

ADOPTING REFORM-BASED PEDAGOGY IN POST-SECONDARY
MICROBIOLOGY EDUCATION

by

Jeffery W. Bonner

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Dissertation Committee:

Dr. Angela T. Barlow, Co-chair

Dr. Grant E. Gardner, Co-chair

Dr. R. Stephen Howard

Dr. Ginger H. Rowell

Dr. Terry Goodin

To my boys, Easton and Grayson,
I hear your train a comin'.

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ABSTRACT

Current emphasis on improving student learning and retention in post-secondary science education can potentially motivate veteran faculty to reconsider what is often a traditional, instructor-centered instructional model. Alternative models that foster a student-centered classroom environment are more aligned with research on how students learn. These models often incorporate active-learning opportunities that engage students in ways that passively taking notes in an instructor-centered classroom cannot. Although evidence is mounting that active-learning is an effective strategy for improving student learning and attitude, university professors, without formal pedagogical knowledge and training, can face uncertainty about where to start and how to implement these strategies.

The research presented here was conducted in two parts under the same context during one semester of a post-secondary microbiology course. First, a quantitative study was conducted to compare collaborative and individual completion of a reform-based instructional strategy that utilized a student-centered, active-learning component. Students were evaluated on learning, critical thinking, and epistemological beliefs about biology. Results indicated no significant differences between treatment groups. Interestingly, the impact of active-learning implementations had positive effects on students' epistemological beliefs. This was a finding contradicting previous research in which epistemological beliefs became more novice-like in science majors enrolled in courses without an active-learning component.

Study two represents one case in which a professor with a traditional instructional model became motivated to pursue instructional change in his introductory microbiology

course. A single-case qualitative study was conducted to document the professor's initial effort at instructional reform. Results indicated that his utilization and understanding of reform-based instructional strategies improved over the course of one semester. Furthermore, this sustained effort of reform resulted in positive opinions developed by the professor regarding the use of reform-based instructional strategies in the future.

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CHAPTER ONE: INTRODUCTION

Introduction

The modern initiative to improve science education in the United States can be traced back to the 1980's and the publication of *A Nation at Risk* (National Commission of Excellence in Education, 1983). This document reported that American schools and universities were producing fewer scientists and engineers as compared to other industrialized nations. Furthermore, it described a lack of emphasis on science and mathematics in both secondary and post-secondary education, particularly implicating the quality of teachers and instruction available in chemistry, physics, biology, and mathematics.

Since then, there have been multiple government-funded initiatives and publications calling on educators in science, technology, engineering, and mathematics (STEM) disciplines to transform curriculum and instruction at all levels of education (American Association for the Advancement of Science [AAAS], 1989, 2011; National Research Council [NRC], 1999; National Science Board, 1986; Project Kaleidoscope, 1991). Grounded in cognitive science research on human learning, many of these efforts called for more effective teaching through the incorporation of active, student-centered instruction to promote content relevance, students' critical thinking skills, attitudes, and learning. These particular constructs have been identified as points of emphasis to recruit, retain, and prepare post-secondary students for 21st century jobs in STEM fields (e.g., NRC, 2000, 2003).

Among calls to transform STEM education, there are more specific pleas within the biology education research community to improve how biology is taught at the post-secondary level. These are most evident in discipline-based education research (DBER) literature leading up to (e.g., Allen & Tanner, 2005; Michael, 2006; Smith et al., 2005; Wood, 2009) and following (e.g., Ding & Mollohan, 2015; Linton, Farmer, & Peterson, 2014; Merkel, 2012) the publication of the seminal piece, *Vision and Change in Undergraduate Biology Education: A Call to Action* (AAAS, 2011). Among these efforts are numerous examples of biology professors attempting to shift their pedagogy away from a solely traditional, instructor-centered model toward a reform-based, diversified model that fosters active, student-centered learning in traditional classroom environments (e.g., Ebert-May, Brewer, & Allred, 1997; Knight & Wood, 2005; Powell, 2003; Rutledge, 2008).

Although there is a growing body of evidence that these reform-based initiatives are effective in regards to students' performance measures and attitudes, biology education reformists are concerned that adoption of these strategies are not happening as rapidly or as broadly as needed. These concerns arise from decreased student performance in biology and lack of preparedness for future professional careers in science and allied-health fields (Brownell & Tanner, 2012; Merkel, 2012; Miller, Pfund, Pribbenow, & Handelsman, 2008; Tanner & Allen, 2004; Wieman, Perkins, & Gilbert, 2010). Although numerous studies have focused on identifying barriers that impede faculty adoption of reform-based instructional strategies (RBIS) including resources (Merkel, 2012), time, pedagogical knowledge, and incentives (Brownell & Tanner, 2012; Tagg, 2012), there remains a need to further engage in DBER in an attempt to utilize and

suggest frameworks to address and diminish these barriers. In particular, there is a need for: (1) research-based, content-specific resources that promote active, student-centered learning (Laurer, 2003; Rutledge, 2008); (2) research designed to inform best practices for implementing RBIS to improve student success (Wood, 2009); and (3) research investigating the adoption of RBIS using frameworks that support faculty who are novices at implementing RBIS.

The research presented in this dissertation sought to answer calls to reform biology education and specifically addressed concerns about broad adoption of RBIS. Two separate studies were carried out within the context of a microbiology course taught by a professor with a traditional pedagogy and no experience utilizing RBIS. After 21 years of teaching this course, the professor developed an intrinsic motivation to alter his instructional model. He pursued this goal through a collaborative partnership with the researcher, a biology education researcher and author of this work. Through this collaboration, the following was an effort to promote adoption of RBIS in a traditionally taught microbiology course: (1) development of a set of microbiology active-learning exercises (MicroALEs) designed to promote student engagement and critical thinking by making key concepts of microbiology relevant to learning; (2) evaluation of two distinct active-learning strategies in a microbiology course implemented by a novice to RBIS; and (3) characterization of the perception of instructional change when this microbiology professor implemented RBIS for the first time.

Background of the Study

As noted earlier, research on human learning indicates that the traditional, instructor-centered model, a stalwart in post-secondary science courses, is an inadequate

method for promoting student learning gains, critical thinking skills, and positive attitudes about science (AAAS, 2011; NRC, 2000). Halpern and Hackel (2002) observed that, in regards to the traditional, instructor-centered model used at most colleges and universities, “it would be difficult to design an educational model that is more at odds with current research on human cognition” (p. 3).

Faculty commonly claim they teach this way because this is how they were taught and what worked for them as students (Henderson, 2005). Beyond comfort and familiarity, it is an efficient model for disseminating a large body of scientific facts (Tanner & Allen, 2004). Unfortunately, for these educators that continue to rely on this monoculture of classroom instruction, their instructional model is being recognized as a major factor contributing to underperforming, frustrated students leading to recruitment and retention concerns within scientific disciplines (AAAS, 2011; Mazur, 1998; NRC, 1999; Wood, 2009). These broad concerns in science pedagogy have prompted widespread discipline-specific efforts. Of particular interest here, biology education reformists are actively calling for sweeping changes in the instructional model for post-secondary biology courses including student-centered strategies and scientific teaching practices (Allen & Tanner, 2005; Handelsman et al., 2007).

A reform-based, active, student-centered instructional model is commonly described as fostering engagement in the process of learning and is adapted from constructivist learning theory such that “learning involves the active construction of meaning by the learner” (Michael, 2006, p. 159). In this learning environment, students are asked to build upon their existing knowledge, by assimilating facts and concepts to construct new knowledge. To do this, students interact with their peers and the instructor

to analyze, synthesize, and evaluate evidence (Armbruster, Patel, Johnson, & Weiss, 2009). In contrast, the instructor-centered model is often described as a passive-learning environment well suited for presenting large amounts of facts in a limited amount of time (Tanner & Allen, 2004). Although this is an efficient model for disseminating information, instruction typically stops here, leaving students to memorize outside of class rather than actively engage in knowledge construction during class (Armbruster et al., 2009; NRC, 2000, 2003). This type of instruction has been shown to promote lower-order cognitive skills (i.e., knowledge and comprehension) in students (Bloom, 1956; Crowe, Dirks, & Wenderoth, 2008).

Calls to reform science education recommend incorporating active, student-centered learning components into the traditional lecture model to better prepare students for careers as scientists and healthcare professionals (e.g., NRC, 2003; Wood, 2009). These opportunities provide students with a framework (Michael, 2006) to practice higher-order cognitive skills such as analysis, synthesis, and evaluation of related content (Bloom, 1956; Crowe et al., 2008). Examples include in-class activities such as problem-based learning, think-pair-share, inquiry-based learning, and collaborative learning (Michael & Modell, 2003). Although the positive benefits of active, student-centered instruction have been widely documented in peer-reviewed journals emphasizing biology education (e.g., *CBE—Life Science Education*, *Journal of College Science Teaching*, *Science*) and books (e.g., *Scientific Teaching* [Handelsman et al., 2007]), there is still limited adoption of instructional change that incorporates RBIS in STEM fields at the post-secondary level (Wieman et al., 2010). According to Brownell and Tanner (2012), “the key challenge is convincing many faculty—not just a handful of faculty scattered

across the country but the majority of life science faculty in every institution—to change the way they teach” (p. 339).

