Not only the instructors but also the students need to be aware of the role their preconceptions play in their learning. Students' previous experiences and interactions inside and outside of the classroom shape their knowledge construction – to wit, student experiences exert influence over their own constructivist tendencies. Instructors should recognize the patterns and tendencies within students so as to either augment or infuse a cessation of just how students are synthesizing their own conceptual understanding (Bransford, Brown & Cocking, 2000). Students' conceptualizations of the subject matter being learned will not be the same with their instructors. Students often represent novice characteristics where their instructors embody expert characteristics.

As is eloquently pointed out in *How People Learn*, there are key differences between novices and experts within any given field (Bransford, Brown & Cocking, 2000). Experts tend to work through their own understanding while also acknowledging where their own synthesized models need more information or rationale. The experts continually assess themselves so as to identify where their own understanding is lacking. Experts also have the material organized in their own minds in a way that faster recall and applicability can be facilitated. Instructors need to be mindful of *how* this process works so as to allow as many students as possible the exposure to these methods. As a corollary, teachers need to introduce metacognitive principles into their own instruction. Students may not grasp the need for these principles but that does not diminish the need for student reflection, explanation, and eventually, problem-based learning. Instructors are expected to promote metacognitive principles within the classroom so as to facilitate a student's ability to think, understand, and reflect upon the new knowledge they learn. An instructor's ability to foresee students' cognition and her practical knowledge to guide her actions can be referred to as her "pedagogical content knowledge," as initially described by Shulman (1987).

For any instructor to gain pedagogical content knowledge (Shulman, 1987), it is important to consider the differences between experts and novices when it comes to a particular subject. Experts tend to recognize meaningful patterns as they bolster their general knowledge base. Experts tend to relate cause, effect, and downstream implication at a faster rate than ordinary learners. Experts organize knowledge by context so that it is not only applicable but also easily retrievable (Bransford, Brown & Cocking, 2000). This does not necessarily mean that experts will be terrific instructors. Experts still need to utilize pedagogical content knowledge to effectively teach a subject. Putting forth information to novices in an expert manner is not always conducive to learning.

Transfer of Knowledge

Expert instructors with pedagogical content knowledge, like expert physicists or expert chess players, have allowed their cognition to understand what they do and do not know. Even if the process takes longer – especially due to metacognitive processes taking place – experts will eventually allow information to become part of the bigger picture. Expert teachers understand not only their target audience, but they also understand how those students tend to organize information. Once the organizational patterning process has come to fruition, the expert teacher will thus instill in her students the ability to configure information for later recall and application. As mentioned earlier, metacognition is critical for learning as well as active participation. Instructors should strive to put forth information and scenarios that serve as application outlets so that students learn how to address the problem while also working towards solving the problem. Students must be taught to analyze competing claims so as to promote their own sense of understanding. While most agree that there are many intervening variables associated with one's abilities to think critically, expert instructors should weave the aforementioned (the basics of thinking critically) into as many lessons and learning opportunities as possible (Bransford, Brown & Cocking, 2000).

Context is the key when it comes to conditioning information – a useful trait most experts possess (Bransford, Brown & Cocking, 2000). The context of application allows experts the ability to categorize certain subsets of information thus facilitating easier recall or applicability in the future. This ease of information usage, along with the requisite experiential learning by the expert, leads to fluency within the topic. Fluency within a subject frees up more of the expert's intellectual capacity to observing other details, causes, effects, and implications (LaBerge & Samuels, 1974; Schneider & Shiffrin, 1985; Anderson, 1981, 1982; Lesgold et al., 1988). Expert teachers allow students to not only acquire a deep knowledge base about a particular subject but these same expert instructors allow students to recognize particular problem types. Problem type recognition promotes a student's ability to confer knowledge about a real-world problem in a meaningful way (Simon, 1980). Students who tend to absorb knowledge while also reflecting metacognitively on what they know and do not know allow for what Hatano and Inagaki (1986) refer to as “adaptive expertise” (see next paragraph) – the ability to continue learning no matter how long a particular subject has been studied by any particular individual. Once an instructor has enabled her students to connect with the notion of the absence of a final draft, that instructor has essentially allowed for the continued exploration of knowledge - an esoteric element of one’s teaching repertoire, but an important element nonetheless.

Adaptive Expertise

One way to facilitate student growth and lifelong learning is for the instructors to be aware of the concept of adaptive expertise ((Bransford, Brown & Cocking, 2000). The concept of adaptive expertise is important because it enables the confluence of flexible problem solving to overlap with metacognition. This allows for experts within a field to ascertain whether the problem as presented is the best way to define the question. Miller (1978) presented adaptive expertise in terms of the differences between an “artisan” and a “virtuoso.” An “artisan” enjoys applying his or her tool set to requests put forth – thus allowing for tried and true problem solving methods to be put forth in an efficient manner. The “virtuoso” sees new problems as an opportunity to explore new and creative solutions. Hatano and Inagaki (1986) addressed adaptive expertise in terms of approaching a problem with flexibility thus avoiding the constraints of previous attempts that failed. They found that incorporating a metacognitive element into one’s approach to problem solving is important because an expert essentially knows that he or she does not know it – thus a continuation of exploration of the subject ensues and the learner adapts to perceived deficiencies. The model that Hatano and Inagaki used was the difference between a sushi chef that used a step-by-step recipe for preparing sushi as opposed to another sushi chef that often times will prepare sushi creatively – adhering to limitations in ingredients or the special requests put forth by customers. Similar studies have been performed on history teachers (Wineburg, 1998) whereby the metacognitive element was allowed to flourish as experts of non-historical subject matter eventually knew that they did not know enough and continued to research a subject. These experts in history – although not within the explicit field put forth in a particular seminar – eventually figured out that their conclusions were not based on grounded historical theory and continued their exploration of a subject. Once students understand that there is no end to the subject matter, then they will be reluctant to entitle themselves as experts who know all the answers. It is impossible to know all the answers and instructors should make that principle clear to their students.

The contextualization of information is another important element of knowledge transfer. Certain individuals may assimilate information within one context and even become experts in the field but be unable to apply various concepts towards other scenarios. In other words, such experts fail to be adaptive. For example, one may excel at calculus and yet be unable to take principles of calculus and apply that information to physics problems. That said, it is incumbent upon teachers of all disciplines to show the interconnectedness of information. It should also be regarded as fundamental that instructors teach a concept using multiple contexts. These multiple contexts allow students the opportunity to analyze many subtypes of a subject, so as to allow the student an opportunity to practice model synthesis and application. Students should be allowed to form “flexible representations of the knowledge,” so as to promote the transfer of a student’s knowledge base onto any one of a number of problems or scenarios (Gick & Holyoak, 1983).

How can instructors facilitate the knowledge transfer within their students? Instructors must enhance their teaching repertoire by knowing how and when to use different cognitive representation strategies. Instructors must allow their students an opportunity to observe and process different subjects within the same class (Bassok & Olseth, 1995). Schemata are postulated as guides to complex thinking, which eventually lead to better memory retrieval and eventual knowledge transfer (National Research Council, 1994, p. 43).

The transfer of information does not have a singular form or format. The process in and of itself is regarded as a dynamic process. The active view of information transfer has a very different mindset and approach than static views of information transfer. Instructors are to evaluate strategies based on learner’s abilities to solve problems. It is the learner’s abilities to solve problems that many instructors regard as the adequate transfer of information from to instructor to student (Bransford & Schwartz, 1999; Brown, Bransford, Ferrara, & Campione, 1983; Bruer, 1993).

Current research suggests that students stay interested and motivated to learn when they are contributing (Bransford, Brown, & Cocking, 2000). Students tend to stay interested in a subject if they feel there are strong social consequences for their actions within the learning environment. To wit, are they able to contribute meaningfully to the class while helping their fellow students. It also warrants mention that some students are “learning oriented” while other students are “performance oriented.” Students who are categorically “performance oriented” may become discouraged by the abstract especially if they are assessed poorly within the constructs of the assessment. “Learning oriented” students may be less affected by a poor grade while staying on task vis-à-vis the scope and sequence of the lesson.

Active Learning

Active learning promotes students’ interest and keeps their motivation high. Active learning includes that students make their own learning visible by reflecting on how they processed the information and metacognition – a student’s ability to assess themselves in terms of their own learning. Allen and Tanner (2005) describe active learning as “seeking new information, organizing it in a way that is meaningful, and having the chance to explain it to others.” Students typically cannot understand a concept until they do something with that concept. Active learning dovetails into constructivist learning theory as students learn by doing. Furthermore, students should be allowed to think out loud while discussing subjects and they should be allowed to ascertain their own abilities in terms of their own strengths and weaknesses.

One tactic that is associated with active learning is referred to as reciprocal teaching. Reciprocal teaching is a procedural facilitation for instruction that that leads to metacognition which in turn leads to reflection, assessment, elaboration, and creativity. Students need to know what they did and why (White and Frederickson, 1998). The transfer of one's knowledge must be built upon preexisting knowledge. That preexisting knowledge though has many moving parts that educators must be aware of, including, but not limited to: one's culture, one's experiences, one's previous knowledge base, and one's misconceptions about a subject.

Social psychologists and educators believed for many years that children were blank slates – the term *tabula rasa* was used early and often to describe the mental status of a young learner. Recent research has shown that children are far from blank. From Piaget's work through the most recent findings, the corpus of literature regarding early childhood development grows. Children are active learners who gradually develop cognitive strategies as they encounter "environmental stimulation." As Vygotsky (1978) postulated in his now famous work, children's abilities to assimilate and process information is associated with social environments and culture as a mode of influencing development of the mind – commonly referred to as *the zone of proximal development* (Vygotsky, 1978). Vygotsky's work showed interactions between and among many influences on the young learner including formal and informal pedagogical contexts.

While Vygotsky and Piaget laid the foundation for a paradigm shift in our understanding of early childhood behavior, many modern theorists researched the learning and cognitive abilities of the early childhood learner. New theories emerged within the field of early childhood development that allowed information to be assigned to the subject in terms of parental interactions and the early predispositions of the learners themselves (Newman, D., P. Griffin, and M. Cole., 1989; Moll & Whitmore, 1993; Rogoff & Wertsch, 1984; Bidell & Fischer, 1997). These studies have been refined for studying early infant memory development using bodily actions, such as leg kicking and arm movements, for determining object recognition (Rovee-Collier, 1989). Since the late 1980s, it has become a well-established principle that children do perceive stimuli and that deduction opened up a whole new world of experimental questions for researchers. And the answers to those questions *do* augment as well as mold and shape the models and theories that carry over to how all people process information (Bransford, Brown & Cocking, 2000).

Young children do have a baseline level of knowledge regarding physical interactions and they often will need a physical demonstration to apply what they already know. For instance, children have shown the ability to distinguish between animate and inanimate objects (Massey & Gelman, 1988). Children have also shown the ability to distinguish between numerical representations (Wynn, 1992). Children acquire language based on social and situational contexts and that children can improve their memory by such means as rehearsal, elaboration, and summarization. Miller (1956) showed that a students' ability to engage in information clustering is also beneficial in augmenting one's memory. These principles for improving memory have been demonstrated in children yet they are still applicable to all learners. All learners, regardless of age, need to notice categories when information is being presented to them. One's own abilities to learn and process information – which can be strengthened by many of the aforementioned techniques – must ultimately be subjected to metacognitive techniques within the learner. It is important that learners be allowed to assess their own strengths and weaknesses while instructors should promote the elucidation of categorization techniques.

Discussion based teaching is one way to integrate ongoing assessments within the instruction itself. An ideal learning environment, therefore, is one that includes ongoing assessments and actively engaging the students in their learning process. What are the other elements an instructor should consider implementing in her instruction? The *How People Learn* framework discussed in the following section answers to this question.

How People Learn **Framework**

Bransford, Brown, & Cocking (2000) advocated that an ideal learning environment should be synthesized and assessed in terms of to what extent they are student-centered, knowledge-centered, assessment-centered, and community-centered (Figure 2). To promote learning-centered environments, instructors must allow students to engage in a learning task while being cognizant of the prevailing mindsets students have towards a subject. As mentioned earlier, all instructors must see students for who they are – and not as mere extensions of themselves. Instructors must bridge the subject matter to student understanding while monitoring both sides of the equation or the bridge in the aforementioned metaphor. Instructors must recognize student interests and passions and simultaneously try to ascertain what the student already knows, what they can do and what their inherent interests are.

Figure 2. How People Learn Framework (Bransford et al., 2000)

Knowledge-centered learning environments help students make sense of the material (Bransford, Brown & Cocking, 2000). To facilitate sense making, the material must be organized in a meaningful way. That is to say, the material must be presented in a manner consistent with hierarchical organization patterns. The students need to be shown how to extract patterns within the material and later they must be able to synthesize and elucidate these patterns of information on their own. Objectives must be connected as part of the larger learning landscape and the students must be led through the landscape. Students should also be able to make their learning visible. Teachers should relegate themselves as facilitators – thus backing off a bit and putting students center stage as they make visible their organizational constructs. The scope and sequence of the material must also be made visible to the students. Students need to understand why they are studying this subject and how the teacher intends to approach the subject. A teacher should have a roadmap and teachers should also make that roadmap available to her students. Ideas and concepts that are introduced by instructors work more effectively if students see a need for the usage of the material. Instructors must make learning relevant at the time of instruction. Statements such as, “you will need this material in the future” are contrary to the collective effectiveness of the pedagogical approach. Skill sets need to be developed and knowledge needs to be imparted but students must also understand why they are studying a particular unit.