A substantial amount of work has been published on the difficulty of instructional change in STEM education (e.g., see literature review by Henderson, 2011). For example, Tagg (2012) argued that many faculty are still unaware of education research, and even if they are, simply resist because they do not view it as a viable or beneficial endeavor for their career. For those that are aware and recognize potential benefits, many experience a level of uncertainty about how to proceed with the task when it requires navigating the research and language of an unfamiliar discipline (AAAS, 2011; Dolan, 2007). Furthermore, for those that do attempt change, additional barriers remain for sustaining reform including: (1) lack of initial improvement in student performance when innovative strategies are first utilized (Mazur, 1998); (2) divergent professional identity from science researcher to education researcher (Brownell & Tanner, 2012); and lack of institutional support (Henderson, Dancy, & Niewiadomska-Bugaj, 2012). These barriers are contributing impediments to the absence of widespread reform in post-secondary science education.

Henderson et al. (2012) argued, despite recent efforts to promote change and disseminate pedagogical knowledge, approximately one-third of faculty who adopt some form of RBIS ultimately quit using it, suggesting that “more attention needs to be given to developing ways to support faculty to be successful in their implementations” (p. 11). Therefore, for faculty interested in alternative teaching strategies, it is simply not enough to provide them with knowledge of resources and implementation strategies. Further, providing brief training and one-day to one-week professional development seminars

does not appear to support sustained pedagogical change (Brownell & Tanner, 2012). In fact, Henderson, Beach, and Finkelstein (2011) concluded from their review of instructional change literature that “effective change strategies: are aligned with or seek to change the beliefs of the individuals involved; involve long-term interventions, lasting at least one semester” (p. 952).

Beyond specific barriers to change in post-secondary science education, Fullan (2007) described instructional change, and the lack of progress in general, at all levels of education. Reviewing the modern history of secondary education reform in the United States, he contended that since the 1960s there has emerged a vast number of ideas on what needs to be done in education; however, “knowing what must be done, . . . is not the same thing as getting it done” (p. 19). Similarly, Elmore (1996) described limited adoption of widespread instructional change as, “We can produce many examples of how educational practice can look different, but we can produce few, if any, large scale numbers of teachers engaging in these practices” (p. 11).

Similar sentiments are expressed in post-secondary science education literature where it is well documented that, although awareness of RBIS is growing, there is limited evidence of sustained reform (Henderson, Finkelstein, & Beach, 2010). This is despite extensive amounts of time and money being spent on efforts to improve teaching and learning (Henderson et al., 2011; Tagg, 2012; Wieman et al., 2010). Unlike secondary education, however, faculty in post-secondary education often lack the formal pedagogical training that their K-12 counterparts possess due to the nature and scope of their preparation as higher education faculty.

Rogers's *Diffusion of Innovation Model* (1995) identified the acquisition of knowledge as the first stage in adopting an innovation. Henderson (2005) confirmed that this was particularly true for a university physics professor attempting to implement innovative instructional practices for the first time. He revealed how this lack of knowledge led to additional barriers such as time constraints and frustration arising from lack of successful implementation. For post-secondary science departments, there is commonly a deficit of science education experience and pedagogical knowledge among faculty. This is largely due to the fact that, historically, departments make faculty hires based on scientific research emphasis and grant funding, not on qualifications associated with teaching and learning (Bush et al., 2006). There is an indication, however, that science departments are increasingly interested in hiring faculty with discipline-specific science education experience (Bush et al., 2013). These new hires are poised to bring valuable experience and knowledge into their respective departments to support instructional reform.

Henderson et al. (2011) offered a thorough critical review of past attempts at instructional change describing a conceptual framework as a potential solution to the lack of widespread adoption. Their framework included four core change strategies for individuals and departments seeking to implement instructional change grounded in DBER. Two of these core change strategies specifically target the individual and are presented here. The first strategy involves disseminating curriculum and pedagogy through workshops and seminars. This represents an accessible way for an interested individual to view demonstrations of RBIS and to ask questions directly about the implementation. Additionally, this person would likely leave with a resource to utilize in

class that supports RBIS. However, as Henderson et al. (2011) indicated, even with knowledge and exposure, faculty may not be able to effectively implement the new curricula once they return to their own classrooms as it may interfere with their traditional instructional model or initially negatively impact students.

The second change strategy presented by Henderson et al. (2011) suggested developing reflective teachers for the purpose of encouraging faculty to introspect on their own teaching. This can be carried out through collaboration with groups of similar faculty seeking to reform their practice by developing a new curriculum. This could also include consultation with a faculty development specialist such as ones located in a center for teaching and learning. Finally, this may include the collection and analysis of student performance data when a new instructional strategy is implemented in order to assess its efficacy.

Although innovative, content-specific resources are needed to facilitate change, it is reasonable to suspect that a biology professor novice to RBIS will encounter difficulty implementing and adopting lasting change if only provided instructional resources but lacking a sustained intervention. Insufficient attempts at instructional reform will continue to produce outcomes driven by instances of change rather than widespread adoption (Wieman et al., 2010). Biology education researchers should not only continue to explore the obstacles that impede but also seek to utilize change models that include sustained support and reflective practices as Henderson et al. (2011) recommended.

The Problem Statement

Currently, there are a growing number of resources that foster RBIS in biology education (e.g., see on-line resources for CourseSource, Data Nuggets, and National

Center for Case Study Teaching in Science); however, there remains a need for content-specific resources designed to support student-centered pedagogies (NRC, 2003; Horak, Merkel, & Chang, 2015; Rutledge, 2008), particularly in high enrollment science courses (Wood, 2009). This is especially true for an introductory microbiology course, where the American Society for Microbiology (Merkel, 2012) has called on instructors to adapt active, student-centered pedagogies that address learning needs of typical students enrolled in this course (i.e., students majoring in biology or preparing for an allied health career). To retain these students and prepare them for professional careers, Merkel (2012) recommended moving beyond the traditional instructional model that emphasizes rote memorization toward approaches that promote lasting understanding of concepts in microbiology as identified in the *American Society for Microbiology Curricular Guidelines for Introductory Microbiology* (see Merkel, 2012).

Additionally, even with access to innovative, content-specific resources, there is real concern that simply providing curricula to a professor, without formal pedagogical training, is not enough to support effective or sustained use of the resource (Henderson et al., 2011). Consequently, professors working independently with an unfamiliar resource are likely to revert back to their traditional instructional model (Henderson, 2005). Ineffective dissemination models of instructional change (Rogan & Anderson, 2011) are considered along with cultural and institutional barriers (Brownell & Tanner, 2012) as primary contributors to the slow pace of widespread adoption of RBIS (Tagg, 2012; Wieman, 2010). Implementing an unfamiliar curriculum that requires new instructional practices is potentially daunting for a professor who self-identifies as a biology research scientist in a department or institution that does not have a framework in place to support

instructional reform (Brownell & Tanner, 2012). Considering deficits of knowledge, experience, and support, it is understandable that only providing reformed curriculum and information on how to use it, fosters uncertainty and, thus, impedes the widespread adoption of RBIS.

The Purpose Statement

The purpose of this dissertation was to report on a grassroots effort to sustain the process of instructional change in a post-secondary microbiology course utilizing a content-specific, student-centered instructional resource and effective change strategies identified by Henderson et al. (2011). To accomplish this, the researcher developed MicroALEs designed to foster an active, student-centered learning environment to engage students in the process of learning and to promote critical thinking about key concepts of microbiology. Rutledge (2008) argued that a lack of content-specific resources is likely a primary factor contributing to continued reliance on the instructor-centered model that emphasizes passive learning. MicroALEs were specifically created to address this concern by offering a content-specific tool for incorporating active learning into a traditionally taught microbiology course. Second, the researcher designed a study to compare two implementation strategies of MicroALEs by a professor without formal pedagogical training or experience utilizing RBIS. Last, the researcher conducted a qualitative study to characterize this professor's perception of utilizing RBIS for the first time. The following section presents the research questions for these two separate studies.

Study One, Chapter Two

The study presented in Chapter Two sought to compare the effect of collaborative student group completion and individual completion of MicroALEs. The purpose was to

evaluate the effect of two active learning strategies on students' critical thinking skills, learning, and epistemological beliefs about biology. Science is often practiced in a collaborative environment in which scientists function in teams to tackle scientific problems. Therefore, a potentially interesting nuance to consider when implementing RBIS is the need to structure student-centered activities in a manner similar to how science is practiced.

The study was conducted over the span of one semester in two sections of a post-secondary microbiology course. Students in one section completed MicroALEs collaboratively and students in the other section completed them individually. A quasi-experimental design was utilized to quantitatively compare collaborative and individual completion of MicroALEs.

Research question one. Does collaborative student group completion of MicroALEs improve students' critical thinking ability compared to when students work individually to complete them?

The researcher was interested in the potential impact on critical thinking when team discussion was utilized to solve scientific problems versus working alone to solve these problems.

Research question two. Does collaborative student group completion of MicroALEs increase students' learning gains of key concepts of microbiology compared to when students work individually to complete them?

There are numerous strategies for incorporating active learning in the classroom; however, the literature was lacking in regards to comparing specific strategies and their effect on learning. Therefore, this question sought to reveal a difference, if any, that

collaborative versus individual cognitive processing had on learning when completing MicroALEs.

Research question three. Does collaborative group completion of MicroALEs shift students' epistemological beliefs about biology toward more expert-like views compared to students working individually to complete them?

As previously noted, Handelsman (2004) recommended that science be taught as it is practiced and typically science is practiced in professional communities that rely on peer-to-peer collaborations to advance scientific knowledge. To support reformed teaching practices in post-secondary biology education, consideration should be given to the effect that these instructional strategies have on students' beliefs about knowing biological knowledge. For this study, the researcher was interested in the effect that collaboration had on epistemological beliefs compared to individual students working alone to complete MicroALEs.