Assessments provide instances whereby metacognition is applied to one’s own learning and development (Bransford, Brown & Cocking, 2000). Assessments are typically categorized as either a summative assessment or a formative assessment. Summative assessments are end of unit exams, chapter tests, etc. Formative assessments represent a more instantaneous feedback system whereby students keep journals, create portfolios and receive feedback from the instructor. The teaching community is often guilty of diagnosing a student’s inabilities or cognitive shortfall without the introduction of a cure as the medical metaphor unfolds. Allowing someone to see that their answer is wrong is one component of the process. Making sure that true learning has taken place means that instructors go beyond the red ink of an answer being marked as incorrect. Instructors must allow students the opportunity to assess themselves and offer alternative explanations while the instructor acts as facilitator of the process.

Community-centered learning environments allow for learners to receive information and feedback from educators outside of the school (Bransford, Brown & Cocking, 2000). Parents and grandparents make for excellent sources of non-school education because they know the child. They know what the child likes and dislikes and they know of the child's experiences. Programs like 4-H and The Boy and Girl Scouts of America allow for instruction in a non-traditional setting. Most educators would agree that there are many curricula associated with a learner's academic endeavor – some are explicit and other curricula are more subtle if not altogether hidden. The totality of these curricular effects and the totality of different learning environments add to the overall educational experience of the learner and no component of the process should be devalued. Community-centered approaches allow parents and instructors an opportunity to create a nexus between the school and the home.

Instructors must allow all four components of the learning environment to overlap because the interconnectedness of the four is a powerful synergy – a synergy whereby students are allowed to learn, analyze and see the relevance of the material. Instructors need to design curricula and episodic assessments that are not always summative. Formative assessments should be incorporated into the curriculum as well to make sure students are connecting the dots in a meaningful way. After all, students need to be aware of what subject they are studying and be shown how that subject relates to their communities and the world they live in.

Different disciplines are organized in different ways such that various approaches within these disciplines must be varied. An instructor must be in tune with the content of a subject, the pedagogical techniques that best convey the material and she must be aware of the student mind that is interpreting the information put forth.

When experts and novices intersect in a classroom as teacher and student, there exist the inherent possibility that a communication divide will derail and potentially undermine the entire learning experience. The communication gap may compromise the abilities of both groups thus interfering with the student's abilities to comprehend and the instructor's abilities to convey. Expert teachers have an understanding of the subject and are able to connect with their students thus creating a road map for students to follow. This road map allows for continued assessment – both formative and summative – reflection, metacognition, group discussion and continued analysis of various problems. Students should have inherently, or, be given questions that ultimately allow them to develop the cognitive abilities to solve or shed light upon that question as part of a larger effort. Expert instructors focus on conveying principles that help students ultimately solve problems. Knowing information is one thing. Being able to categorize, analyze and interpret the implications associated with that information is something altogether different. Students should be made to see the difference between extracting information from a slide or textbook page and the application of information that ultimately leads to a defense of the applied information within a real world framework (Bransford, Brown & Cocking, 2000).

Expert teachers try to promote sense making. Of course, information being conveyed to students is part and parcel of the process but students should be charged with constructing their own knowledge. Teachers can help facilitate this process by making learning visible, asking students to defend certain positions, etc. Students need to be more than passive spectators. Students need to be actively engaged so as to help facilitate their own knowledge building – another fundamental component of constructivist epistemology. Perhaps an easier way to absorb the preceding message is to reflect on a statement heard by instructors all over the planet - especially at the collegiate level. How many times have students remarked with a fair degree of scorn and contempt, “I had to teach myself all of the material in that class. The instructor was so bad, I had to teach myself!!” While most would agree that the statement is intended to be a ringing indictment of that instructor’s ability to teach, it really is quite a powerful statement. Learners, regardless of age or subject, essentially synthesize their own knowledge about every subject (Bransford, Brown & Cocking, 2000). How did one learn to tie his or her shoes? Someone probably showed them how but that knowledge was eventually constructed by that student. In constructivism, teaching one’s self any subject is axiomatic – perhaps not consciously, but nonetheless axiomatic. Furthermore, it is imperative that students be made to understand that learning constructs are ultimately their responsibility.

A common myth about teachers is that if a teacher is good at teaching one subject, she will be equally competent at teaching other subjects as well. Many times, this simply is not the case. And while certain aspects associated with communication may carry over from one classroom to the next, the specific subject knowledge is probably not there which means that the teacher has not been afforded the opportunity to comprehend and organize the principle of that subject. This lack of organization will manifest itself in that instructor's inability to transmit information about the subject in question. What one knows – one's ability to create and convey patterns within a certain discipline – affects what one teaches and the way that they teach it (Bransford, Brown & Cocking, 2000). Expert instructors convey information while also being acutely aware that students should be able to ascertain if a model is reasonable or not. Students must be permitted the opportunity to think critically about a subject far, far away from the mindless chatter of straight forward, didactic, teacher-centered instruction. The instructor should be the sage on the stage as well as the guide on the side.

To help promote student knowledge construction, teachers should put forth models that allow student exposure to many concepts in a short period of time. These models promote student interaction as well as allowing students to see a concept or principle as a physical manifestation. Talking about a ball rolling an incline plane is perhaps acceptable as introduction to a subject. Allowing students to hypothesize, test and later analyze data with an actual incline plane model within the confines of the learning environment is something very different and much more effective. Modeling practices should be incorporated into the curriculum at every age and for every subject (Clement, 1989; Hestenes, 1992; Lehrer & Romberg, 1996; Schauble, Glaser, Duschel, Schulze & John, 1995). Furthermore, time on task matters and deliberate practice facilitates assessment. For instance, think of songs people can sing on demand without fail, word for word. Did people actually sit down and try to learn the "Star Spangled Banner"?? Most people would intuitively suggest that they learned the song because they heard it enough times that it went from short-term memory in the temporal lobe to long-term memory in other areas of the brain. Teachers should understand that their students are novices and novices struggle with describing the nature of problems found within a subject or discipline. Effective instructors understand that their students cannot answer a question when they cannot accurately convey just what exactly the question is (Bransford, Brown & Cocking, 2000). The organization of knowledge is something that instructors can help facilitate to their students. Expert teachers know that understanding and comprehension supersedes memorization and they approach their subject accordingly.

Part II: Evidence Based Pedagogies in Post-Secondary and in College Level Biology

In this section I discuss evidence based pedagogies pertaining to post-secondary level and biology education. Current research into biology coursework at the college-level has focused on many factors directly and indirectly associated with promoting student achievement, advancements of minority students within STEM programs and active learning for majors and for non-majors biology students. Various programs and interventions have been implemented, studied, and analyzed in an attempt to further elucidate course structures and instructor components that will enhance a biology student's abilities to answer questions and solve problems as well as accentuating student achievement. Science education, like almost all subsets of the educational realm, is often times complicated in terms of just what exactly constitutes a "valuable" program or effective learning or teaching strategy. This complicatedness is derived from these subjects, questions, and studies having many moving parts and the introduction of potentially intervening variables into the studies being analyzed.

Science instructors at institutions of higher learning have often times been concerned with whether large classrooms are too impersonal – thus limiting an instructor's ability to interact with students and to ascertain student reactions to questions and various assessments. As a corollary, science instructors in large college classrooms have also wondered whether the number of students in a classroom inhibit the degree to which student learning is facilitated within these large science classrooms. Smaller class size at the collegiate level allows instructors to engage in more active learning exercises as well. These smaller class sizes also allow instructors to facilitate a more analytical classroom environment that enables students to assess, understand, and ultimately solve real-world problems. Litke (1995), Cuseo (2004), and Williams, Cook, Quinn, & Jensen (1985) reported that the size of the class can affect student perceptions of the science course content. But this study and previous research by the researchers listed above also shows that the quality of instruction within in the classroom – whether the classroom is large or small – may affect student achievement and perceptions more so than the size of the class or type of active learning instrument utilized. Goodman (2005) also analyzed parameters associated with two important research questions: (1) Do active learning activities in smaller settings enhance student learning more so than in larger classroom settings? and (2) Are students more satisfied with an educational experience within a smaller classroom than they would be within a larger and less personable lecture setting? And while Goodman et al. (2005) found there was no statistically significant difference between the pretest and posttest scores among the control (larger class size) and research group (small class size), there was, however, and increase in the mean score of the overall course grade observed within the experimental group. Satisfaction survey results show that the number of students in the experimental group was appropriate and aided learning of the scientific method. Persky and Pollack (2010) found smaller class size at the collegiate level allows instructors to engage in more active learning exercises. These smaller class sizes also allow instructors to facilitate a more analytical classroom environment that enables students to assess, understand, and ultimately solve real-world problems. The issue with smaller class sizes is that economic constraints often times preclude universities and colleges from implementation even though professional and academic communities are responsible to adequately qualifying today's graduates. Therein lay the inherent issue. How can departments and programs turn large classes with traditional lecture-based formats into cooperative and active-learning classrooms that promote creativity and long-term retention of essential information? These are issues that must be addressed by science instructors at the college-level in the future.

Science, technology, engineering, and mathematics (STEM) instructors have been challenged to increase student enrollment and retention within STEM programs at the university-level. STEM instructors are concurrently saddled with the task of increasing STEM enrolments for the minority and socioeconomically disadvantaged students (SDS). Haak, Freeman, HilleRisLambers & Pitre, E. (2011) analyzed an experimental group that was subjected to an intensive practice via active learning environment in a university-level biology class in an attempt to mitigate the existing achievement gap found between students of differing socioeconomic status as well as underrepresented minorities. Structured environments via active learning include pre-class reading, in-class questions followed by student answering and frequent (weekly) assessments. Two quarters of low structure were compared to two quarters of mild and highly structured environments in Biology 180 at The University of Washington. All sections were taught by the same instructor. Students in Washington's Educational Opportunity Program (EOP) – a program that has mostly low SES and minority students – were compared to non-EOP students with predicted-actual grades and grade point average achievement gap being the dependent measures. High structured biology classes diminished the difference between predicted and actual student performance in both EOP and non-EOP groups with a more significant decrease in the EOP group. Furthermore, the achievement gap is halved between EOP and non-EOP groups when comparing low structured treatment to the highly structured course treatment. These data help to solidify previous research at the collegiate and K-12 levels that shows highly structured active learning environments can decrease achievement gaps without significant increases in costs. Active learning was shown to promote student interaction and the consideration of other points of view. These data and implications help to solidify the need for implementation of constructivist models for teaching *and* learning.

Furthermore, many factors play a role in the achievement of college students enrolled in science classes – including prior knowledge, study habits, and confidence as well as models of formative assessment. And while the results and implications of previous research on continuous assessment are not conclusive, many studies have shown that assessment models that promote higher rather than lower numbers of assessments are extremely beneficial to the students in the short and long term.

Increasing levels of research have been enacted to try to understand the recent trends associated with university-level students taking part in gateway science, technology, engineering, and mathematics courses (STEM). Many researchers are particularly interested in the notion that data from the American College Testing (ACT) shows that 49% of high school students in 2005 were not ready for college-level reading. Freeman, Haak, and Wenderoth (2011) found that fewer students failed a three-term gateway course as the failure rates dipped from 18.3% in the low structure to 6.3% in the high structured course. This research helps to elucidate that students who are underprepared but still capable do benefit from high structured courses that have more group discussions and promote greater class participation. These students benefit in a myriad of ways but ultimately, there was a lower failure rate which means more students stay in STEM programs as well as mitigating the unintended consequences linked to student failure.

Many education researchers including Vygotsky (1978) have remarked on the nexuses between academic achievement, motivation, and student confidence levels. A student's motivation has many moving parts and many intervening variables. It is possible however, to create and analyze correlations between student motivation and attendance. Attendance promotes time-on-task and repetition – both of which are key fundamental cogs in the wheel of human cognition. Ergo, regardless of whether student motivation comes from achievement or vice versa the message that motivation, confidence and achievement are inextricably linked remains the same. These feelings of competence and belief in their potential to solve new problems are derived from first-hand experience of the mastery of problems. Student achievement and a sense of self-accomplishment are much more powerful than any external acknowledgment and motivation (Prawat & Floden, 1994). Moore et al. (2008) demonstrated a link, albeit non-statistically verified or derived, between one's grades, attendance and ultimately, time-on-task. As time-on-task is up regulated or enhanced, the student's probability of making a letter grade of "A" went up and the probability of making a letter grade of "D" or "F" went down. And while the author astutely points out that this study has certain limitations (previous educational experiences and socioeconomic status matter, etc.), the author does present a marked, positive correlation between attendance and student achievement.

Many students at the collegiate level, especially students that are not science majors, often times find the concept of evolution difficult to comprehend for a variety of reasons (West, El Mouden, & Gardner, 2011). Pedagogical models and intervention strategies that promote transformative experiences have been implicated in enhancing student conceptual understanding of biological evolution and the fostering of positive academic emotions within students. Heddy & Sinatra (2013) used the Transformative Experience Survey (TES) to collect data regarding the extent of the student's transformative experience. Researchers also used the Evolutionary Reasoning Scale (ERS) to assess concept comprehension. Finally, researchers implemented an Evolution Emotions Survey (EES) that explored student perception of and emotions associated with the subject of biological evolution. The researchers found that there was a higher level of transformative experience found within the treatment group when compared to the control group. Significantly greater levels of conceptual understanding were detected post-analysis of the ERS. The EES showed that the treatment group had a significant impact on student emotions specifically within the realms of “enjoyment” and “pride.” These data corroborate previous findings (Pugh, 2002) that student transformative experiences promote more academically positive emotions as well as greater conceptual understanding for students studying biological evolution. Furthermore, long-term implications of student transformative experiences include greater retention of students within collegiate STEM programs.