Study Two, Chapter Three

The study presented in Chapter Three sought to characterize the experience of a veteran microbiology professor, with 21 years of experience teaching with a traditional, instructor-centered model, seeking to implement a reform-based instructional change. A qualitative, single-case study was conducted to characterize his sustained adoption of MicroALEs, bound by one semester in a post-secondary microbiology course. The following three questions were addressed from data collected in the context of this study.

Research question one. What motivated a veteran professor, with a traditional instructional model, to engage in the process of instructional change?

Researcher question two. How did the professor experience the process of instructional change within the context of this study?

Researcher question three. What changes, if any, occurred in the professor's beliefs about utilizing student-centered strategies?

Significance of the Study

There are numerous examples in the literature of studies comparing active learning to traditional passive learning (e.g., Armbruster, Patel, Johnson, & Weiss, 2009; Ebert-May, Brewer, & Allred, 1997; Hake, 1998; Knight & Wood, 2005). Additionally, there are many studies claiming that collaborative group activity (as an active learning strategy) is an effective intervention to promote student success (e.g., Dauer, Momsen, Speth, Makohon-Moore, & Long, 2013; Smith et al., 2009). Although informative, these studies are often designed as a pre-instruction and post-instruction assessment presented as action research in that an intervention was evaluated but not experimentally compared to an alternative intervention. Therefore, to broaden the implication of this study beyond just the evaluation of MicroALEs, the research design included a nuanced investigation of two distinct active learning strategies utilizing the same reform-based resource. Specifically, the researcher compared the differences between individual and collaborative group completion of MicroALEs on three measures of student performance and success. The details of which will be further discussed in the methodology overview presented next and then again in Chapter Two where a description of both strategies will be described in detail as they relate to the context of the study.

In addition to reform-based curriculum design and evaluation, the researcher was interested in models to support the formation of communities of practice for promoting

broader adoption of RBIS. To address this, the researcher sought to characterize the experience of a veteran professor implementing an active, student-centered RBIS for the first time while he was engaged in a collaborative learning community to support his adoption and implementation of reform-based instruction. Specifically, the researcher was interested in how his perception of himself changed from an administrator of an active-learning activity versus a facilitator of active learning. This qualitative study provided meaningful insight on how professors, with a similar background, conceptualize instructional change of this nature, an area addressed in other disciplines (e.g., post-secondary physics education [Henderson, 2005]) but absent in biology education literature. Finally, the researcher sought to contribute to widespread reformation efforts in post-secondary biology education by investigating reform through the lens of a grassroots collaborative partnership between a biology education researcher and a microbiology professor with a traditional instructional epistemology.

An overarching goal for this research was to describe a full semester dissemination model that supported the professor in his attempt at instructional reform. This model and the context of this dissertation are described next.

Overview of the Methodology

This research was conducted in a biology department at a large, public university in the Southeastern United States under the approval of the university's Institutional Review Board (protocol #15-027, see Appendix A). The purpose of this dissertation was two-fold:

1. to evaluate a reform-based, content-specific tool (MicroALEs) utilizing two distinct active-learning strategies implemented by a professor with a traditional instructional model; and
2. to characterize the experience of this professor's attempt at instructional reform.

A biology education researcher and a professor of microbiology that was interested in RBIS collaborated on the development of a set of active-learning exercises (MicroALEs) to be used by the professor as a tool to diversify the traditional instructional model on which he had relied for the past 21 years. This tool was developed utilizing RBIS and the established learning goals set forth by the professor for an introductory microbiology course. Following a semester in which the researcher piloted MicroALEs in an introductory microbiology course, two studies were conducted to evaluate their use and implementation during a 14-week semester. This dissertation reports on data collected and analyzed in the context of this research in which the professor implemented MicroALEs using two distinct implementation strategies. Following recommendations by Henderson et al. (2011), the researcher provided direct and sustained support to the professor for the duration of the semester as he attempted to implement RBIS for the first time.

Quantitative and qualitative approaches were utilized to conduct the two studies within the larger dissertation study. Both studies were conducted within the same research context. Study One (Chapter Two) was a quantitative study utilizing a quasi-experimental design to compare two distinct active learning strategies for their effect on three constructs of student performance and success. First, to evaluate critical thinking

skills, the Holistic Critical Thinking Scoring Rubric (HCTSR) was used to score participant responses to an individual summary question completed at the end of each MicroALE. Second, to evaluate participant learning gains, the Host-Pathogen Interaction (HPI) concept inventory was given in a pretest and posttest format on the first day of class and again on the last day. Finally, to evaluate participant epistemological beliefs about biology, the Colorado Learning Attitudes About Science Survey for use in biology (CLASS-Bio) was utilized in a pretest and posttest design to determine the effect of instruction on students agreement about learning biology and biological knowledge as compared to experts in the field of biology.

Study Two (Chapter Three) was a qualitative single-case study design. The purpose was to characterize the perception of instructional change attempted by a microbiology professor. This professor had 21 years of experience utilizing a traditional, instructor-centered model but was increasingly dissatisfied with student performance and engagement in his microbiology course. Through a collaborative partnership with a biology education researcher (the author) he attempted to implement RBIS for the first time in his career. The researcher conducted pre-semester and post-semester semi-structured interviews to understand his motivation to change and overall perception of implementation of RBIS. Semi-structured interviews were conducted after each MicroALE implementation to characterize his self-efficacy, his perception of the value of the strategy, and his role as the instructor in the implementation of each MicroALE. The researcher collected reflective journal entries written by the professor. Journal entries were intended to prompt deeper reflection on his teaching practice and perception of value of RBIS and specifically MicroALEs. Finally, the researcher collected classroom

observation data as a non-participant to provide a rich description of the classroom setting and the professor's implementation of MicroALEs.

Limitations

This study had two primary limitations. First, the same professor taught two sections of a large lecture microbiology course in the same semester; however, the sections met in different classrooms. The collaborative treatment sections met in a new classroom with mobile chairs and desks whereas the individual treatment section met in an older, stadium-style lecture hall. The two distinct classroom settings should be noted here as a potential confounding variable. As Kober (2015) discussed, mobile classroom arrangement is thought by some to enhance opportunities for active learning while others contend that, the lack of an ideal space for active learning is not necessary, as student-centered instruction is adaptable and still effective in traditional lecture hall designs.

Second, MicroALEs were used as the instructional intervention in both sections. These were developed and piloted in a previous semester; however, data was not collected during that time on their use. This study marks the first time in which the impact of MicroALEs was measured, therefore findings from this study are potentially limited by the quality of MicroALEs as an effective resource for implanting instructional change.

Delimitations

This study had two notable delimitations. First, although the purpose of the quantitative study was to evaluate MicroALEs as they were implemented by a novice, it is possible that the impact of the interventions were not fully realized due to the learning curve required for effectively implementing active, student-centered instructional

strategies. This delimitation, however, was purposeful and an important component, particularly to the purpose of the qualitative study and the interpretation of the overall dissertation.

Second, the quantitative study (Chapter Two) was a quasi-experimental design without a true control sample. This is commonly encountered in educational research, particularly when assessing the practical value of an instructional intervention.

Manipulating participants in an educational research setting to include a true randomized control is challenging and subject to ethical concerns.

Definitions

Active Learning

Active learning is the process of having students make meaning of the content and formulate explanations in their own words through engagement with each other and/or the instructor in some activity relevant to key concepts of the discipline (Allen & Turner, 2005). Smith et al. (2005) developed the Active Learning Course Framework and stated that “active learning is designed to engage students in activities valuable to a research scientist” (p. 144). Active learning differs from passive learning regarding the role of students and the instructor in the classroom (Michael, 2006; Volpe, 1984).

Passive Learning

Passive learning is characteristic of a traditional instructional model where students take notes on verbal and visual information provided didactically by the instructor (Volpe, 1984). It differs from active learning in that in a passive learning environment information presented is intended to be memorized for recall on a test rather

than utilized in the classroom in activities involving peer-to-peer or student-to-instructor interaction (Wood, 2009).

Student-centered Instruction

Student-centered classroom instruction revolves around the student and features student-student and instructor-student interaction. It is often contrasted to the traditional, instructor-centered pedagogy. In this model, the emphasis is on what the students are doing to support learning, rather than what the instructor is saying as content to be learned; the instructor fosters opportunities in the classroom for students to interact with the content either individually, collaboratively, or both (Michael, 2006).

Instructor-centered Pedagogy

The instructor-centered pedagogy is a transmission approach that revolves around the instructor's plan for lecturing to students, and is often contrasted to the student-centered model. The instructor-centered model emphasizes the teaching process rather than the students' process of learning (Wood, 2009), and typically lacks opportunities for student-student or instructor-student interaction.

Chapter Summary

Numerous studies, across a variety of scientific disciplines, have documented the positive impact that even moderate shifts in the instructional model can have on student learning and attitude (Hake, 1998; Michael, 2006; Powel, 2003). These include studies within university-level biology courses that demonstrate the benefit students receive from adding active learning opportunities in large lecture settings (Armbruster, Patel, Johnson, & Weiss, 2009; Knight & Wood, 2005) or flipping the classroom where that direct

lecture is entirely replaced by whole class discussion and content delivery is moved to out-of-class experiences (Marcey, & Brint, 2012).

Although many studies have documented the positive effects of the utilization of active learning, these treatments are often compared to no intervention at all with a traditional instructional model serving as a control group (Linton, Farmer, & Peterson, 2014; Michael, 2006); however, not all efforts to promote active learning are effective (Andrews, Leonard, Colgrove, & Kalinowski, 2011). Therefore, to encourage broader adoption of RBIS among faculty with traditional instructional practices, more in-depth research must ensue to identify components of active learning that are effective (Linton, Farmer, & Peterson, 2014), resources that are accessible and relevant to learning goals (Merkel, 2012), and that can be implemented with minimal, formal pedagogical knowledge and support staff (teaching assistants, co-instructors, etc.).

CHAPTER TWO: COMPARISON OF TWO DISTINCT ACTIVE-LEARNING STRATEGIES IN AN UNDERGRADUATE MICROBIOLOGY COURSE

Introduction

Recent national reports have compiled convincing evidence to encourage college and university science faculty to adopt instructional strategies grounded in discipline-based education research (DBER) (American Association for the Advancement of Science [AAAS], 2011; National Research Council [NRC], 2012). The findings described in these reports stem from efforts by a growing field of science education researchers (Bush et al., 2015) responding to calls to reform post-secondary curriculum and instruction. The fact that these ongoing calls extend back several decades and continue today is evidence that concerns of reform persist despite receiving nationwide attention from policy documents (e.g., AAAS, 1989; NRC 1999, 2000, 2003; National Science Foundation [NSF], 1986, 1996; Project Kaleidoscope, 1991, 2006), peer-reviewed science journals (e.g., *Nature*, *PLOS ONE*, *Science*), DBER journals (e.g., *Journal of College Science Teaching*, *CBE—Life Science Education*), and substantial financial support from public and private sources (e.g., NSF and Howard Hughes Medical Institute [HHMI]) (Brownell & Tanner, 2012; Tagg, 2012).

A primary concern noted in these reports is the adverse effect of traditional science instruction on student performance and success in STEM disciplines. This traditional approach characterizes the student role as “a passive note-taker and regurgitator of bits of facts” (Volpe, 1984, p. 431) and “learning fragmented factual information and rote problem solving methods” (Wood, 2009, p. 95). These characterizations are instigating the numerous and sustained calls for educators to shift

away from the ubiquitous didactic lecture of a traditional, instructor-centered pedagogy to a multi-dimensional model that diversifies instruction to include student-centered components (e.g., inquiry-based activities and collaborative active learning) interwoven with traditional instruction (Preszler, 2006; Rutledge, 2008; Smith, Wood, Krauter, and Knight, 2011). The following sections describe both of these instructional practices and present specific calls and research supporting the shift toward a more diversified model of instruction in post-secondary science courses that emphasizes conceptual understanding and creative problem-solving skills in lieu of sole reliance on rote memorization of facts fostered by traditional instruction.

Instructor-centered Model

The instructor-centered model, a stalwart in science courses at large universities, is characterized as traditional didactic instruction. This model revolves around the professor lecturing to the students while most students sit passively taking notes (Wieman, Perkins, & Gilbert, 2010). Students are considered passively learning in this model because they are not actively interacting with or using the content, rather they are just transcribing what the professor is saying. Because this model is efficient for delivering vast amounts of content, it is typically the primary form of instruction in content-heavy courses (Powell, 2003); however, the process of passively taking notes fosters superficial learning and often does not promote cognitive engagement nor allow time for critical analysis of information (Handelsman et al., 2007). Notably, critical analysis of information is a skill considered vital for scientific education and practice in the 21st century (NRC, 2003, 2009). Furthermore, many argue that sole reliance on

traditional instruction is failing students and their future success as scientists and healthcare professionals (NRC, 2000, 2003; Powell, 2003; Wood, 2009).

Although science education research has demonstrated effective, alternative methods to improve student learning and success through active engagement during lecture, there remains a lack of widespread adoption of reformed-based practices that promote active learning (Brownell & Tanner, 2012). Many have discussed causes for this which include lack of time, knowledge, and resources available to faculty for adopting new instructional strategies, lack of acceptance that student-centered instruction is effective, and insufficient models for disseminating and supporting broad instructional change (D'Avanzo, 2013; Henderson, 2005; Kober, 2015). These recognized impediments are thought to foster a culture of resistance among faculty to reduce their dependence on traditional pedagogy (Tagg, 2012; Wieman, 2010). In addition, they themselves often succeeded in this traditional style during their own undergraduate education, and these anecdotes from experience may ironically take precedence over rigorous data (Andrews & Lemons, 2015).

Even as reliance on the ubiquitous traditional pedagogy remains, there is evidence that change is occurring (Gardner, Bonner, Landin, Ferzli, & Shea, 2016); therefore, when change does occur, one wonders what is promoting traditionalists to adopt reform-based instructional approaches. Gess-Newsome, Southerland, Johnston, and Woodbury (2003) reported that pedagogical discontentment with one's current teaching is a leading factor for motivating instructional change. Notably, the research presented in this dissertation was founded on a case of pedagogical discontentment. In particular, a grass-roots initiative of instructional reform was attempted by a traditional microbiology

professor who was dissatisfied with student performance and engagement in his courses. As a result of this discontentment, the professor initiated a sustained, collaborative partnership with the author, a biology education researcher, to diversify his traditional instructional model. The instructional model is discussed next.

Diversified Instructional Model

An alternative method to the traditional didactic lecture approach is a diversified instructional model. This model incorporates active-learning practices such as peer-to-peer discourse and instructor-led inquiry into the traditional instructor-centered lecture format as described and evaluated by Rutledge (2008) in a university-level, introductory biology course. According to Rutledge, the diversified model was demonstrated as an effective format for maintaining efficient traditional lecture components while also promoting students' active engagement in the process of learning during lecture.

Specifically, students in this classroom were divided into small groups of three to four to discuss scenarios posed by the professor related to biological content of the course interwoven with societal issues related to biology such as cloning and global warming. Following the peer-to-peer component, the professor guided students in a whole class discussion in which individual students were called on to present their group's analysis of the posed scenarios.

In a similar study, Preszler (2006) found that "student-centered activities result in meaningful learning at a meta-cognitive level" (p. 25), and stated that small collaborative student group learning opportunities can "compliment lecture by providing a social context in which a student constructs individual understanding of the content presented in lecture" (p. 21). Darland and Carmichael (2012) provided additional evidence that

supports the inclusion of active-learning practices into traditional, teacher-centered lectures by including explicit opportunities for students to critically analyze information individually, through active engagement with their peers, and whole class discussion with the instructor. These types of opportunities for student-centered learning in a traditional lecture can potentially reduce emphasis on rote memorization, while fostering deep and meaningful discussions associated with higher levels of cognition.

In a diversified model, the role of the instructor shifts from strictly a content deliverer to one that is a facilitator of student-centered activities intended to engage students in the process of learning (e.g., Armbruster, Patel, Johnson, & Weiss; Knight & Wood, 2005; Rutledge, 2008). There are at least three fundamental shifts in a student-centered classroom that potentially challenge faculty not formally trained in reform-orientated pedagogies. First, facilitating active learning may place a professor in an unfamiliar role in the classroom. For example, the professor is challenged to use novel resources while moving about the classroom, interacting with students through direct discourse, and thus breaking invisible barriers that exist when students are in their seats and the professor is on the stage. This shift includes nurturing relationships between students' prior knowledge and experiences with new information to promote their conceptual understanding of the content (Alters & Nelson, 2002).

A second fundamental shift from the traditional lecture calls for faculty to relinquish control, at times, of the conversation in the classroom. For example, to incorporate student-centered learning in a traditional lecture the professor is no longer the only source of information, but is the facilitator of knowledge construction in which students are contributing to the conversation about content covered in class. The

professor must relinquish some control of the lectern, letting this conversation develop while at the same time being aware of students' interpretation of facts which may be rife with misconceptions or require further elaboration (Knight & Wood, 2005; Smith et al., 2005). Leaving this comfort zone is more than a physical challenge of crossing the imaginary barrier between where students sit and where the professor lectures. It is also an intellectual challenge that may be viewed positively or negatively by the professor as it requires an ability to redirect conversation and counter with factual scientific content.

Finally, the professor must fundamentally shift the allocation of time spent on delivering content. The diversified approach requires efficient use of time in order to present a sufficient amount of facts in a traditional manner while allowing ample time for student-centered learning (Knight & Wood, 2005). Considering these fundamental shifts, it is reasonable to suggest the professor will need a different set of resources, preparation, confidence, and pedagogical knowledge in order to diversify one's traditional pedagogy using constructivist practices that feature active learning components.

In addition to considering the shifting role of the professor, an emerging emphasis on active learning in post-secondary science courses is altering the student's role in the classroom. According to Knight and Wood (2005), "the unfamiliar demands of an active-engagement course may take [students] out of their comfort zone" (p. 306). This is not to say the idea of learning has historically been absent, but rather the type of learning and purpose of instruction is changing as a result of numerous studies documenting the benefits of active engagement in student-centered classrooms (Michael, 2006). Still, the shift students face when they encounter active learning in a course typically taught in a traditional manner is potentially considerable, thus students' successes and perceptions of

instruction should be subject to experimental testing when seeking to shift instructional practices.