STEM Education – The Need for Change

Institutions of higher education need to be mindful of trends found within STEM education in the United States. There is a growing concern that the United States will not be able to meet demands for STEM graduates as the globalization and technological advancement progress. The shortcomings of STEM education have received a lot of attention and have been the focus of several governmental agencies (Koch, 2013). For instance, a committee convened by The National Academy of Sciences (2007) noted:

> *“The United States still leads the world in many areas of science and technology, and it continues to increase spending and output. But our share of world output is declining, largely because other nations are increasing production faster than we are….The biggest concern is that our competitive advantage, our success in global markets, our economic*

growth, and our standard of living all depend on maintaining a leading position in science, technology, and innovation. As that lead shrinks, we risk losing the advantages on which our economy depends. (p.218).”

Another governmental report from The Office of the Director of National Intelligence (2011) stated:

“The engines of our country – innovation, economic competitiveness, national security, and a strong and agile military – are dependent on the application of STEM; the last 50 years have seen more advancement in STEM-related fields than in any other period in history. Yet the U.S. is falling behind. (p. 3)”

These STEM education concerns are magnified as a report put forth by The President’s Council of Advisors on Science and Technology (PCAST, 2012) has noted that the need for STEM graduates not only in the United States but worldwide as well will only increase in the upcoming years (Tyson, Lee, Borman & Hanson, 2007). Concerns are heightened as the United States has seen an increase in the number of bachelor degrees awarded in general, yet an overall decrease in the number of STEM degrees (Green, 1989; PCAST, 2012). Lang (2008) found that students who change their major from biology to another major typically do so in the first two years. Lang cited in her dissertation that dissatisfaction with the course, faculty and peers were the main reasons for the change in major at the University of Texas. She also notes that being African-American or Latino and females change majors out of biology at greater rates.

To address the aforementioned concerns, institutions of higher learning must continue to try new educational strategies and continually assess not only the effectiveness of those strategies but remain attentive to student perceptions of how STEM subjects are taught. STEM instructors need to me mindful that engaging their students is one potential method to connect with STEM students early in the undergraduate tenures and that these methods are also inextricably linked to constructivist epistemology. These connections can be facilitated by a variety of methods including *continuous assessment, the Socratic Method, interactive discourse and smaller class size.*

STEM education is not unlike many forms of education in that it must continually assess and evaluate the methods used within the field. Traditional methods of science education have focused on teacher-centered learning environments with students sitting passively by. Students may perhaps take notes or occasionally ask a question within these conventional science classroom formats. But these strategies are not interactive. Conventional straight forward, didactic modes of information dissemination fall short of allowing students to feel engaged within the process of education. These teacher-centered modes of science education must be questioned as innovative and more learner-centered classroom and lab strategies embrace new technology and the advancement of fundamental elements associated with the development of student cognition.

So why is there now a need for the change in science education formats and a restructuring of goals associated with science education? STEM educators and those who evaluate science educators have become increasingly concerned that traditional tactics focus on lecturing facts that simply promotes the memorization of facts. The memorization of facts has led to widespread speculation that student motivation may be affected as student perceive a disconnect between random facts and the application of the material (Burrowes, 2003). Analyses of science traditional science education found that there were serious repercussions associated with a lecturer-centered session whereby professors simply regurgitated parts of textbooks or read from slides and so on. Students then had difficulty applying information because it appeared as if the steady stream of facts had no real purpose – students struggled to apply the knowledge they had gained (Adams & Slater, 1998; Anderson, 1997; Rice, 1996; Yager, 1991).

To counteract the traditional methods of science teaching thus sending science education in a different direction, Lord (1998) decided that a new approach to STEM education should be ushered in and subsequently examined. Lord used constructivist teaching methods to alleviate limitations connected with traditional science teaching methodologies, such as a lack of student engagement and the inability to apply concepts. Lord incorporated active teaching via constructivism to promote higher order thinking skills. Student-centered methodologies proved to be effective as they were applied to general biology and environmental science courses at the Indiana University of Pennsylvania (Lord, 1997, 1998, 1999). Other researchers showed that for the students to think scientifically, they must participate in the science process – another variant of the student-centered methodology (Marbach-Ad & Claassen, 2001). Other researchers took the theoretical model put forth by Lord to develop higher thinking skills and a modification of student attitudes towards the life science. For instance, Burrowes (2003) substantiated that constructivist, student-centered learning environments promoted positive attitudes towards science while simultaneously enhancing higher level thinking skills.

Role of Small Class Size, Interactive Discourse, Socratic Method, and Continuous Assessment

Science education should promote critical thinking. Science educators need to embrace the notion that individual fields within the realm of science are all interconnected. Chemistry is inextricably linked with physics, which is inextricably linked with biology, and so on. Students must be steered away from passive note taking and allowed time to struggle with the organization of information to be later used for scientific inquiry while also understanding the interconnectedness of all science fields (Bimbacher, 1999). Learners should be created instead of passive non-participants (Faust & Paulson, 1998).

As previously stated, science instructors at the college-level have often times been concerned with whether large classrooms create disconnect between student and instructor.

Seminal studies from Litke (1995), Cuseo (2004), and Williams et al. and Cook at al. (1985) have all published studies that demonstrate the size of the class can affect student perceptions of the science course content. Goodman, Koster & Redinius, (2005) have also shown that the quality of instruction within in the classroom – whether the classroom is large or small – may affect student achievement and perceptions more so than the size of the class or type of active learning instrument utilized. Smaller class size at the collegiate level allows instructors to engage in more active learning exercises. These smaller class sizes also allow instructors to facilitate a more analytical classroom environment that enables students to assess, understand, and ultimately solve real-world problems. Persky & Pollack (2010) found that large, lecture-based classrooms could be transformed into smaller groups with fewer cohorts using eBooks and visual models for pre-class transmission of basic knowledge. These researchers also found that survey data showed that students preferred smaller class sizes and the eBook format. Students also felt there was an increase in the quality of instruction within the smaller-class format. These studies help to elucidate the need for science educators to try new and innovative strategies to promote student engagement and ultimately allows for critical thinking.

Another way in which science educators can keep their students engaged is by using continuous assessment. Myers & Myers (2007) have demonstrated that continuous assessment has many benefits for students taking STEM classes at the university-level. Continuous assessment promotes student-centered learning models, which allow students the opportunity to attain feedback from instructors, as well as learn from their mistakes on early assessments. Tang (2010) astutely pointed out that continuous assessment and interactive discourse allows science educators the opportunity to better synthesize and implement instructional scaffolds. Tang also points out that continuous interaction within a classroom allows the students to refine their argumentation skills. Continuous assessment studies such as this one also provide evidence that instructors, as well as students, are able to make adjustments based on student feedback as the semester progresses. Continuous assessment, active learning, Socratic teaching methods and other student-centered modes of education must be implemented and evaluated as new research is published. Researchers and science educators should strive to work together as science education transitions out of constraints associated with conventional science teaching methods.

Another way to promote critical thinking within science education is use of the Socratic teaching methods. Initially, an instructor will validate student responses. But as students become more familiar with an instructor's Socratic teaching methods, students tend to understand what is expected of them as these questions are asked. It is at this point that a skilled instructor adept at incorporating Socratic teaching methods can narrow the student's focus to more linear thought processing which promotes independent student thought in and outside of the classroom (Malacinski, 2003). And while some contend that instructor questioning limits the participation of much of the class, many instructors combine the Socratic teaching method with active learning strategies. When science instructors combine the use of thought-provoking questions used in conjunction with active learning components such as one-minute reflection papers then students become active learners instead of passive non-participants (Faust & Paulson, 1998). York (2010) showed statistical significance when Socratic method and inquiry were applied to nursing school learning modules. Croasmun (2010) that the Socratic method is helping adult learners assimilate to science education by enhancing the learners self-directedness, self-efficacy and the learner's autonomy.

There are certain components of the Socratic method that instructors should be aware of prior to implementation. First, student's prior knowledge and familiarity with the Socratic method can play a substantial role in the effectiveness of the method. Second, Instructors must also be aware that they will have to relinquish some control of the classroom. And lastly, many instructors are simply not trained in the administering of the Socratic method and as a result, the benefits of Socratic inquiry are diminished or non-existent (York, 2010). There are however, continued efforts to allow college instructors to understand that new and seldom-used techniques in science education can be used effectively if the instructors understand the basics of pedagogy as well as allowing instructors to receive the training they need to be effective. Novel approached demand more of students but that is a fundamental component of the transition away from traditional science teaching practice. This was the essential message found at a teaching and learning conference held at Harvard in 2012. Science education should be dynamic and not be about information that students lose three weeks after an exam is given. Science must engage students and students should be expected to explain concepts (Berrett, 2012). The Socratic method is an excellent technique if the instructor is trained properly and is willing to let go some classroom control.

CHAPTER III

METHODS

This study is a mixed methods design (Creswell, 2014; Johnson & Christensen, 2014). Creswell (2014) pointed out that the three approaches -- quantitative, qualitative, and mixed methods-- are not indeed discrete. Neither the quantitative and qualitative approaches should be “viewed as rigid, distinct categories, polar opposite or dichotomies” (Creswell, 2014, p. 3). It is recommended that quantitative and qualitative approaches represent two ends of a continuum. In this continuum, a mixed methods approach is located somewhere in the middle (Johnson & Christensen, 2014). The premise is that a mixed methods design includes the elements of quantitative and qualitative research and it most effectively utilizes the tools and applications of both approaches. A mixed methods researcher adopts a pragmatist worldview in order not to be committed to any one system of philosophy and reality. Pragmatists do not see the world as an absolute unity (Creswell, 2014,). Truth is not based in a duality between the reality independent of the mind or within the mind. Instead, it is what works best at the given time. This flexibility allows a mixed methods researcher to use the elements of quantitative and qualitative research approaches at the same time and ask questions that include both “how” and “what.” In other words, a mixed methods researcher can study both a causal relationship and the naturalistic setting (Denzin & Lincoln, 2012) of the context under investigation.

Research Questions

The main research question posed in this study is: “What are the unique characteristics of Dr. X’s biology classes and what impact do they have on students’ learning outcomes and experiences?”

The sub-questions that guided the investigations in this study are stated as:

1) What does Dr. X’s biology class look like? What is the nature of Dr. X’s biology class?

2) What are the students’ perceptions of Dr. X’s biology class?

3) What are the students’ experiences with Dr. X’s biology class?

4) What are the differences between student grades in Dr. X’s Biology 111/112 class when compared to traditional biology classes in the same department?

5) What impact has Dr. X’s teaching had on students’ academic achievement over three years?

The sub-questions one, two, and three are answered with qualitative research methods. To answer the first three questions, I collected data in naturalistic setting (Denzin & Lincoln, 2012). The sub-questions four and five are answered with quantitative research methods. For the last two questions, I analyzed the data to explore the causal relationships between students’ academic achievement captured through final course grades and the type of undergraduate science courses students were enrolled in (Dr. X’s biology classes versus the other professors’ classes).

Dr. X’s approach to teaching two lower level biology courses (Biology 111 and Biology 112) is considerably different from the other professors’ approaches in the same department. One easy-to-capture difference between Dr. X’s classes and the other classes in the same department is that Dr. X’s class size is 85-100 where the other professors’ class sizes range from 300-350.

Overview of the Study Participants

In this study, I explored Dr. X’s biology 111 and biology 112 classes and her teaching approach. Therefore, the primary participants of this study included Dr. X, her students in her classes, and the teaching assistants working with Dr. X. The secondary participants were the students enrolled in other biology courses in the same program with other professors.

Dr. X has taught biology over the 40 years at the college-level. She received her Ph.D. degree in Biology from a Research I institution in the western part of the U.S. Dr. X’s current position is at a Research I university in the southern U.S. and she has worked there for over 37 years. She is currently a full-professor and has mentored over 20 graduate students and 50 undergraduate students. Her duties as a full professor also require her to serve on academic committees as well as the writing and review of scientific research grants.

Dr. X’s class sizes have averaged 90-100 students over the past 5 years. Over the past five years, the female student population has been approximately the same as the male student population (50% and 50%), although there have been a few semesters where the females slightly outnumbered the males (spring of 2014 female enrollment at 59%). Around 90% of the students (89-90) are biology, chemistry, wildlife and fisheries, biomedical science, and kinesiology majors. There are also 9-10% of the students (9-10) enrolled in these classes who are English, philosophy, or sociology majors that are taking the prerequisite classes to apply to medical, dental, or veterinary school. The majority of these students are White with the minority composition not deviating radically from the university. The students who enroll in Dr. X's class are often freshman and sophomores with the occasional junior or senior enrolling to attain pre-professional school requirements.

Each semester Dr. X works with two teaching assistants (TAs) who are assigned to her. Over the past three years, Dr. X has had the same TAs. She often works with the TAs who are also the members of her lab. She advises her TAs and makes sure that her version of laboratory instruction is applied to her lab sessions. The TAs Dr. X has had for the past three years consist of one male US citizen and one female international graduate student.

Students in the other professors' classes have essentially the same composition in terms of sex, race, and major. Their characteristics as students are not different from Dr. X's students' characteristics. The TAs teaching the traditional Biology 111 and 112 labs also do not differ significantly from Dr. X's TAs except that traditional lab TAs are often times not teaching the same lab and format for three years. Traditional lab TAs are often times teaching a lab for one to two semesters and the traditional labs are not as investigative as Dr. X's labs. The professors of traditional labs have almost no weekly interaction with the traditional lab TAs and these professors did not train their TAs in any way. The training of traditional lab TAs is provided by The Lower Division Biology Program at the university and coordinated by the researcher in this study.

Study Design

In this mixed methods study, I assessed and analyzed the impact of non-traditional teaching methods on biology education at the college level. The data collected were attained within three different subsections of the study's design as illustrated in Figure 3. The first two subsections involved qualitative research methods in their design and the third subsection involved a quantitative research model.

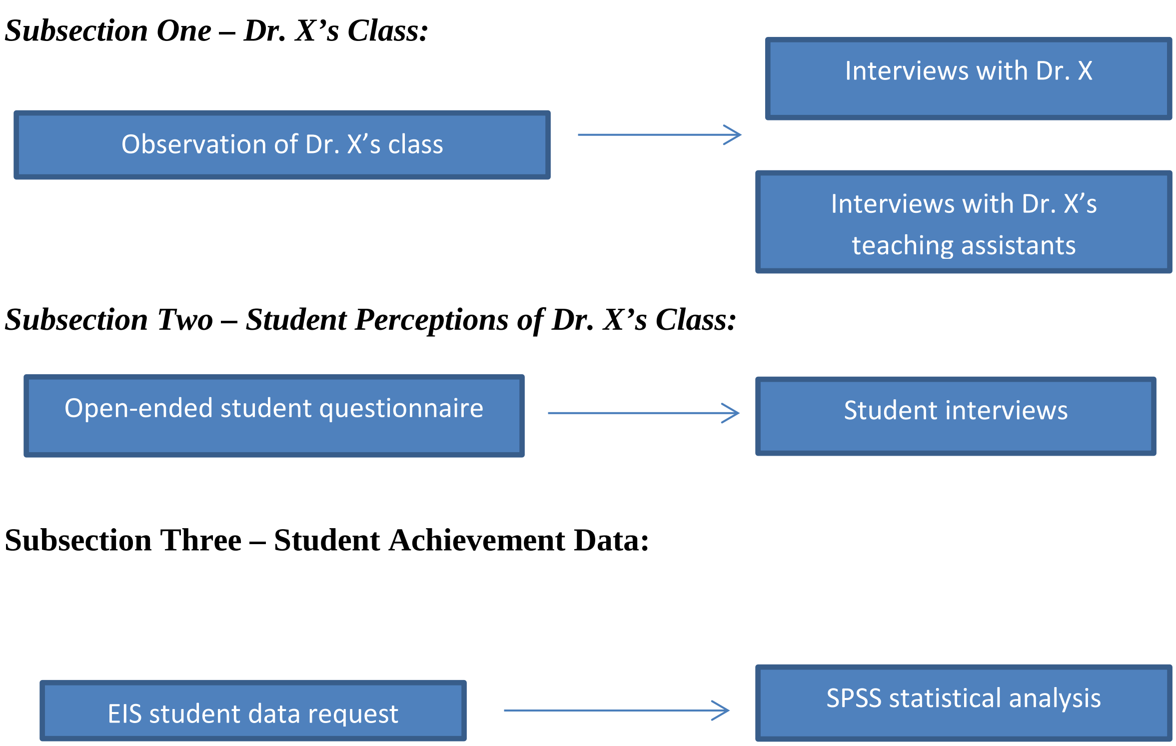

Figure 3. The sub-sections of the study design

Researcher Role

Certain observational components of this study stem from my role as Teaching Coordinator for the program being studied. My role as Teaching Coordinator over the past ten years has allowed me to formally and informally observe the traditional biology teachings of many instructors and Teaching Assistants as well as the teachings of Dr. X. As Teaching Coordinator, I am in charge of 35-50 Teaching Assistants every semester. I coordinate most of the freshman labs which includes oversight of Teaching Assistant performance in their teaching lab as well as their attention to administrative tasks required of them. My role as a participant in this research project is associated directly with my role within the program. I have had considerable interactions with professors and Teaching Assistants who teach freshman biology using a traditional format as well as Dr. X and Dr. X's Teaching Assistants. Some of the observations I report in this study are from my personal experiences within this program prior to the onset of this research project.

Participants Redefined for Each Sub-Section

Subsection One – Dr. X's Class

The participants for this sub-section comprised both of Dr. X's teaching assistants as well as Dr. X herself. Dr. X has had the same two lab TAs conducting labs for her students for the past three years, as previously described.

Subsection Two – Student Perceptions of Dr. X's Class

The participants for this sub-section consisted of 59 students who had taken both Biology 111 and 112 with Dr. X. These students took the full-length questionnaire and 20 of them agreed to participate in a follow-up interview. As described previously, these students were participants in Dr. X's classes and labs for two semesters – taking both Biology 111 and Biology 112 with Dr. X. These students consisted of basically 50% male and 50% females and 95% of these students were freshman and sophomores. They were mostly White and 95% of these students were science majors.

Subsection Three – Student Achievement Data

Data from Dr. X's students were compared to a random selection of students who took Biology 111 and 112 at the same university, but within traditional biology class formats. There have been 100-140 student participants who took the Biology 111 and 112 with professors other than Dr. X. Dr. X's student achievement data were compared and analyzed via SPSS statistical analysis to student achievement data from the traditional Biology 111 and 112 formats.

Data Collection Procedures

Data obtained from this study were in five forms. All participants engaged in this study on a voluntary basis.

1) Open-ended student questionnaire (see Appendix B) were used to solicit student opinions on the general structure and effectiveness of Dr. X's Biol. 111 class and lab as well as an attempt to gauge motivation of students attending Dr. X's class if applicable. I attended the last lecture for Dr. X's Biol. 111 class in the fall of 2012 and

explained the purpose of the study to the students. Then I solicited potential participants by passing out the informed consent forms approved by the Institutional Review Board (IRB) at the university, as well as the questionnaire. An external evaluator collected the questionnaires. Because I was also an instructor in the same program, I waited until the course grades were assigned and then received the questionnaires from the external evaluator. Some of the students, who completed the open-ended questionnaire, were asked to volunteer for an open-ended interview, if additional data were warranted.

2) Open-ended interview (Appendix C) that solicited student opinions on the general structure and effectiveness of Dr. X's Biology course and the student's motivation for attending were utilized. The interview questions were developed based upon the group responses to the initial open-ended questionnaire. The interviewees' responses were recorded via digital audio format. I also took notes at the time of the interviews. The interview recordings were used to compare the notes taken during the interviews and the students' responses in the questionnaires.

3) An Enterprise Information System (EIS) request for class grades was submitted to ascertain final grades given for Biology 111/112 courses, as well as other 200, 300 and 400-level science courses that students took after their time in either Dr. X's or a traditional biology class. The students' demographics and course grades were tabulated in an excel sheet.

4) Open-ended interviews with Dr. X (Appendix D) and both of her teaching assistants (Appendix E) were conducted. The interviewees' responses were recorded via digital audio format, as well as transcribed in hand-written note form. I also took notes at

the time of the interviews. The digital recordings were transcribed verbatim. The transcriptions and the notes taken by the interviewer were analyzed simultaneously.

5) I observed Dr. X's class sessions. During my observations, I was seated at the back of the classroom and took notes on what was observed. Dr. X was informed that I would be attending her class. I was present on over 20 hours of Dr. X's Biology 111 and 112 class sessions and observed classroom behavior of the students and instructional methods used by Dr. X. I kept notes to document the styles of teaching and student reactions to the events that transpired within Dr. X's classes. Notes were analyzed to develop themes that portray Dr. X's instructional methods; the student reactions including in-class participation and the nature of the classroom environment.

Data Organization and Analyses

The interview data and field notes were analyzed using the constant comparative method. I read the written notes several times and generated codes to illustrate the incidents the interviewees explained. The codes were organized into main categories. In the findings section, I report the main themes of these categories and provide quotations from the actual interviews to illustrate these themes.

The quantitative data were analyzed using SPSS. T-tests, ANOVA, and MANCOVA were run to compare the student achievement data between the traditional Biology 111 and 112 formats and Dr. X's format. Students' SAT scores were considered as a covariance to make sure that the experimental group had the same abilities as the control group. The quantitative data collected for this study were organized in a database before the analyses. The longitudinal data consisted of student grades over a 3 year period after completion of Biology 111 and Biology 112 courses. SPSS was used to conduct the various analyses for the study. In Figure 4, the variables included in the database are presented. Students' instructor (Dr. X versus others), students' sex (male versus female), and students' SAT math scores as well as SAT verbal score were the independent variables. Students' course grades in the biology, chemistry, and genetics courses (8 course in total) and the number of times they q-dropped were the dependent variables.

SN	X/O	Sex	SATM	SATV	Biol 111	Biol 112	Biol 213	Biol 214	Biol 351	Chem 227	Chem 228	Gene301 or 302	No. Q Drops (for these 8 classes)

Figure 4. The independent variables used in the analyses.

Key for figure 4:

"SN" = Student Number.
"X/O" – Dr. X is the instructor (1) versus Any instructor other than Dr. X (0).
"Sex" = Male (1) or Female (0).
"SATM" = SAT Math Score (high school).
"SATV" = SAT Verbal Score (high school).
"No. Q Drops" = Number of Times a Student Q-Dropped Any of the Six Classes Listed Beyond Biol. 111 and 112.
Grades for the "Biol 111," "Biol 112," "Biol 213," "Biol 214," "Biol 351," "Chem 227," "Chem 228," "Gene301 or 302": "A" = 4.0 "C" = 2.0 "F" = 0.00 "B" = 3.0 "D" = 1.0
Note: If a student took a class more than once then the grades were averaged and entered only once.

CHAPTER IV

FINDINGS

This section is organized in three parts. In part I, I report the findings from the analyses of my interviews with the course instructor and my notes taken during my classroom observations. I attempt to answer the questions: “What does Dr. X’s biology class look like? “ and “What is the nature of Dr. X’s biology class?” In part II, I discuss the data collected from the students enrolled in the course instructor’s classes based on completed surveys and interviews with the students. In part II, I answer the questions: “What are the students’ perceptions of Dr. X’s biology class?” and “What are the students’ experiences with Dr. X’s biology class?” In Part III, I report the findings of the analysis of the longitudinal student data, including independent and dependent variables over three years. In part III, I answer the research questions: “What are the differences between student grades in Dr. X’s Biology 111/112 class when compared to traditional biology classes in the same department?” and “What impact has Dr. X’s teaching had on students’ academic achievement over three years?”

Part I: Findings from the Interview with the Course Instructor and the Notes Taken During the Class Observation

Traditional Instruction in the Program

Because I have been teaching and mentoring at the program, I have had the chance to observe the traditional, freshman-level biology instructors numerous times. As a researcher participant, I have observed that the traditional 100-level Biology courses at the university generally consist of 200-300 students. Lectures are given in large lecture halls. The lectures are often teacher-centered. The lectures' syllabus is standardized and conveys a teacher-centered, knowledge-oriented curriculum approach towards teaching and learning biology. The lab syllabus is standardized in these large biology sections. The textbooks are focal points as large quantities of information are thrown at students at each lecture. There are no ancillary readings. The typical assessments in these traditional biology courses are in multiple-choice format. The answers to the questions posed in class and in exams have one right answer. All questions in traditional biology lecture assessments are multiple-choice summative assessments given every three to four weeks for a total of four per semester. As a participant researcher, I have observed that the traditional biology lectures are given with PowerPoint slides and very rarely do students ask questions or do the lecturers allot time for student questions. The labs in the traditional biology sections are "cookbook" labs where real science is rarely performed. Traditional biology sections at the university are indicative of large biology classes at many major, research-intensive universities. A major criticism of these traditional science classes is that they do not promote critical thinking and they are not set up to engage students (Armbruster, Patel, Johnson, & Weiss, 2009).

Dr. X's Instruction in the Program

Dr. X's main goal of teaching was to convey problem solving skills to her students. The rote memorization of the knowledge in the field was not an end goal. Therefore, rote memorization was not taught and not assessed.

Dr. X strived to produce scientifically literate citizens who could critically evaluate information, analyze data, and reach reasonable conclusions. Dr. X commented:

> "Right is when one wins. True is when things are elucidated for the way they really are based on evidence. People can tell their version of the truth and be wrong. Right is what succeeds."

According to Dr. X, Biology is central to human existence and essential in preparing students' to become independent thinkers.

Dr. X tries to be interesting, engaging, and inspirational to increase student motivation. Dr X feels that teachers must make the course interesting somehow and then student motivation ensues.

> "The teachers' job is to motivate! To adopt another philosophy is absurd – a copout! "I do not want to be boring. I want to be interesting. I want them (my students) to want to make me proud! I make it clear what it takes to do that."

Dr. X's Background

Dr. X had a high school teacher who ran actual experiments in her high school biology class. In spite of her early struggles, Dr. X was encouraged by her high school instructor to remain in the honors program. Her instructor knew her students well and could see past the typical teenage rebellion and that Dr. X was a scientist in the making. Intelligence can be ascertained relatively quickly and that intelligence should be challenged. Dr. X's biology teacher connected with her students and was therefore able to challenge them to reach their full potential. Dr. X told me at the interview:

> "My freshman (high school) biology teacher (had the greatest impact on me when I was a student). She made us do *real* science... *It was* recommended I leave the honors program (in high school). I got a call from *my instructor* (over the summer) and she recommended that I stay in the honors program – she said I know you can do this. There was somebody who saw past all of the warts and blemishes – and saw that there was an incipient scientist in there."

The Scope and Sequence of Dr. X's Lecture

As a participant researcher, I found out that that Dr. X's desire to teach Biol. 111 and 112 began after engaging in conversations with colleagues. These conversations began with the idea that our students should know more than facts. What Dr. X believed was that the freshman courses were not preparing the students for upper-level biology courses - especially the upper-level course he was teaching. She wanted to allow researchers the opportunity to teach. Students were not prepared for sophomore biology courses and she also found that students in her 400-level biology courses could not write.