For example, Smith et al. (2005) evaluated the effect of an active-learning, student-centered component fused with a traditionally taught large enrollment undergraduate biology course. They found that the redesigned (diversified) course increased students' engagement in the content and that students' expressed appreciation of real-world context that the active-learning component fostered. Through the incorporation of active-learning components, students were presented with opportunities to reflect on content and develop critical-thinking skills by activating higher order cognitive processes (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956). These opportunities, demonstrated successful by many biology education researchers, have sustained the on-going calls to reform post-secondary biology teaching and learning.

Furthermore, these reports inform faculty that students should be doing more than just taking notes in class. Rather, they should be actively learning during class by completing tasks, interacting with their peers, and engaging in meaningful conversation with the professor. These reform-based, active-learning activities are shown to promote engagement and improve student learning outcomes (Ambruster, Patel, Johnson, & Weiss, 2009; Linton, Farmer, & Peterson, 2014).

Active Learning

Active learning, as an instructional strategy, is informed by research on how humans construct knowledge through individual or collaborative problem solving. It is often shown to positively impact post-secondary science students' attitude and performance when compared to passive, instructor-centered teaching (Hake, 1998; NRC

2000; Wood, 2009). Active learning is often contrasted directly to a traditional pedagogy centered around didactic instruction in which students leave the classroom with a written or audio record of an instructor's presentation of content. For example, Barr and Tagg (1995) discussed this contrast as an educational paradigm shift from a traditional instructional model that emphasizes *teaching* to a student-centered model that emphasizes *learning*. With the inclusion of active-learning components into the traditional lecture, students' have the opportunity to evolve from note-taking machines to socially engaged participants in learning that combines listening and note-taking skills with critical analysis and communication of information. Notably, the latter of these represents attributes supported by consortiums of scientists and educators (AAAS, 2011; NRC, 2003) for preparing students who enter into professional roles in the science fields.

Although there are numerous studies documenting the use and benefits of active learning across all science disciplines (reviewed by Michael, 2006), Andrews, Leonard, Colgrove, and Kalinowski (2011) found that most active-learning research efforts that reported positive student outcomes were taught by instructors with a background in science education. Furthermore, when they included active learning studies conducted in introductory biology courses taught by faculty without science educational experience, they found minimal or no evidence of student learning after an active learning intervention. This finding is particularly troublesome since the faculty being called to reform their instructional practices are often those without a science education background (Andrews et al., 2011).

According to Henderson (2005), educational reform for faculty without formal pedagogical training is challenging and time consuming, potentially reducing the benefits

of active learning or even negatively impacting student learning and attitudes. Furthermore, Henderson (2012) investigated the sustainability of reform-based instruction and found that 32% of faculty that attempted active-learning strategies reverted back to their traditional practices, thus indicating a problem with the dissemination of curricula. With biology departments across the country composed of mostly faculty trained in biology research, the broad adoption of reform-based instruction likely hinges on the dissemination of curricula and the initial implementation success experienced by these traditional faculty, who may lack formal pedagogical knowledge.

To address the lack of pedagogical knowledge, training, and experience, there are a number of recent publications describing the implementation of specific reform-based strategies designed to support traditional faculty attempting to diversify their instructional model (e.g., AAAS, 2011, Handelsman et al., 2007; Kober, 2015). However, even with access to these valuable resources, there are concerns that accessing and interpreting these types of resources is challenging for the traditional faculty they target (Dolan, 2007). Henderson, Beach, and Finkelstein (2011) described this as the dissemination model in which simply creating and providing resources to faculty lacking formal pedagogical training is not enough to support effective or sustained use of reformed instructional practices. Furthermore, many attribute ineffective dissemination models of curriculum and instructional practices (Rogan & Anderson, 2011) as a primary contributor for the slow pace of widespread reform (Tagg, 2012; Wieman, 2010). Therefore, to advance the progress of initiatives to reform biology education, plans of action should include the adoption of proven frameworks to support this challenging endeavor.

In summary, there is real concern that over-reliance on the traditional, instructor-centered lecture model at the post-secondary level is failing students in science (Powell, 2003). Particularly within the biology education community, there is concern that traditional biology instruction and assessment over-emphasize rote memorization and lower-order cognitive skills (Crowe, Dirks, & Wenderoth, 2008). Despite the evidence indicating active learning is an effective instructional practice (D'Avanzo, 2013), adoption of active, student-centered instruction is not occurring as broadly or as rapidly as desired (Tagg, 2012). Considering the challenges of reform, biology education researchers must continue to promote DBER and pursue opportunities to positively engage traditional faculty through utilization of proven frameworks to support sustained practices of reform-based instructional strategies (RBIS).

Purpose of the Study

The purpose of this study was to compare two distinct strategies for diversifying a traditionally taught microbiology course. Both strategies utilized the same customized set of active learning exercises designed to incorporate student-centered learning opportunities into a didactic lecture course. Specifically, this study compared the effectiveness of individual versus collaborative student group completion of active-learning exercises when active learning was facilitated by a professor without previous pedagogical training and, therefore, considered a novice to reform-based instructional strategies. An overarching goal of this study was to evaluate a customized student-centered resource for incorporating active learning into a traditionally taught microbiology course.

If student-centered, active-learning approaches are considered effective, but only when implemented utilizing particular strategies and by faculty with experience utilizing RBIS, then research needs to consider active learning frameworks that distinguish effective components that can be successfully implemented by faculty without a formal background in science education. To promote broader adoption of student-centered, active-learning components that support reform efforts in post-secondary biology education, this current study sought to distinguish the difference between two active learning strategies implemented by a microbiology professor who was a novice at using reform-based instructional strategies. Notably, this professor was engaged in a collaborative partnership with a biology education researcher that provided guidance outside of the classroom for planning the implementation of these two particular strategies. The following describes three research questions that were investigated within this context.

Research Question One. Does collaborative student group completion of active-learning exercises improve students' critical thinking ability compared to when students work individually to complete them?

Research Question Two. Does collaborative student group completion of active-learning exercises increase students' learning gains of key concepts of microbiology compared to when students work individually to complete them?

Research Question Three. Does collaborative group completion of active-learning exercises shift students' epistemological beliefs about biology toward more expert-like views compared to students working individually to complete them?

Methods

This study emerged from a collaborative effort between a biology education researcher and a microbiology professor. The purpose of this partnership was to facilitate adoption of a reform-based instructional strategy into a traditionally taught introductory microbiology course. The result of this effort was the creation of a customized set of 10 microbiology active learning exercises (MicroALEs) and a comparison of two distinct implementation techniques (treatments) utilizing MicroALEs. A description of MicroALEs design and a brief rationale for their construction is presented next followed by the methods utilized to compare implementation techniques.

MicroALE Design

This study was meant to broaden the existing body of research on active learning in that this is not a comparison of traditional instruction versus some form of innovative teaching practice carried out by a science education specialist, as the researcher and others (Andrews et al., 2011) believe such comparisons have been sufficiently addressed in the literature. Rather, the emphasis here was a comparison of two active-learning implementation strategies utilized by a novice to reform-based instructional strategies.

MicroALEs were designed to be incorporated into a traditional, instructor-centered microbiology course. Their design was based on the protocol published by Rutledge, Bonner, and Lampley (2015), who described and evaluated the use of a similar active-learning curriculum developed for a general education biology course. One MicroALE can be completed in less than one 50-minute class period, thus they are not a case study activity that can extend across multiple class meetings. Their design is flexible in that the professor does not have to use them in a particular order, and their

implementation time can be adjusted depending on students, and specific directions can be given for their completion. In particular, this study sought to differentiate two strategies for completion that varied by the instruction given to students for completing each MicroALE.

MicroALEs were designed to follow a brief period of lecture, generally 10-20 minutes. Students are provided a MicroALE as a handout in class. Appendix 2.A provides an example of a MicroALE utilized in this study. Each MicroALE consists of four structurally similar elements that guide their implementation—*scenario*, *expert analysis form*, *debriefing*, and *summary question*.

Scenario. The *scenario* is a brief reading that relates to the content of the lecture. The nature of this reading presents societal and/or scientific positions related to historical contexts or current events in microbiology. The *scenario* serves as a hook that aims to prompt students to think about the relevance of content covered in lecture in relation to the field of microbiology. Students are given approximately five minutes to read the *scenario*.

Expert analysis form. Each MicroALE contains three to five inquiry-based questions. These are presented on the *expert analysis form* in which a student utilizes his or her information from course content, general scientific knowledge, and personal beliefs to construct an expert-like response. Possible responses include creating graphs, modeling, designing experiments to test claims, or taking a position or making inferences based on provided evidence. Students are given approximately 15 minutes to complete the *expert analysis form* depending on the preference of the professor. While students work on this form, the professor moves about the room interacting with students by

offering advice on responses and evaluating student progress. The role of the professor is not to provide answers to the questions but to engage students as they think critically about the *scenario* and questions.

Debriefing. Following student completion of the *expert analysis form*, the professor facilitates a whole-class discussion based on student responses. He selects students at random asking them to give their responses aloud to the entire class. During this time, the professor can elaborate and/or correct student conceptions on which their responses are based. Here again, the role of the professor is not to provide explicit answers but to foster construction of knowledge through discussion. The *debriefing* is allotted approximately 10-20 minutes depending on the professor's decision as the facilitator.

Summary question. At the conclusion of the *debriefing*, the *summary question* is distributed to students. This question serves to summarize the preceding whole-class discussion. Students are expected to demonstrate critical thinking and scientifically accurate information. In general, students will be prompted to take a scientific or personal position or to make an inference based on evidence presented and discussed during the prior three elements of the MicroALE. Students are given approximately five minutes to complete before submitting their response to the professor.