As participant researcher I often times observed that one word written by Dr. X in yellow chalk on a green chalkboard and was often followed by a discussion with questions embedded in a story. As participant researcher I observed that Dr. X incorporated elements of physics and chemistry into the biology lecture. I observed lectures about pH with physiological references to Le Chatelier's Principle.

There were no power point presentations when she lectured. The optional textbook was used for reference only.

Dr. X's students are forced to think. Dr. X likes to get people interested by painting broad strokes and allowing student's imagination to fill in some of the specifics. Dr. X is excited about what she teaches and it shows. If one were to see: "When was the last time you thanked Jupiter?" on the board written in yellow chalk, you might wonder just exactly the lecturer is asking. Dr. X urges students to 'read for interest – do not read to study.'

Dr. X asked 4-8 questions every lecture with the intent to make students respond while simultaneously think critically and evaluate their positions scientifically. The questions Dr. X posed contained elements of class readings from books like "The Red Queen" and "The Eighth Day of Creation." Dr. X wanted students to understand big ideas and processes and not get bogged down in factoids. Dr. X noted that, "The facts will drown students out! The ideas and the concepts are important."

Based on my observations, there was much more engagement by Dr. X's students than those taught in more traditional lectures. Dr. X instructed students to remain engaged in class by checking mistakes, thinking of questions, and anticipating outcomes based on scientific history and process. Her students asked many questions and she actually expressed pride when her students caught mistakes. Dr. X made a point to be provocative to keep the topics interesting and students interested.

As participant researcher I noticed that Dr. X asked a lot of questions in class. She wanted to keep students on their toes. She told a story in each class and the end of each story could be interpreted differently from different points. She processed information out loud to provide input and question processes. She promoted student reflection as they synthesized their own ‘conclusions.’

Dr. X believed in interactive discourse because it promoted student engagement and also allowed students to become responsible for their own learning. As participant researcher I observed that Dr. X’s elements of teaching style resembled Socratic Method (Birnbacher, 1999; York, 2010). Dr. X’s students debated and defended positions. Dr. X asked questions which required reflections well after the instructional period ended.

Dr.X understood fully that out of discomfort brought development. She made students question their own preconceived notions. She deconstructed students’ positions while never invalidating their positions. Dr. X rarely invalidated a student’s position though she did lead and clarify through questioning strategies. She also used student responses to lead the discussion in different directions.

As noted in my interviews with Dr. X, Dr. X had very high expectations for her students and she did not compromise her positions even though some people, including her teaching assistants, had characterized her expectations as unrealistic. Dr X believed that “If instructors raise the bar of expectation, students will jump over that bar. Conversely, if instructors lower their expectations, then students will trip over that bar!”

Supplemental Instruction for Dr. X’s Classes

Supplemental instruction (SI) sessions were peer-led review sessions held by Dr. X’s former students to help current students. SI sessions have been held for many classes on campus and were intended to be a more relaxed format through which students can ask questions about challenging material. SI was peer instruction provided by the university. As research participant I noted that Dr. X chose her own SIs (supplemental instructions) based on performance and dedication to being a SI instructor. SI instructors helped with student understanding and provide background information as needed. SI instructors helped students organize and interpret information presented by Dr. X, key concepts in student cognition. Dr. X and the SI modeled for the students how to take a complicated subject and organize it logically and see subtle interconnections.

Assigned Readings

The Eighth Day of Creation was assigned in Dr. X's Biology 111 course. The book illustrated the human element behind scientific endeavors and covered the basics of DNA, protein structure, and gene regulation. The book also highlighted how the physicists were involved fundamental areas of molecular genetics. Dr. X wanted students to gain an understanding of the timeline of scientific research and the modern speed of discovery. Dr. X had his first semester students read *The Way of the Cell* by Franklin Harold understand cellular life. Dr. X remarked:

> "I have them read the "8th Day of Creation" in Biol. 111 so that they will understand that science is done *by* people. It very carefully goes thru important parts of biology. These are important ideas and it shows the synthesis of all of those things. We have learned so much in the last 20 years. There is an enormously fast progression. I want *students* to see that."

Books Dr. X asked the students read in Biology 112 were: *The Red Queen* by Matt Ridley, *The Prisoners Dilemma* by Stephen Chapman, *All Things Most Beautiful* by James Herriot and *The Making of the Fittest* by Sean Carroll. *The Red Queen* was the main book. In keeping with her proactive class topics, Dr. X began Biology 112 with discussing "sex," why it existed, and whether it was inefficient way maintain a species.

Assessment Basics

Dr. X gave one quiz per week (thirteen weekly quizzes total) – ten over his lectures and incorporated readings and three that are over just the readings (Appendix C). Students were given 30 minutes to write their answers. She expected students to build upon previous material and connect concepts logically. A question from a preceding week often led next week's question. This weekly summative approach was intended for students to understand the cumulative nature of biological processes they were discovering each week. These assessment required student complete assigned readings. Dr. X noted "Ten of the thirteen to be able to write—three of the thirteen demonstrate your ability to read."

The Scope and Sequence of Dr. X's Lab - Comparison of LDB versus Dr. X's 111 and 112 Labs

As with all laboratory sections of Biology 111 and 112, Dr. X's laboratory met once per week and constituted the 25% of the overall grade. There was a liberal make up policy for the laboratory assignments. A 12-15 page comprehensive lab report was required in Biology 111. Biology 112 also involved laboratory assignments but the reports were limited to 1-2 page group presentation. This format was remarkably different from the traditional laboratories in Biology 111 and 112.

Training for TAs – Dr. X used graduate students from her research laboratory since 2010. By doing so, Dr. X was certain the graduate students understood her teaching philosophy and goals and the need for student centered-teaching strategies in the laboratory.

On the topic of how she runs her labs, Dr. X remarked:

> "There is a tight correlation between lab and lecture. Students will interact with each other more. The idea of the lab is that there is no fixed end point. Labs can be *repeated if necessary*."

Dr. X's Teaching Assistants reported that Dr. X wanted students to learn how to think about the experiments before arriving in the laboratory and to be able to analyze the data after they leave. Students learned both techniques and the ability to troubleshoot. TAs did not micromanage the learning; they simply provided the learning outcomes. TA develops Power Points were available for reference to assist in preparation. Students having difficulty in the lab were encouraged to see TAs in office hours.

Students had unlimited access to teaching assistants through email and could attend labs later in the week. Experiments were ongoing throughout the entire semester. Students observed that experiments might not work and the need to take experiment in a different direction. Students learned by doing, underscoring the metacognitive element in Dr. X's labs.

Dr. X's Teaching Assistants reported that Dr. X's students were allowed to fail while also taking an ownership for their work. The labs were similar to real science. The students did not know the expected results. The ownership of the lab experience was a key component. Dr. X's Teaching Assistants reported that if the students isolated a mutation then the students could design PCR primers and try to isolate the mutant and potentially continue the experimentation. The data were theirs. Their conclusions were theirs.

Ownership over One's Work in Lab

Dr. X's Teaching Assistants reported that Dr. X's students were allowed to use their work in "Student Research Week" – a program at the university that allowed students the opportunity to present their research. They were allowed to make posters and were allowed to submit their work to journals. Students enjoying their first real taste of research were invited to participate in undergraduate research. It was estimated that students in each semester eventually participate in undergraduate research, some for multiple semesters.

Labs Reinforcing Lecture Material

In many Biology undergraduate programs, the disconnect between the lab and lecture material is noticeable and frustrating to students. Students are forced to hear a lecture in the morning over photosynthesis and then later that day make their way to biology lab and perform a lab over animal diversity. The asynchrony of lab and lecture makes it appear as if they are independent courses. Traditional science course will often times have labs that fail to reinforce concepts recently delivered in lecture. The disconnect in Dr. X's course was not an area of concern because bacterial chemotaxis was the focus of the experiments throughout her Biology 111 and they lasted 11-13 weeks. Dr. X's lectures reinforced labs. Teaching assistants reported that they heard students using terms in lab that they had heard in lecture.

The Differences – An Overall Summary

As research participant I have observed that there was a support system in Dr. X's classes. Dr. X's Teaching Assistants reported that they talked to Dr. X on a regular basis and attended the lecture portion of the course. SIs conveyed to Dr. X problems that students were experiencing. These constant communications meant that the key topics were reinforced and re-emphasized. The entire instructional design worked together in such a way that the students felt that all modes of input were pushing them in towards the same end point – collect information, organize it in a meaningful way, and think critically.

As stated in *How People Learn* framework (Bransford, Brown & Cocking, 2000), there needs to be measures implemented to make sure that the differences between experts and novices not undermine the value of the communication between the two parties. If the expert cannot find a way to communicate with the novice then both parties are filled with frustration as their interactions appear to be a waste of both parties' time parties. TAs and SIs were critical pieces in bridging any perceived gaps between Dr. X and her students and served as valuable intermediary role translating and coaching and reinforcing key concepts and fundamental biological processes.

Part II: Findings from the Interview and Questionnaire Given to Dr. X's Students

In this section I answer the questions: "What are the students' perceptions of Dr. X's biology class?" and "What are the students' experiences with Dr. X's biology class?"

A total of 90 students were enrolled in Dr. X's class during the semester data were collected. Fifty-nine students consented to participate in the study and completed both questionnaires. Among these 30, ten students were interviewed.

The average student in the class was 18-19 years old, had between two to four semester of high school biology and was majoring in life science. Some students know about the course format and sought out the opportunity to register for the course, while others registered for the course without knowledge of the different instructional format.

Dr. X's students commented that she was more concerned about deep learning and the ability to problem solve than with student grades. Students participating in the interviews were asked the following research question: 'How would you characterize Dr. X's style of teaching?' This question helped me to understand more about how Dr. X's communication style was perceived by her undergraduate students.

A student, Erin (a pseudonym) remarked:

> "Dr. X's course is different in that it is not a course focused on memorization. I feel that I actually understand the subjects covered by exploring the topics logically, not by memorizing facts."

Another student, Reed (a pseudonym) responded with:

> ‘This class is very unique when compared to others. There are almost no assignments the entire semester other than the readings. We come to class with no knowledge of what she will be teaching. She normally starts with a couple of main ideas and expands with greater detail throughout the lecture. Much of what she teaches is *information* we should have a basic understanding of prior to this course. I have had to teach myself much of what she doesn’t explain in class. About 80% of my knowledge is self-taught from this semester. There is a test every other lecture.’

“Be a mapper – NOT a stacker.” Interviews with Dr. X’s students have revealed. This was a constant theme in her course. Dr. X wanted students to understand the interconnectedness of biological concepts and not just rote memorize factoids.

Students reported that they favored Dr. X’s teaching method because it excluded traditional Power Point. Students remarked that it found them to take their own notes, which was beneficial to their learning and reinforced attending class.

When addressing Dr. X’s in-class pedagogical style and smaller class, Craig, (a student and a pseudonym) remarked:

> ‘The writing (on the board) helped me! It (the smaller class size) was helpful because students can ask question.’

When students were asked, “What one thing you would take away from Dr. X’s as they moved forward with their courses?” Several common themes emerged: the importance of the central dogma of molecular biology, be a lifetime learner, understand human nature, and seek the bigger picture, don't get lost or fixated on the details. Simone (a student and a pseudonym) remarked:

> 'She (Dr. X) wants us to be more of an independent learner. She wants you to figure it out yourself. Her class was helpful and overwhelming. It helped me to be less dependent on the instructor.'

Harriet (a student and a pseudonym) said:

> 'She (Dr. X) stuck with me. She makes you think outside the box! She would often times say, 'All you students are concerned about are grades!' Look at the bigger picture.'

Students suggested Dr. X had one to three messages for each lecture and messages were connected. Students remarked that they felt it was their responsibility to extract the main ideas of the lecture and relate the material to the assigned readings.

Students commented that their time in the Supplemental Instruction (SI) sessions was very helpful. Students felt that the SI instructors already established helped the students to clarify and organize the material and anticipate and prepare for weekly essay assessments. The SI instructors were also helpful in translating learning outcomes from the classroom discussions and essays.

Students held a favorable view of the laboratory of Dr. X's courses. Students liked working at their own pace and being able to leave when finished. Students enjoyed that they were conducting real science and that the labs were not as rigid as many other science labs they had later taken at the university level.

Smaller class size – Dr. X had 90 students per sections versus the normal size of around 250-300 students. Students favored the smaller class size because they felt like they got to know their classmates and Dr. X. Connections with Dr. X promoted engagement and two-way discourse.

As participant researcher I inferred that students felt like Dr. X was an engaging instructor lecturer, remarking on her passion for the subject, and sense of humor.

Students did indicate Dr. X's lectures were "..all over the place." However, in the follow up interview, students did indicate the classroom discussion contained a theme or a central message.

As participant researcher, I observed that students felt the outside reading took a long time. However the majority of the students liked reading stories better than traditional textbooks. Some students felt that the outside reading made the weekly assessments harder because there were too many details to absorb in a short period of time. Students felt that the outside readings promoted creativity. Katie (a student and a pseudonym) said:

> 'They (the outside readings) were a wakeup call for me! I had to do more than memorize facts. I had to do more – it helped me moving forward.

Students were asked the following question as part of the questionnaire: 'How do you think that Dr. X's class has prepared you for future science classes at this university?' This question helped me to understand more about how Dr. X's students feel about their level of preparedness in future science courses. 76.78% of all students who filled out the questionnaire responded favorably to this question in terms of their level of preparedness. Jacky (a student and a pseudonym) described her level of preparedness by saying:

> "This class taught me how to really prepare for a challenging test which will help me in future classes. There is also a great deal of responsibility that students need to have in this course because Dr. X in no way "babies" us."

Another student, Patty (a pseudonym) stated:

> "Dr. X's class definitely prepared me well for future science classes because I actually know the material."

Analyses of student interviews and questionnaire data uncovered three negative components of Dr. X's teaching style. The first is that Dr. X required too much reading from her students. The outside readings required too much time and effort from the students. Two, Dr. X lectures were not organized. Dr. X often times lectured with no pre-conceived format and the information appeared to be disconnected when conveyed to the students. And finally, Dr. X could be confusing when communicating with her students. Dr. X used esoteric language that was not fully comprehended by her students.

Part III: Findings from the Analysis of Student Achievement Data

In this section, I answer the research questions: "What are the differences between students' grades in Dr. X's Biology 111/112 class when compared to traditional biology classes in the same department?" and "What impact has Dr. X's teaching had on students' academic achievement over three years?"

To facilitate a statistical comparison, I filled out an Enterprise Information Systems (EIS) request for student achievement data. These students would be randomly chosen by the EIS computers to return requested grade information. I requested 50-75 students who had either taken Biology 111 and 112 in either the traditional introductory biology format or with Dr. X. I also requested that only students who had also taken Biology 213 and 214 be added to the data file. The grade request also asked for information, if available, regarding student achievement in Biology 351, Chemistry 227, Chemistry 228, Genetics 302 and the number of Q-drops the students had within those courses.

Demographic Information

At the time the study data were collected, there were 96 students enrolled in Dr. X's section. Sixty-one of these students participated in the study. Thirty-three of them were female and twenty eight of them were male. All of the 61 students' were in science major.

Table 4.1. presents the demographic information for the study participants. Sixty-seven students were randomly selected from other sections. Among these 67, 37 were female and 30 were male. Sixty-three of them were in science major. Four were in non-science major.

Table 4.1.
Demographic Information of the Students

Treatment	Male	Female	Science Major	Non-Science Major	Totals
Traditional	30	37	63	4	67
Dr. X	28	33	61	0	61
Totals	58	70	124	4	128

Correlations were run to identify potential covariances. Only students' SAT-Verbal (SATV) scores statistically significantly correlated with the students' grades from seven of the eight classes evaluated. All other correlations were not significant.

T- Tests

The first comparison of the means run was a series of T-tests. Three statistically significant findings were found. As indicated in Tables 4.2 and 4.3, Dr. X's students (n=61, M_{B111}=3.38, SD_{B111}=.608, M_{B112}=3.31, SD_{B12}=.592) had a statistically significant higher achievement in Biology 111 (t(126)= -2.486, and p<.05) and Biology 112 (t(x)= -4.25 and p<.001) than the traditional section's students (n=67, M_{B111}=3.07, SD_{B111}=.784, M_{B112}=2.79, SD_{B12}=.754).

As in indicated in Table 4.4, biology students taking the traditional format scored significantly higher in Biology 213 (n=67, M_{B213}=2.93, SD_{B213}=.825) than Dr. X's students (n=61, M_{B213}=2.49, SD_{B213}= 1.03) (t(126)= 2.662, p<0.05). There were no other statistically significant differences.

Table 4.2.
T-Test Findings for Biology 111

Variable	Groups	n	Means	SD	t	df	2-tail pr.
	Traditional	67	3.07	.784			
Biol. 111					-2.486	126	.014*
	Dr. X	61	3.38	.608			

(*)p<0.05

Table 4.3.
T-Test Findings for Biology 112

Variable	Groups	n	Means	SD	t	df	2-tail pr.
	Traditional	67	2.79	.754			
Biol. 112					-4.25	126	.000**
	Dr. X	61	3.31	.592			

(**)p<0.001

Table 4.4.
T-Test Findings for Biology 213

Variable	Groups	n	Means	SD	t	df	2-tail pr.
	Traditional	67	2.93	.825			
Biol. 213					2.662	126	.009*
	Dr. X	61	2.49	1.03			

(*)p<0.05

Results indicate that Dr. X's Biology 111 and 112 students' final grades in Biology 213 were significantly lower than students taught in traditional sections of Biology 111 and 112. This finding contradicts with the assumption that Dr. X's teaching style would promote higher student achievement in future courses.

ANOVA

An analysis of variance (ANOVA) was also run to determine if there were any significant differences in the variance and to potentially validate or refute the T-Test findings. ANOVA findings validated the T-test findings. Three statistically significant findings were found. Dr. X's students (n=61, M_{B111}=3.38, SD_{B111}= .608, M_{B112}= 3.31, SD_{B12}=.592) had a statistically significant higher achievement in Biology 111 (F(1, 128)= 6.179, p= p<.05) and Biology 112 (F(1, 128)= 18.06, p= p<.001) than the traditional section's students (n=67, M_{B111}=3.07, SD_{B111}= .784, M_{B112}= 2.79, SD_{B12}=.754). Biology students taking the traditional format scored significantly higher in Biology 213 (n=67, M_{B213}=2.93, SD_{B213}= .825), (F(1, 128)= 7.089, p= p<.05) than Dr. X's students (n=61, M_{B213}=2.49, SD_{B213}= 1.03). There were no other statistically significant findings.

ANCOVA

Based on the high correlation scores between SAT-Verbal (SATV) and student achievement within the 8 courses analyzed, an Analysis of Covariance (ANCOVA) using SATV as the covariate was run.

Table 4.5.
ANCOVA Findings for Biology 111

Variable	Groups	n	Means	SD	F	df	2-tail pr.
Biol. 111	Traditional	61	3.04	.783	6.742	1	.011*
	Dr. X	58	3.38	.614			

(*)p<0.05

A one-way between-subjects ANCOVA was calculated to examine the effect of treatment group (Traditional vs. Dr. X) on Biology 111 student achievement, covarying out the effect of SATV. SATV was significantly related to Biology 111 score (F (1, 119) = 13.06, p<.001). The main effect for treatment group (Traditional vs. Dr. X) was significant (F (1, 119) = 6.74, p<.05) as indicated in Table 4.5, with Dr. X's students scoring significantly higher (n= 58, M = 3.38, SD = .614) than traditional biology students (n= 61, M= 3.04, SD = .783).

Table 4.6.
ANCOVA Findings for Biology 112

Variable	Groups	n	Means	SD	F	df	2-tail pr.
	Traditional	61	2.79	.760			
Biol. 112					14.604	1	.000**
	Dr. X	58	3.27	.586			

(**)p<0.001

A one-way between-subjects ANCOVA was calculated to examine the effect of treatment group (traditional vs. Dr. X) on Biology 112 student achievement, covarying out the effect of SATV. SATV was significantly related to Biology 112 score (F (1, 119) = 5.26, p<.05). The main effect for treatment group (traditional vs. Dr. X) was significant (F (1, 119) = 14.6, p<.001), with Dr. X's students scoring significantly higher (n= 58. M = 3.27, SD = .586) than traditional biology students (n=61, M = 2.79, SD = .760) as indicated in Table 4.6.

Table 4.7.
ANCOVA Findings for Biology 213

Variable	Groups	n	Means	SD	F	df	2-tail pr.
	Traditional	61	2.92	.784			
Biol. 213					8.48	1	.05*
	Dr. X	58	2.46	1.03			

(*)p<0.05

As indicated in Table 4.7, a one-way between-subjects ANCOVA was calculated to examine the effect of treatment group (traditional vs. Dr. X) on Biology 213 student achievement, covarying out the effect of SATV. SATV was significantly related to Biology 213 score (F(1, 119) = 7.73, p<.05). The main effect for treatment group (traditional vs. Dr. X) was significant (F(1, 119) = 8.48, p<.05), with traditional students scoring significantly higher (n=61, M = 2.92, SD = .784) than Dr. X's students (n=58, M = 2.46, SD = 1.03).

Non-Statistically Significant Differences

T-test, ANOVA, and ANCOVA analysis found no other statistically significant differences when comparing Dr. X's student's grades to the grades attained by students in the traditional biology courses. T-test, ANOVA, and ANCOVA analyses of Biology 214, Chemistry 227, Chemistry 228, Biology 351 and Genetics 301/302 all found no statistically significant differences. Furthermore, there were no statistically significant differences in the number of courses dropped or the number of STEM courses taken beyond Biology 111 and Biology 112.

CHAPTER V

CONCLUSION

The purpose of this research study was to incorporate a mixed-methods approach into an observational analysis of a non-traditional biology classroom at a Research I institution. The main research question was "What are unique characteristics of Dr. X's biology classes and what impact do they have on students' learning outcomes and experiences?" Research sub-questions included questions that address student perceptions of Dr. X's course, descriptions of their experiences, and differences in grades.

Qualitative findings include that Dr. X is less concerned about grades and more concerned with student comprehension of topics found within the subject of biology. Findings also suggest that students felt that Dr. X's teachings represented a narrative and a puzzle with students having to connect the puzzle pieces to make sense of the material. When examining the longitudinal student grade information of one cohort over three academic years, the researcher found that there were statistically significant differences in Biology 111, 112, and 213 when using T-test, ANOVA, and ANCOVA statistical analyses. Dr. X's students had statistically significant Biology 111 and 112 grades while traditional biology classes had significantly higher Biology 213 scores. There were no other statistically significant differences in all other independent measures analyzed.

Learner-Centered Classrooms

This study revealed that Dr. X's instructional practices included many learner-centered strategies. The persistent questioning and classroom discussions promote student engagement, and peer interaction. Hearing, processing, and agreeing/disagreeing allow students the opportunity to organize their take on the information put forth by instructors and authors. Questioning and answering also promote diagnostic teaching. Diagnostic teaching allows the instructor to ascertain how her or her students are arranging the information. Student expressions allow the instructor to gauge the depth or level for which students understand the material. If an instructor were to decide that her or her students were not using a term correctly within a certain context then the instructor knows of the apparent misinterpretation of the term (Bransford, Brown, & Cocking 2000).

Learner-centered environments allow for student creativity. Within the learner-centered environment, students are encouraged to express ideas that may not normally emerge within a teacher-centered classroom. Not only is the creative idea refined within the head of the one sharing the idea, but others listening to the speaker are exposed to the creativity as well. Ideas are often times the impetus for other ideas. Study results suggest that Dr. X aimed to promote creative thinking within her classroom. Because science is about problem solving and creativity is often times an invaluable attribute needed to solve problems. There is a collaborative elaboration component when an exchange of ideas takes place and Dr. X has been trying to promote that. Jonassen (1994) described one of the fundamental components of constructivist learning to be context-driven knowledge acquisition. Personal experiences and intellectual refinement are accentuated when the learner is allowed to fully understand the context within which information applies or should be used. Questions, answers, and the flow of ideas allow students to better comprehend the context within which the problem is being framed – or the question is being asked.

And what context often mattered to Dr. X? The context associated with science's connection to humanity and the world around us. Dr. X used the outside readings instead of the standard text to expose students to the ideas and positions of the authors. Textbooks are often void of such intentional connections of information to science to world as a whole. The outside readings allowed Dr. X an opportunity to show differences between biology and culture – two fundamental influences upon the way in which students organize information. These outside readings promoted an understanding of the history of science. And while some texts do expose the student to certain historical components of scientific endeavor, Dr. X tended to incorporate these historic moments of science into her narrative. Showing students the history of science gives science a face.

Dr. X's classroom was small, had fewer students and to me just had a different feel to it than larger classrooms that lacked any sort of connectedness. As stated in Chapter V, students felt that the smaller class size in Dr. X's classroom allowed them to get to know Dr. X and their fellow classmates better. These connections allowed the students to feel more comfortable speaking up. Students get to know each other better in the more intimate setting of a smaller room which I believe also promoted group study which enhanced repetition and time on task. Both of the aforementioned are fundamental components of enhancing human cognition.

Students Need to Think Critically

One of if not *the* finding of this study is that Dr. X wanted her students to think. If her students could also think critically then that was even better because answering questions and solving problems are what science is all about. “He wants you think critically!” resonates not only from Dr. X’s TAs but from her students as well. As pointed out in Chapter V, Dr. X did not care about grades – she wanted the students to think. Think about the overall message, think about what the readings meant, think about the direction of your bacterial mutagenesis project – just think. And woven through their intention to promote critical thinking was the *process* specifically designed to achieve that intended result – the result that was students thinking critically.

From the information transmitted in lecture to the organizational strategies espoused in SI sessions to the messages reinforced in lab, it was a process. A process designed to have students read, discuss, reflect, and then write. If you walked into a room and the following was seen on the board in yellow chalk, “When was the last time you thanked Jupiter?” – what would you think about the scope and sequence of that class. Dr. X asked questions and then was hopeful that her students would confer and work through the material to formulate and refine and answer. I once asked Dr. X if she felt that students learn by doing. She was quick to point out that “doing” comes in many forms but trying to figure something out is “doing.”

Putting the Puzzle Together

Dr. X's information transmission was a series of puzzle pieces. The majority of the students interviewed characterized the experience as a process – or validated the notion of a process if asked. Dr. X's lectures contained a series of puzzle pieces. As stated in Chapter IV, Dr. X's lectures appeared to be disconnected. Students remarked that Dr. X was "…all over the place…" when she lectured. The students were forced to take those puzzle pieces and try to create the borders of the puzzle. Dr. X's TAs and SI instructors were also acutely aware of her lecture messages. Both SI instructors and TAs were required to attend Dr. X's lectures. Teaching Assistants (TAs) and Supplemental Instruction (SI) instructors took the puzzle pieces put forth by Dr. X and helped the students to arrange the pieces. SI instructors showed students how to organize thoughts and be able to write an answer to the one essay question students must answer each week. SI instructors were able to translate to the students just exactly what Dr. X was trying to convey to them if the students missed the "take home" message of a lecture. Dr. X's TAs were also Dr. X's graduate students and they understood that lecture information must be made relevant in lab. People learn by doing (Bransford, Brown, & Cocking 2000). Dr. X's TAs were aware of their and as stated previously, Dr. X's 111 labs were real science – not cookbook science.