MicroALE Rationale

The rationale for the design of MicroALEs was to facilitate student-centered instruction using active learning. That is, MicroALEs were created to engage students in the process of learning microbiology by providing a framework for the construction of knowledge in the classroom as an alternative to rote memorization fostered by didactic

lecture. Specifically, this resource was intended to prompt critical thinking, improve conceptual knowledge of microbiology, and align students' epistemological beliefs about biology toward more expert-like beliefs of practicing scientists. The following describes the rationale for the measurement behind each of these performance measures that were utilized in this study.

Critical thinking. Calls to reform biology education emphasize the importance of curricula that capture the nature of science and bring the process of scientific-inquiry and discovery into the classroom (AAAS, 2011; Kober, 2015; NRC, 2003). For example, Handlesman, Miller, and Pfund (2007) called for “scientists to bring to teaching the critical thinking, rigor, creativity, and spirit of experimentation that defines research” (p. 1). Facione and Facione (1994) described critical thinking as “the process of making purposeful, reflective, and fair-minded judgments about what to believe or what to do” (p. 1) and that “individuals and groups use critical thinking in problem solving and decision making” (p. 1). Critical thinking is a valuable skill to foster among all students of higher education (Glaser, 1985), and it is an especially important construct to promote in students majoring in science and pre-allied health fields who will one day rely on critical analysis to make informed decisions about problems they face in their professional careers (Daly, 1998; Facione, Sanchez, & Facione, 1995).

Student learning gains. MicroALEs were designed to actively engage students in the process of learning. That is, they are intended as a tool for the professor to utilize in-class to promote active participation, which has been associated with increased learning gains (Knight & Wood, 2005). MicroALEs prompt students to use principles of microbiology, simply delivered as facts in a traditional instructional model, and to

conceptualize host-pathogen interactions. Their implementation is designed to construct deep, meaningful learning opportunities rather than relying on a passive learning instructional model that promotes short-term retention of information associated with the memorization of facts.

Epistemological beliefs. Epistemological beliefs about biology are an important construct to consider when implementing innovative instructional strategies (Semsar, Knight, Birol, & Smith, 2011). Student attitude and acceptance about the nature of scientific knowledge and learning science is potentially tied to retention and student success (Moll & Milner-Bolotin, 2009; Perkins, Adams, Pollock, Finkelstein, & Wieman, 2005); therefore, it is important to consider nuanced components of instructional strategies that seek to engage students in the discipline utilizing active-learning strategies. The demographic of students majoring in pre-allied health and biology is predominantly represented in a microbiology course, and thus, is an important group to consider in regards to epistemological beliefs about biology. As future professionals, these students need to practice and develop expert-like thinking that drives habits of the mind similar to those within the field in which they will continue. Interestingly, Ding and Mollohan (2015) and Semsar et al. (2011) demonstrated that students majoring in science experienced shifts toward more novice-like beliefs after one semester of a content intensive science course.

Collaborative and Individual Completion of MicroALEs

In this study, collaborative student group completion was compared to individual student completion of the *expert analysis form* component of MicroALEs. In this nuanced approach, the goal was to compare the impact of collaborative student group

work versus individual student work on three measures of student performance: critical thinking, learning, and epistemological beliefs about biology. Quantitative data was collected to compare the effect of two distinct implementation strategies (treatments) of MicroALEs in a general microbiology course. Data collection spanned the length of one, 14-week semester in two large-lecture sections. Prior to the first day of class, a randomization method was used to determine which section received Treatment 1 (henceforth referred to as Section 1) – individual student completion of the *expert analysis form* and Treatment 2 (henceforth referred to as Section 2) – collaborative student group completion of the *expert analysis form*. Effort was made to keep all other components of the course identical between the two sections. Data was collected in both sections utilizing three pretest and posttest instruments for analyzing the effect of each strategy within group (section) and for comparing the active-learning strategies between groups on the constructs of student learning, critical thinking skills, and epistemological beliefs about biology as defined in the literature background section above.

Research Context

This research was conducted in a biology department at a large, public university in the Southeastern United States under the approval of the university's Institutional Review Board (protocol #15-027). The setting for this research was a general microbiology course designed to cover the principles of microbiology targeting students majoring in science and pre-allied health fields. The pre-requisite for enrolling in the course was a two-semester sequence of General Biology. Two sections of the microbiology course were taught in the fall of 2014 by the same professor and met three times per week on Monday, Wednesday, and Friday for 55-minutes. Section 1 met from

12:40 to 1:35 PM, and Section 2 met from 9:10 to 10:05 AM. Both sections received the same lecture notes in a didactic lecture format in which the professor provided notes to the students orally and by displaying pre-prepared written notes, diagrams, and scientific journal articles. Technology used to display these notes included PowerPoint and an ELMO document camera.

Faculty. The professor attempting change in this study had taught microbiology for the past 21 years at this university using the same traditional, instructor-centered instructional model. The utilization of active learning for this study marked his initial experience for implementing reform-based instructional strategies (a single-case qualitative study documenting this experience is presented in Chapter Three). The professor described his traditional pedagogy as direct lecture with minimal interaction or discourse between himself and the students either before or after class. According to the professor, this imaginary wall was not purposeful, but it developed as a consequence of his content delivery mechanism.

Role of the researcher. The researcher and author is a doctoral candidate specializing in biology education. The researcher was not involved in day-to-day classroom instruction or implementation of MicroALEs; however, as previously mentioned, the professor and the researcher formed a collaborative partnership at the bequest of the professor attempting to reform his pedagogy for this particular microbiology course. This collaboration included meetings before each MicroALE implementation intended to prepare the professor for incorporation of MicroALEs into his traditional lecture format.

Notably, the professor was familiar with MicroALE topics as a result of a previous semester (fall 2013) in which the researcher co-taught a section of this course with the professor for the purpose of piloting MicroALEs. At that time, however, the focal professor did not have a role in implementing MicroALEs, nor was he present in the classroom while students completed MicroALEs. Therefore, he was unfamiliar with their specific strategies for use prior to this study. To customize MicroALEs for his course, the professor contributed to the creation of the MicroALEs by providing exhaustive lecture notes and handouts from his previous experience teaching the course.

Prior to data collection, the researcher aligned each MicroALE with specific content topics (original to the course) listed in the syllabus and advised the professor on the timing of utilization of each based on his progression through these topics (Table 2.1). It was ultimately the discretion of the professor as to the specific date (Table 2.1) a MicroALE was implemented. The original research design called for 10 MicroALEs to be implemented over the span of the semester; however, scheduling conflicts, such as approximately scheduled exam dates, resulted in deviation from the original design and the need to eliminate three MicroALEs. A preparation meeting preceded each MicroALE implementation. During this time the researcher reviewed the MicroALE to be implemented with the professor and the guidelines of implementation for both sections to maintain the integrity of the research design (individual versus collaborative).

Table 2.1

MicroALEs Used for the Related Course Topic and Date of Implementation

MicroALE	Topic	Date
No. 1	Introduction to Pathogens	9/10
No. 2	Prokaryotic Cell	9/22
No. 3	Biotechnology	10/15
No. 4	Control of Microorganisms	10/27
No. 5	Epidemiology and Disease	11/10
No. 6	DNA and RNA Synthesis	11/24
No. 7	Epidemiology and Disease	12/1

Participants

A total of 142 students signed consent forms to participate in the study. See Appendix 2.B for demographic survey. Section 1 began the semester with 99 students enrolled, and 86 (87%) agreed to participate in the study. Section 2 began the semester with 60 students enrolled, and 56 (93%) agreed to participate. For all participants, 35% self-identified as majoring in biology, and 50% identified themselves as being in a pre-allied health field. In general, females (77%) made up the majority of the students enrolled in this course and participants were mostly sophomores and juniors with 77% of all students being between the ages of 18 and 22.

Treatments

Section 1: Individual completion of MicroALEs. For the days on which a MicroALE was utilized (seven times) in Section 1, the professor began by informing the students that there would be a short lecture followed by a MicroALE. The lecture lasted approximately 20 minutes, thus leaving approximately 30 minutes to complete the MicroALE. Following the lecture, the professor distributed the MicroALE to students. This included the *scenario* and the MicroALE *expert analysis form* that contained inquiry-based questions with space provided for student response. The *summary question* was distributed after the students completed the MicroALE and the professor-led *debriefing* concluded. The professor verbally gave instructions for completion and a brief summary of the scenario and inquiry-based questions.

For Section 1, students were instructed to read the *scenario* and complete the *expert analysis form* individually. Students were encouraged to use class notes, the scientific reading, and their understanding of microbiology concepts to form responses. Following this period, the professor led the whole-class *debriefing* in which students were selected at random to verbalize their individual responses to a particular question on the *expert analysis form*. During this time the professor interacted with the students to determine if this was a suitable response or if further explanation was needed. He encouraged students to form their own correct answers rather than explicitly telling them possible answers. After the *debriefing*, the professor distributed the *summary question* and instructed students to use the remaining class time to provide an individual written response. Students turned in their completed MicroALE with the *summary question* as they exited the classroom.

Section 2: Collaborative completion of MicroALEs. The treatment for Section 2 followed the same general implementation procedure as Section 1 with the exception of how students completed each MicroALE. That is, for each class period that a MicroALE (seven times) was implemented, the professor informed the students of a brief lecture (approximately 20 minutes) followed by a MicroALE (approximately 30 minutes). Following the lecture, the professor distributed the MicroALE and introduced the topic and instructions for completion. However, instead of individual completion of the *expert analysis form*, students were instructed to read the *scenario* and then form student groups of three to four.