Dr. X threw the pieces of the disarticulated puzzle on to the table for the students. The TAs and SIs helped students create the framework or borders of the puzzle. The students were responsible for putting the pieces of the puzzle together. Students, through informational processing and organization, as well as trial and error, ultimately put the puzzle together. One of the foundational tenets of constructivist teaching is that students must organize the material to make sense of it. Their idea of student analysis followed by the construction of ideas should not be understated. Furthermore, students often times felt that the material Dr. X was presenting allowed them to engage others in conversation. This was because the material was interesting and Dr. X's use of the Socratic method allowed students to formulate ideas in class that were presented in class as questions were answered. The evolution and refinement of those ideas was also allowed for based on the in-class discussions on Tuesday becoming a more parsimonious essay written by students on Thursday. Dr. X told stories, related the stories to assigned book readings and then her essay questions required that students make sense of the material prior to trying to answer an essay question. The flow of ideas that started with Dr. X was later returned to Dr. X by her students and the cycle continued. Students then saw how Dr. X had deconstructed their essays thus allowing for a continued refinement of those ideas.

Nexus between All Science Courses

Dr. X. routinely incorporated elements of physics and chemistry into her biology lectures. Dr. X operated under the assumption that not only is Science, Technology, Engineering and Math (STEM) one big happy family, but biology, chemistry, and physics are as well. The thread that is woven through all of these subjects is noteworthy. In much the same vein that the MCAT assesses chemistry, physics, and biology, Dr. X did so as well. As referenced on pg. 53 of Chapter IV, if one were to discuss the bloodstream, them one would need physics to understand flow rates – ergo, Bernoulli's equation is relevant in that context. While discussing blood pH, the carbonic anhydrase blood buffering system would certainly be discussed. Both pH and Le Chatelier's principle would also be relevant in their context – both of which are typically discussed in chemistry classes. There is a nexus between these three subjects and Dr. X was proficient and seamlessly incorporating physics and chemistry into biology lectures. Why is this important? I would point out that many undergraduate science majors take physics, chemistry and biology – many times concurrently. Yet the connections between all of the science sub-disciplines may not be established by the students. Dr. X went out of her way to establish these connections and puzzle pieces from other subjects were added to the puzzle and put into place by the students as the student organized the material.

Future Studies

The research contained within this dissertation represents only one set of potential evidence to an unending set of questions associated with the future of STEM education. As follow-up studies, I would like to study the impact of teaching assistant characteristics on student achievement. These data might help shed light on the impact of non-native speakers within the science learning environment. I would like to study the impact of supplemental instruction (SI) sessions on STEM education. The impact of peer-led review upon freshman-level biology courses should be studied further. Future studies may also include the impact of lab review sessions on student achievement. Hearing lab information from more than one perspective is worthy of future study. These studies and many more will hopefully add to the overall body of knowledge connected to

STEM education. These corpora of research projects and subsequent data collection and associated analysis will hopefully create a better learning environment as well as a more meaningful experience for STEM students.

Concluding Remarks

Education is communication and the first rule of communication is to know one's audience. What does one's audience want? What are there inherent strengths, their limitations and are these constructs being considered when trying to communicate with them in a meaningful manner? Science education is no different than most other forms of education. The concepts and facts may be different than other disciplines but fundamental components of instructor and learner are the same in science education as they are in other fields. Using constructivism as a theoretical framework, educators now have a more well-rounded understanding of how people assimilate process and later use information. Constructivism allows educators and students alike to engage in meaningful discourse and ultimately allows students to experience education firsthand. People learn by doing but doing has many forms and faces. In science education, learning by doing is not narrowly defines as time in the lab running experiments. People can experience a lecture for more than a didactic and emotionless monologue. Students can feel that the learning environment is conducive to a social element that also allows for the student to reflect on problems and questions outside of class – there too represents a form of doing. Students can be presented a loose framework and allow their imaginations to fill in the gaps as well as form new questions to augment the preexisting corpora of information associated with a subject. The most basic and the most important component of constructivism is that students must be actively involved in their own learning as they incorporate new experiences into their educative framework.

Dr. X would agree that the inherent beauty of science education is that people of science are molded to become problem solvers as well as people who answer questions. That said, science students and scientists must be allowed to learn how to think – more importantly, to think critically. People of science must be able to examine evidence as well as the way the evidence was collected. People of science must be able to deconstruct the interpretation and the methodology while potentially defending a position based on the evidence. Lab experiments and trips to the museum of natural history are in and of themselves important experiential education episodes. They will not, however, create critical thinkers. There is where an important construct of science education emerges – that being the notion that the science teacher precedes the scientist. If traditional science classes fail to create critical thinkers then those traditional science classes themselves have failed. The science instructors have likewise failed to achieve the ultimate goal – the goal of creating critical thinkers and people of science who can ultimately answer questions and solve problems. The philosophy of all science educators should be to produce students that can collect evidence, think critically to eventually answer questions and potentially solve problems. If the science education community is not operating under the tenets of the aforementioned philosophy then the science education community should take long, hard look at the way classes are conducted and the way labs are run.

Dr. X's version of science education is that science education is a process - a process with the key players being Dr. X, her TAs and the SI leaders. The process has more moving parts than a traditional undergraduate biology class but that is because the goals are to make people think while engaging in real science. Making students think within the classroom or lab so that later questions can be answered and later problems can be solved takes time and effort that many traditional science teaching models lack. Dr. X's science teachings led to real science. It was real science for two reasons: (1) The students conduct real experiments in her labs, and (2) anyone who transmits the information – from Dr. X to her TAs to her SIs – was doing so in such a way that it went beyond informational regurgitation by the students. The inherent beauty associated with "read, reflect ,and then write.." should not be understated either. There is also part of the process. Dr. X took the time to give essay assessments once per week. A student might be able to limp her or her way through 45 multiple-choice questions while unprepared. But writing essays was something altogether different and required a more diligent preparation on the student's part.

Which comes first, one's time in a science class or one engaging in actual scientific exploration? If one were to say that one's time in the science class comes first, then perhaps the scientific community should think long and hard about science education. Science educators often times represent the first portal that the scientists of the future make their way through. Science educators must be mindful that science is not an academic decathlon whereby students need to be able to instantaneously spout off facts. If the science educator is not conveying science to her or her students, then one must question just what exactly is that instructor attempting to achieve with her or her students. Information transmission by instructors which leads to knowledge acquisition by students that ultimately leads to the application of that knowledge or intelligence bolstering by the students is a critical component of education in general - especially STEM education.

The future of STEM education resides within the science education community's ability to assess new strategies, validate preexisting strategies and to be accountable along the way. Dr. X represents a new strategy of teaching biology at the undergraduate level. Her strategy is a break from traditional science teaching that is often times teacher-centered and lacks any semblance of creativity, collaborative elaboration, engagement or connectedness. Her strategy is in keeping with constructivist teaching theory. Dr. X's teaching methodology and pedagogical content knowledge represented a breath of fresh air. The learner must synthesize her or her own knowledge while instructors and books can only transmit information. Dr. X was acutely aware of these fundamental components of constructivist ideology – even if she did not know she was been doing so for years.

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APPENDIX A

STUDENT QUESTIONNAIRE

This questionnaire is voluntary. The person administering the questionnaire has no access to your grades for lab or lecture or your TA and will not know who does or does not complete the questionnaire. The questionnaire will be encrypted for security purposes and will not be shared with your course instructor or with Mr. Lee until after all grades are final. The purpose of the questionnaire is to improve the quality of Biology education at your university for future students. As part of that process, it is helpful for us to connect your actual grade with your answers. For instance, do students who attend Dr. X's class make better grades in Chemistry classes? As soon as the grade has been attached to the file, the UIN number will be completely removed so there is no connection between the data or results and you as a person. Please provide complete answers by typing your responses to the questions below.

Gender:
Major:
Classification (freshman, sophomore, etc.):
Letter grade expected in Biol. 111 (Dr. X):
Number of Biology courses you have taken at the University (including Biol. 111):
Number of Biology courses you took in grades 9-12 inclusive (high school):
UIN:

1) How is Dr. X's course **different** from other science classes you have taken or are currently taking at the university?

2) How is Dr. X's course **the same** as other science classes you have taken or are currently taking at the university?

3) **(Yes or No)** – Were you aware that Dr. X's Biol. 111 sections were smaller (total enrollment) than *other* Biol. 111 sections offered for the fall of 2012?

4) Please offer your personal thoughts as to how Dr. X conducts/teaches Biol. 111 lecture. Comment on the structure and effectiveness of his approach to teaching Biol. 111.

5) **(Yes or No)** Did you feel that you were offered the opportunity to speak up and/or ask questions in Dr. X's Biol. 111 lectures? And if so, did you speak up in class this semester and how many times?

6) What impact, if any, would you say that the laboratory component of Biol. 111 had on your Biol. 111 grade?

7) What is the most effective part (or parts) of Dr. X's Biol. 111 class? Why?

8) What is the least effective part (or parts) of Dr. X's Biol. 111 class? Why?

9) Would you agree to participate in follow-up interviews (maximum of two interviews of 30-60 minutes given face-to-face or over the phone)? If so, please provide your contact information below.

Thank you for your participation

APPENDIX B

STUDENT INTERVIEW PROTOCOL

The items below will be asked to the selected students who took a course from Dr. X. If the interviewee already responds to some of the questions, then those questions won't be asked. Based on the conversation, emerging questions might be posed. This interview is semi-structured.

1- How many semesters with Dr. X?
2- How many semesters of high school biology?

(The above two questions served as warm-up questions)

3- Do you think Dr. X cares about grades? How does that affect your perception of her class?
4- How do you feel about the smaller class size Dr. X has for her Biol. 111 and 112 classes?
5- How would you characterize "the class location" and what do you like or dislike about it?
6- What do like about 111/112 lab in Dr. X's course?
7- What do you dislike about111/112 lecture in Dr. X's course?
8- How would you characterize Dr. X's teaching style?
9- What do you like about Dr. X's style of teaching?
10- What do you dislike Dr. X's style of teaching?
11- What do like and dislike about his assigned outside readings?
12- What do you like or dislike about his weekly assessments?
13- Did you attend SI sessions for 111 or 112? How many times? Why did you attend these SI sessions?
14- What do you think about the impact of SI sessions (if applicable)?
15- How would you compare Dr. X's science courses to other science courses you have taken?
16- If I asked you about the one thing that you will take from Dr. X as you move forward with your classwork, what would that one thing be?
17- Is there anything else you would like to tell me about your experiences with Dr. X and/or his teaching?

Thank-you for your time.

APPENDIX C

DR. X'S SAMPLE ASSESSMENTS

Student number____________________

Mating systems are determined by several factors: the environment, the food required by the young, and the time it takes the young to reach independence. Considering only vertebrates (fish, amphibians, reptiles, birds, and mammals), give specific examples of the type of mating system and the parental care given to th4e offspring in the context of the ecological setting and the developmental pattern of the young. Then consider how human mating systems have responded to their environment, economy, and social organization and the changes that have occurred over the of human evolution up to the present day.

Student number____________________

Although in humans and most other animals the Y chromosome determines "maleness," this is far from being a universal rule. A) Describe some of the mechanisms organisms other than mammals use to set off the programs of gene expression that lead to male and female. B) In a second essay, discuss the male mating strategies of win or woo, the role of female choice in mate selections, and the two hypotheses about what governs female choice: good genes or sexy sons.

Student number __________________

Question #1 In three short points (no more than 3 or 4 sentences each), justify to your congressperson why it is important to study the basic ecology and evolution of protozoan or metazoan parasites. You can use any of the examples from the lecture to support any aspect of parasite biology you are interested in. The three points need not be related and can address different systems and research questions.

Question #2 Our sensory world as humans tends to be dominated by sight and sound, with the visible spectrum being 400-700 nm wavelengths of light and the auditory spectrum being of frequencies 20 to 20,000 Hertz (vibrations per second.) Give three examples of animals that primarily use other sensory modalities or utilize sight and sound outside of the wavelengths and frequencies listed above. Be brief, but provide enough detail to make it clear that you know what you are writing about.

Number__________________

Water (H_2O) is essential to every form of cellular life that we know of. Describe what properties of water make it suitable to support life and how the structure of cells and their component macromolecules is influenced by their contact with H_2O. Then, describe what properties of planet earth and our solar system make water-based life here possible.

Personal Number_________

Describe how idea of The Tragedy of the Commons applies, at the level of cooperation and competition among genes, to the evolution of sexual reproduction by the union of two very unequal haploid gametes.

Number________________

Plants and animals have evolved an incredible array of defense mechanisms to protect themselves from predation. It is probably fair to say that the pressure to avoid predation has been, along with the pressure to resist parasites and the ultimate pressure to reproduce, one of the three great selective forces in the history of the evolution of life on earth. Describe as many different categories of defense against predation as you can, giving an illustrative real-life example of each. (Under the heading of predation I also include the eating of plants.)

Student number_________________

The cost of having two sexes, only one of which is reproductively competent, is high. Only one half of a reproductive individual's offspring will be able to reproduce. Thus, the same individual will produce twice as many descendants if it reproduces asexually, and those descendants will be genetically identical to the parent. Given this fact, sexual reproduction must have some strong selective advantage(s) in order to persist. What theories have been proposed to explain the selection for sexual reproduction, and what arguments can you make in favor or against those theories?