Once groups were formed students were instructed to complete the *expert analysis form* by designating one student per question as a facilitator for the group. The role of the facilitator was to encourage collaboration within the group by prompting students to respond and then recording these responses. For each question a new facilitator would be designated within the group until all questions on the *expert analysis form* were complete. Students were encouraged to use class notes, the scientific reading, and their understanding of microbiology concepts to form responses.

Following this period, the professor led the whole-class *debriefing* in which individual students were selected at random to verbalize their group response to a particular question on the *expert analysis form*. Respondents were not necessarily the facilitator of the question in which they verbalized their group response to the class. As in Section 1, the professor interacted with the students during this time to determine if responses were satisfactory or required further explanation. The professor maintained a

consistent role in both sections by guiding students toward forming accurate responses for each question rather than providing explicit answers.

After the *debriefing*, the professor distributed the *summary question* to each student and instructed students to use the remaining class time to provide an individual written response. Students submitted a completed group *expert analysis form* and an individually completed *summary question* as they exited the classroom.

Assessment Instruments

Student grades for the course were not manipulated or utilized for the purpose of this research. To accurately evaluate instructional interventions related to constructs of student performance, it is recommended to utilize validated assessment instruments rather than typical summative assessments constructed by the professor (e.g. weekly quizzes, final exams, etc.) (Dancy & Beichner, 2002; Ebert-May, Batzli, & Lim, 2003).

Students received a grade credit for completing activities related to MicroALEs, and they were offered this credit regardless of their decision to participate in the study. For example, the professor decided to award students a participation grade for completing pretest and posttest instruments related to the study and for completing each MicroALE. The researcher collected these items, and they comprised the entirety of the data sources utilized for the quantitative analysis in this study. Students were not given extra credit for participating in the study, and the items pertaining to the research were not graded for performance. Students were given full participation credit for completing all the items, and this participation credit was factored into their final lecture grade.

The following is a description of the validated instruments utilized to assess the three performance measures of interest in this study: critical thinking, learning, and epistemological beliefs about biology.

Critical thinking. The Holistic Critical Thinking Scoring Rubric (HCTSR) (Facione & Facione, 1994) was utilized to assess critical thinking skills at the beginning of the semester (initial) and again at the end of the semester (final). Appendix 2.C contains the critical thinking scoring rubric. The HCTSR is typically used to evaluate critical thinking ability on student responses to essays, assignments, or projects using a scoring system of 1 (weak), 2 (unacceptable), 3 (acceptable), or 4 (strong). The score assigned is an evaluation of the reasoning processes (critical thinking) demonstrated by the student and not an evaluation of the correctness of content knowledge.

Hicks-Moore and Pastirik (2006) successfully utilized the HCTSR in a clinical practicum course to assess the impact of an active-learning intervention on nursing students' ability to think critically. To evaluate responses, Facione and Facione (1994) recommended that only whole number scores be assigned (e.g., 1 or 2 not 1.5). Additionally, they recommended scoring be conducted by two independent scorers and when a scoring disagreement occurs between the two scorers, a consensus should be reached to assign a single, whole number score—not an average score. The described recommended procedures were followed in this study.

Learning. The Host-Pathogen Interaction (HPI) concept inventory is a validated, two-tier, 19-item instrument developed by faculty in the College of Chemical and Life Sciences at the University of Maryland (Marbach-Ad et al., 2009). See Appendix 2.D for HPI concept inventory. Each item corresponds to one or more of 13 HPI concepts

identified by the developers during the validation of the instrument. These concepts are shown in Table 2.2 along with their alignment with the topics covered in the microbiology course of interest in this study. For each item on the instrument, there is a choice that serves as a distractor, which was identified during instrument validation as a specific misconception about host-pathogen interactions held by students.

Table 2.2

The 13 Host-Pathogen Interaction Concepts

HPI Concept	Concept Number	Topic from Microbiology
The structural characteristics of a microbe are important in the pathogenicity of that microbe.	1	Prokaryotic Cell
Diverse microbes use common themes to interact with the environment (host).	2	Cultivation /Growth
Microbial evolution is subject to forces of natural selection. Important consequences include changes in virulence and antibiotic resistance.	3	Control of Bacteria
Microbes adapt and respond to the environment by altering gene expression.	4	Genetics
Microbes have various strategies to cause disease.	5	Epidemiology/Disease
Pathogens and hosts have evolved in a mutual fashion.	6	Eukaryotic Cell; Prokaryotic Cell; Immunity
The cell wall and the cell membrane affect the bacterial response to the environment.	7	Control of Bacteria; Prokaryotic Cell
There is a distinction between a pathogen and a non-pathogen.	8	Eukaryotic Cell; Prokaryotic Cell; Viruses
The environment will affect the phenotype (pathogenicity) of a bacterium.	9	Biotechnology; Immunity; Protein Synthesis
Microbes adapt and respond to the environment by altering their metabolism.	10	Metabolism
Immune response has evolved to distinguish between self and non-self.	11	Immunity
Immune response recognizes general properties (common themes versus specific attributes, innate versus adaptive).	12	Immunity
Immune response memory is specific.	13	Immunity

Note. Adapted from Marbach-Ad et al. (2009) and aligned with syllabus for the microbiology course of interest in this study

The HPI concept inventory is not an instrument for evaluating broad knowledge of microbiology, but rather it was designed to target a more nuanced focus of host-pathogen interactions (Smith & Marbach-Ad, 2010). This characteristic makes the HPI concept inventory especially relevant for evaluating students in the course of interest here. For example, the catalog description for this course indicated that students would learn about microorganisms and their adverse and beneficial impact on society.

The HPI concept inventory features a two-tier design. The first-tier consists of a single-response, multiple-choice question with four to six possible choices for each, and the second-tier prompts participants to explain or defend their response to the multiple choice question. The authors designed the instrument to be used before (pretest) and after (posttest) instruction to measure learning and conceptual understanding of the principles of microbiology. For this particular study, the researcher was interested in student learning and did not collect data from the second-tier for evaluating conceptual understanding. Specifically, the researcher was interested in the difference in learning gains, if any, that participants experienced as a result of collaborative student group completion of MicroALEs compared to individual student completion of MicroALEs.

Marbach-Ad et al. (2009) stated that the instrument is a valid and reliable tool for evaluating student-learning gains achieved within a one-semester microbiology course and is recommended as a tool for comparing learning outcomes for different instructional strategies. The authors did not report validity or reliability data; rather, they stated that the process of development followed typical procedures for validating a concept inventory. For example, to establish content validity, the authors indicated that the instrument's concepts and items were peer-reviewed by microbiology content experts and

a science pedagogy expert, and that the authors reviewed responses of students to evaluate validity and reliability of the questions. The authors stated that they have performed item discrimination for each multiple-choice question; however, this data was not published. This instrument is the only peer-reviewed instrument for evaluating students' learning of microbiology concepts that was found in the literature; therefore, it was selected for use here so that no additional instrument would have to be designed.

Epistemological beliefs. The Colorado Learning Attitudes about Science Survey for use in biology (CLASS-Bio) developed by Semsar, Knight, Birol, and Smith (2011) was designed to measure biology students' epistemological beliefs about the nature of biology and learning biology. See Appendix 2.E for the CLASS-Bio instrument. This instrument was utilized here as a pretest and posttest to evaluate shifts in epistemological beliefs between participants that completed MicroALEs in collaborative student groups compared to participants completing them individually. The CLASS-Bio is one of several CLASS instruments designed to measure students' epistemological beliefs about specific scientific disciplines, which includes students' perception about the content and structure of scientific knowledge, the source of that knowledge, and problem-solving approaches utilized by scientists in the field (Adams, Perkins, Podolefsky, Kinkelstein, & Weiman, 2006; Barbera, Perkins, Adams, & Wieman, 2008).

The instrument is composed of 31 five-point Likert scale statements exploring students' perceptions about the content and structure of biology as a discipline, biological approaches to problem solving, sources of biological knowledge, and real-world connections of biology (Semsar et al., 2011). CLASS-Bio scoring analysis characterizes students on a novice-to-expert-like continuum by comparing the scientific thinking of

experts (PhDs) in the field of biology to the scientific thinking of students enrolled in a broad range of biology courses. Student responses are compared to expert responses on the same 31-items and reported as follows: “favorable (agreeing with the expert consensus—not necessarily agreeing with the statement), unfavorable (disagreeing with expert consensus), or neutral (neither agreeing nor disagreeing with the expert consensus)” (Semsar et al., 2011, p. 270). An overall percent-favorable response score is given for each student based on the number of responses identical to the expert responses.

The scores for each student can be sub-divided into seven distinct categories as determined by factor analysis of student responses during development of the instrument to characterize various aspects of student perceptions: real-world connection, enjoyment (personal interest), problem solving (reasoning), problem solving (synthesis and application), problem solving (strategies), problem solving (effort), and conceptual connections/memorization. The CLASS-Bio has been effectively combined with other forms of assessment to reliably examine how student perceptions impact learning and conceptual understanding of biology and to evaluate how pedagogical techniques promote problem solving and expert-like thinking (Semsar et al., 2011). Thus, it was appropriate for this study.

Data Collection and Analysis

The design of this study called for match-paired data collection from pretest and posttest instruments in two sections of a microbiology course to evaluate the impact of two distinct active-learning instructional strategies on students’ critical thinking ability, learning, and epistemological beliefs about biology. Comparisons were made on demographic data between Section 1 and Section 2 using chi-square analysis for each

item collected to test for any differences in student composition of the two sections.