Number_________________

Describe the responses of the immune system to infection from two different sources. First, discuss how the innate immune system reacts to a localized bacterial infection by initiating an inflammatory response and how that is coupled leads to acquired immunity to the bacterium. Second, describe how the innate immune system responds to a viral infection, both to the free virus and to virus-infected cells, and also how the cell mounts an acquired immune response to the virus.

Number__________________

Describe the similarities and the differences in the process of making a translatable messenger RNA (mRNA) in bacteria and in humans.

Personal Number_________

Complex systems, whether biological or technological, are composed of simple parts that by themselves carry out simple functions. One argument against evolution is the idea of irreducible complexity – that is, that complex biological systems (the technological analog is a watch or mousetrap) cannot evolve because the individual parts have no selectable function on their own. Using the idea of "emergy" (the appearance of emergent properties in complex systems) discuss why or why not irreducible complexity is a reasonable argument against evolution by random variation and natural selection.

Personal Number_________

Any thinking human being realizes that there are both genetic (nature) and social/cultural (nurture) differences among people, both between genders and within genders. Normally, natural selection takes care of these discrepancies. How? In modern human societies, the actions of natural selection are restricted to a greater or lesser extent. How? Also discuss whether you think that the actions of natural selection are restricted too much, too, little, or more or less the right degree. (This answer to this question could be book-length, so stay focused and be concise and to the point. I am also aware that the question has strong political/philosophical implications. Try to be as objective as you can, and separate opinion clearly from truly logical conclusions.)

Number__________________

Embryos tend to establish their main body axes using either maternally deposited cytoplasmic determinants or conditional (regulated) cell-cell-signaling. Describe examples of each that were discussed in the context of insect versus vertebrate development and discuss similarities and differences in the two processes.

Personal Number_________

DNA is a stable molecule and well suited to carry hereditary information from one generation to the next. However, DNA can be damaged by chemicals, radiation, and desiccation (drying out), and mistakes can occur when DNA replicates. The result is mutations – any sort of change in the DNA. What types of mutations can occur?

Consider how quickly these mutations will accumulate in bacteria (generation time of hours or days) and elephants (average generation time 20-30 years). Also, discuss what factors will limit the rate at which mutations accumulate in bacteria and in elephants and what factors will allow mutations to accumulate. Predict whether bacteria or elephants will evolve more quickly. There is not necessarily a “right” answer, so explain your reasoning.

Number______________

Mating strategies in nature range from very casual (just shoot your gametes out into the water) to extremely elaborate (e.g., peacocks and elephant seals). Discuss which factors may have contributed to the evolution of different mating strategies and what selective pressures operate to accentuate and to limit the investment made in mating by males and females. Include some consideration of the theories described in the Red Queen, including the “win versus woo” and the “sexy sons versus good genes” controversies.

APPENDIX D

DR. X INTERVIEW PROTOCOL

1. Do you have a philosophy of science? Philosophy of teaching?'
2. Do you make a distinction between your philosophies and your philosophy of life?
3. What was the impetus for wanting to teach freshman biology the way you were teaching biology?
4. Are your classes capped numbers wise?
5. If you could teach to 300 people, would you?
6. The way you teach is different. Did you go into these 100-level courses and think to yourself, I am going to do this, this and this, or did it evolve?
7. You hand pick your TAs. Tell me how you train your TAs.
8. Tell me about your 111 and your 112 labs.
9. Do you feel taxonomy is a waste of time?
10. Why get students in the field?
11. Do you feel science is about observation?
12. Do you have an element of "it's all connected" in your teaching philosophy?
13. Do you believe that biology, chemistry and physics are one happy family.
14. I sensed an element of just how small we are from your lectures – was this a contrivance?
15. Does it bother you that students are using their computers in class?
16. Why show up and not listen?
17. Does that bother you?
18. What if someone was reading a newspaper in the front row?
19. What would you hope after 2 semesters in your class that I had achieved?
20. Why is student research important?
21. Why is independent research more important? There is an ownership component?
22. People learn by doing. Do feel that way?"
23. What are your feelings about textbooks?
24. Can you tell me about your reading lists for 111 and 112?
25. I have noticed that you write in yellow chalk on the blackboard. What is your reason for not using Power Points and writing in yellow chalk?
26. You give a quiz per week – what is your rationale?
27. You use the Socratic method but your version is a bit different. What lead to that? Did you see it at Stanford? Did you see it at Hopkins?
28. You ask a lot of questions – why?
29. Are you trying to promote having students connect their own dots.
30. Do you want your students to ask questions?
31. Do you make mistakes on purpose?

32. Do you want your students to embrace reflection? Solitude? Is this stuff starting to make sense?
33. Why is science THE lens to explain phenomena?
34. You feel empiricism is the lens?
35. How do you feel about student debate?
36. Your assessments have how many questions.
37. You have one quiz a week?
38. You have how many assessments?
39. Three of your assessments of the 13 are knowledge-based?
40. What can students do if they are struggling? What would be your plan?
41. Do you say provocative things? Why is that important?
42. How many students do you feel should get As in your class every semester? Bs? Cs?
43. Do you believe in Ds and Fs?
44. Do you want your students to please you?
45. Do feel the free-thinkers really feel that way?
46. You promote disagreement? Do you respect it (disagreement)?
47. Is there a paternalistic component to your class? To your reason d'etre?
48. Should people only teach what they love?
49. You are taking the pragmatic approach?
50. Is it your job to be motivational?
51. Do you take attendance? Do you care about attendance?
52. Who are the people that have had the greatest impact?
53. How can you tell if a student has talent?
54. Do you feel that connection is part of your notion of being engaging?
55. Do you feel that you have this plan or is it all sort of coming together?
56. Do you trust yourself (when you teach and evaluate students)?
57. What are the differences between right and wrong and true and false?
58. You have also changed your positions and perceptions of what is right and what is wrong?
59. What if I told you that based on the questionnaire information that some of your students characterize you as arrogant?

APPENDIX E

INTERVIEW PROTOCOL FOR DR. X'S TEACHING ASSISTANTS

1. How many times a week do Dr. X's labs meet?
2. What percentage of the total grade does lab account for?
3. If a student misses a lab or does the incorrectly, then how is that handled?
4. Are there lab quizzes?
5. Tell me about the lab assessments?
6. Are there lab homework assignments? Lab practical exams?
7. Did Dr. X give you training prior to you teaching lab?
8. Does Dr. X use only her graduate students to teach?
9. Did Dr. X ever meet with you as TAs to disclose what was expected of you?
10. When did you start teaching for Dr. X?
11. What are some of the things in your opinion that Dr. X would like to see happen in lab from her students?
12. How would you characterize the TA's role in the lab process?
13. What if students do not know anything about bacterial mutagenesis then how do you handle those students?
14. What if students attain no data - what can they write up?
15. Walk me through what you as TAs do during week one of the lab?
16. Do you just say, "Ready, set go!?!?" or what do you do?
17. Is E. coli always used?
18. Walk me through what happens after being introduced to the organism.
19. What kind of bacterial mutagenesis do the students engage in in Dr. X's lab?
20. What is the primary goal after the initial bacterial mutagenesis?
21. Dr. X's lab is interested in chemotaxis so is chemotaxis observation encouraged?
22. Do you as a TA have to sign off on the student's experimental protocol?
23. If the students run the experiment incorrectly, how would you rectify the situation?
24. You take what you see as a problem and formulate a question and pose that question to the students?
25. Have you ever had a student run the experiment incorrectly and ask to come in later the same week? What is the protocol there?
26. What percentage of the students would you say recognize their own mistake and contact the TA and ask to perform the experiment again?
27. You give the students the opportunity to run the experiment again?
28. In Dr. X's lab, if students contact their TA, they are allowed to perform the lab again?
29. There is a metacognitive element to these labs? Students are encouraged to think about what they are doing right and what they are doing wrong?
30. Compare and contrast your time in Lower Division to your time teaching for Dr. X.

31. Is there a continuity component to Dr. X's labs in Biol. 111? Are the labs connected?
32. Is this real science?
33. Do students come up with their own research ideas or research questions?
34. Do you feel there is a student ownership element associated with Dr. X's labs?
35. Have any of the students ever been close to being able to transfer their research to "Student Research Week"?
36. Have any of Dr. X's students been recruited to do student research projects in Dr. X's actual lab?
37. Is it possible for students in Dr. X's freshman biology courses for 9 months to springboard into actual science in another lab within the Department of Biology?
38. Do you as a TA have a plan ready to go if students want to continue the research?
39. Do you feel there is a greater connection to Dr. X's students than to your students you had in the Lower Division Program?
40. Do you have more "face time" with the students in Dr. X's labs?
41. Do you attend Dr. X's lectures?
42. How else would you say there is an increase in "face time"?
43. Would you say that traditional labs the TAs are more of authority figures?
44. Are traditional labs more rigid in your opinion?
45. If students really have a great project, how do Dr. X's TAs facilitate the long-term research?
46. Do you encourage students to come take a look at Dr. X's actual lab, to read Dr. X's papers, etc.?
47. If you have 48 111 students every fall, how many students will ask to come see the actual Dr. X lab?
48. How many will follow through?
49. Is Dr. X's lab course "real science"?
50. Do you feel that Dr. X's lab match Dr. X's lectures?
51. Do you feel lab and lecture are connected in Dr. X's courses?
52. Is lab reinforcing lecture?
53. Are statistics being run in Dr. X's labs? Statistics are being run in 111 and 112?
54. How are the 112 labs different than 111 labs in Dr. X's course?
55. What are the connections between Dr. X's 111 and 112 labs?
56. Tell me about the scope and sequence of Dr. X's Biol. 112 labs.
57. Are there computer simulations in Dr. X's Biol. 112 labs?
58. Are there outside components to Biol. 112 labs? How many trips outside are there in Dr. X's 112 labs?
59. Do you feel there is a value in getting students outside?
60. What are a couple of your observations of how Dr. X lectures?
61. Do you feel she is engaged in a narrative while lecturing?
62. Do you feel the story telling in lecture helps the students?
63. Do you feel she is an engaging lecturer?
64. Why do you feel she asks so many questions in lecture?

65. How do you feel about her selection of outside readings with the use of a reference text?
66. There are many computers that are open during Dr. X's lectures. Do you think that is a sign of the times?
67. Why would a student go to a biology lecture and then open his or her computer to a non-biology website?
68. Why do think Dr. X gives his students a break halfway through the lab?
69. Do students ask questions during the break?
70. Do you think Dr. X says provocative things to her students on purpose?
71. Does Dr. X mention "religion versus science" in her lectures?

APPENDIX F

INSTITUTIONAL REVIEW BOARD (IRB) APPROVAL LETTER

DIVISION OF RESEARCH

Office of Research Compliance

TEXAS A&M UNIVERSITY

APPROVAL DATE: December 18, 2013

MEMORANDUM

TO:	Bugrahan Yalvac TAMU - College Of Education - Teaching, Learning And Culture
FROM:	Office of Research Compliance Institutional Review Board
SUBJECT:	Continuing Review Approval

Protocol Number:	IRB2012-3035
Title:	An analysis of nontraditional biology teaching on student achievement and retention within a biology program at a large research intensive university
Review Type:	Expedite
Approval Date:	11/30/2012
Continuing Review Due:	11/15/2014
Expiration Date:	12/15/2014

Documents Reviewed and Approved:

Provisions:

Comments: 89 of 125 enrolled in study. Following subjects.

This research project has been approved. As principal investigator, you assume the following responsibilities

1. **Continuing Review:** The protocol must be renewed by the expiration date in order to continue with the research project. A Continuing Review application along with required documents must be submitted by the continuing review deadline. Failure to do so may result in processing delays, study termination, and/or loss of funding.
2. **Completion Report:** Upon completion of the research project (including data analysis and final written papers), a Completion Report must be submitted to the IRB.
3. **Unanticipated Problems and Adverse Events:** Unanticipated problems and adverse events must be reported to the IRB immediately.
4. **Reports of Potential Non-compliance:** Potential non-compliance, including deviations from protocol and violations, must be reported to the IRB office immediately.
5. **Amendments:** Changes to the protocol must be requested by submitting an Amendment to the IRB for review. The Amendment must be approved by the IRB before being implemented.
6. **Consent Forms:** When using a consent form or information sheet, you must use the IRB stamped approved version. Please log into iRIS to download your stamped approved version of the consenting instruments. If you are unable to locate the stamped version in iRIS, please contact the office.
7. **Audit:** Your protocol may be subject to audit by the Human Subjects Post Approval Monitor. During the life of the study please review and document study progress using the PI self-assessment found on the

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RCB website as a method of preparation for the potential audit. Investigators are responsible for maintaining complete and accurate study records and making them available for inspection. Investigators are encouraged to request a pre-initiation site visit with the Post Approval Monitor. These visits are designed to help ensure that all necessary documents are approved and in order prior to initiating the study and to help investigators maintain compliance.

8. **Recruitment**: All approved recruitment materials will be stamped electronically by the HSPP staff and available for download from iRIS. These IRB-stamped approved documents from iRIS must be used for recruitment. For materials that are distributed to potential participants electronically and for which you can only feasibly use the approved text rather than the stamped document, the study's IRB Protocol number, approval date, and expiration dates must be included in the following format: TAMU IRB#20XX-XXXX Approved: XX/XX/XXXX Expiration Date: XX/XX/XXXX.

The Office of Research Compliance and Biosafety is conducting a brief survey for the purpose of programmatic enhancements. Click here to take survey or copy and paste in a browser
https://tamu.qualtrics.com/SE/?SID=SV_1CgOkLNU45QebvT

This electronic document provides notification of the review results by the Institutional Review Board.