Demographic data was collected on the CLASS-Bio pretest, and generalizations will be made about participants in the study based on this data.

Statistical comparisons were made within section and between sections on data collected from each instrument: HCTSR, HPI concept inventory, and CLASS-Bio. Only participants with both pretest and posttest scores were considered for analysis. Completed instruments were de-identified prior to scoring and data analysis, and a unique alphanumeric identifier was designated for each participant to track pretest and posttest completion. The sample size for each construct analyzed varied due to participant completion rate of each instrument; therefore, some sample sizes will differ between analyses of the different instruments. Due to the relatively large sample size (> 40) and that the data fulfilled normality assumptions, parametric tests were considered appropriate for all analyses. Raw data for all instruments was managed in Excel and analyzed in SPSS, unless otherwise noted.

Critical thinking. To evaluate critical thinking, data was collected from four of the seven MicroALEs utilized throughout the semester. At the conclusion of the *debriefing* component of each MicroALE, students were asked to complete and submit the *summary question*. Using the HCTSR a score of 1 (weak), 2 (unacceptable), 3 (acceptable), or 4 (strong) was assigned to each response. To establish an initial critical thinking score (i.e., pretest HCTSR), participant responses to the *summary question* from MicroALE No. 1 and No. 2 were collected and averaged. To establish a final score (i.e., posttest HCTSR), student responses to the *summary question* from MicroALE No. 6 and

No. 7 were collected and averaged. Responses were blinded for name and section before being scored.

To establish inter-rater reliability, the researcher and a qualified scorer independently scored all responses from MicroALE No. 1, No. 2, and No. 6. Agreement between the two scorers was 88% for all responses evaluated with the HCTSR. As recommended by Facione and Facione (1994) for responses in which the scorers disagreed, a discussion took place between the scorers until a consensus was reached on a final score. For all disagreements in score, the variation never exceeded one level of measurement. Due to the high agreement percentage between the two scorers, the researcher scored MicroALE No. 7 without the confirmation of the second scorer. After all responses were scored, data were organized by section for the purpose of making within and between group comparisons on initial and final critical thinking skills. To be considered a valid data point, the participant had to have completed all four MicroALEs (No.'s 1, 2, 6, and 7).

A two-sample *t* test was conducted using initial HCTSR scores to determine if there was a difference in critical thinking ability between participants in Section 1 and Section 2 at the beginning of the semester. A paired sample *t* test was conducted to evaluate change in critical thinking scores, if any, within each section. Due to a lack of difference in the pretest scores, to compare the impact of the active-learning strategies at the end of the semester, an independent two-sample *t* test was conducted on final critical thinking scores between Section 1 and Section 2.

Learning. To evaluate learning, participants in both sections completed the HPI concept inventory pretest on the first day of class and the posttest on the last day of class.

The pretest and posttest were identical. The final 25-minutes of class time were used in both sections for students to complete the 19-item HPI concept inventory for the pretest and posttest administrations. Students recorded their responses on a Scantron form. Participant responses were scored with an automated Scantron reader using the key provided by the developers. Participant raw scores were collected by the researcher and blinded by name using a unique identifier. The multiple-choice responses were transformed to dichotomous data, where 0 = incorrect and 1 = correct.

Assessment tools such as the HPI concept inventory are typically evaluated using statistical tests for individual item analysis and internal consistency of subsets of items targeting specific concepts (Adams et al., 2006; Adams & Wieman, 2011; Shi et al., 2010; Smith, Wood, & Knight, 2008). Although the HPI concept inventory was proven valid and reliable by the developing authors, it is recommended that individual item analysis should be performed for each use of the tool because the analysis is dependent on the performance of the participants at a specific instance of use (Ding, Chabay, Sherwood, & Beichner, 2006). For example, the HPI concept inventory was not specifically designed for the introductory microbiology course in the current study, thus it is possible that concepts emphasized in the microbiology courses taught by the developers of the HPI concept inventory were not emphasized by the course instructor in his introductory microbiology course. Therefore, it was appropriate to evaluate participant responses to individual items (item analysis) for this particular use of the HPI concept inventory.

Before any data were analyzed, individual items were evaluated using an item-difficulty index (P) and discrimination index (D) to estimate the effectiveness of each

item on this particular administration of the HPI concept inventory (Adams & Wieman, 2011; Smith, Wood, & Knight). Item difficulty is a ratio of correct responses to the total number of responses and is often reported as a percentage of participants that responded correctly to each item; therefore, P for each item was calculated by summing the total number of correct responses divided by the total number of responses and reported as percentage of correct responses.

$$P = \frac{\text{total number correct}}{\text{total number of responses}} \times 100$$

Item discrimination measures the ability of each item to distinguish high performing students from poor performing students. The developers of the HPI concept inventory reported D values above .30 for all items on the current inventory. Items with D values below .30 were not included in the final version of the HPI concept inventory. There are several common calculations used for D that vary by how the population is separated based on overall performance on the assessment (Ding, Chabay, Sherwood, & Beichner, 2006; Smith, Wood, & Knight, 2008). For this study, D was calculated using the formula,

$$D = \frac{(N_H - N_L)}{\left(\frac{N}{3}\right)}$$

where N_H is the number of correct responses from the high performing participants (top 33%), N_L is the number of correct responses from the poor performing participants (bottom 33%), and N is the total number of responses.

Separating participant performance by the top 33% and the bottom 33% allowed for more participant data to be included while eliminating a larger portion of the middle

performing participants. The final statistical measure of individual item analysis used for the HPI concept inventory participant response data in this study was the point biserial correlation. This value is the estimate of how consistent each item is with all items on the HPI concept inventory, and is the Pearson Correlation Coefficient between each individual HPI concept inventory item (a right or wrong dichotomous variable) and performance on the whole HPI concept inventory (continuous variable) (Adams & Wieman, 2011). The value of each item for this statistic, [-1,1], was calculated for both sections and for both pretest and posttest.

Statistical analysis of participant learning was determined following the logic of previous work for evaluating learning with a concept inventory (Coletta & Phillips, 2008; Smith, Wood and Knight, 2008). Descriptive statistics were calculated for both pretest and posttest scores in both sections. An independent, two-sample *t* test was conducted on pretest mean scores to determine if there was a difference between Section 1 and Section 2 on pre-instruction HPI concept inventory scores. An independent, two-sample *t* test was conducted to determine if HPI concept inventory posttest scores differed between Section 1 and Section 2. Comparisons of match-paired pretest and posttest mean scores within both sections were made using a dependent sample *t* test. Statistical analysis of normalized learning gain is considered an acceptable approach to evaluating learning using pretest and posttest assessments (Hake, 1998); therefore, in addition to comparing posttest mean scores between groups, normalized learning gain (*G*) was calculated for each participant in both sections using the formula:

$$G = \frac{\text{posttest \%} - \text{pretest \%}}{100 - \text{pretest \%}}$$

Normalized gain mean scores were compared between sections using an independent t test to compare the overall effect of the two active learning strategies on student learning.

Epistemological beliefs. The CLASS-Bio was used here to compare the effect of collaborative and individual cognitive processing of MicroALEs toward promoting more expert-like thinking. Specifically, the researcher was interested in the difference in agreement with experts that students displayed after two distinct active-learning implementation strategies. Participant responses were collected and analyzed for 31-statements on the CLASS-Bio. Data collection and analysis presented here was representative of the methodology utilized by the authors of the CLASS-Bio (Semsar, Knight, Birol, & Smith, 2011). Data was collected from the CLASS-Bio pretest during the first week of the semester and from the posttest during the last week of the semester. The assessment formats were identical except for six demographic items added to the pretest. Both tests were given as a take-home assignment to be completed individually on-line. The researcher built an online version of the pretest and posttest on Qualtrics, a web-based survey platform as recommended by the developers. Responses to items on the CLASS-Bio were recorded and collected through Qualtrics. Survey data was downloaded from Qualtrics and a unique identifier was assigned to the raw data in order to de-identify each participant.

Using an Excel spreadsheet provided by the CLASS-Bio developer for data analysis, participant responses were divided by section and compared to experts in the field to determine the level of agreement participants held along a novice to expert-like scale. To evaluate students' epistemological beliefs about the nature of biology and attitudes about learning biology, participant scores on the pretest and posttest were

calculated as a percent favorable agreement with experts in the field of biology for the overall survey and for each of the seven sub-categories identified by the developers: conceptual connections, enjoyment, problem-solving difficulty, problem-solving effort, problem-solving strategies, real-world connection, and reasoning.

Statistical comparisons were conducted within and between Section 1 and Section 2. First, an independent, two sample *t* test was conducted between sections on pretest mean scores to determine if a pre-instruction difference existed between participants in the individual treatment and the collaborative treatment. Second, a dependent sample *t* test was utilized to compare match-paired pretest and posttest data within both sections. Third, gain scores (gain = posttest - pretest) were compared between sections to evaluate a difference, if any, in epistemological beliefs along the novice-to-expert-like scale that occurred over the span of one semester. Rather than just comparing posttest scores, the researcher compared gain scores to fully engage the idea of shifting epistemological beliefs along the novice-to-expert-like scale. Last, mean gain scores within Section 1 and Section 2 were analyzed by conducting a one-sample *t* test on each of the seven sub-categories.

Results

Demographic Data

Overall demographic data is reported on participants from both sections in Table 2.3. There were a total of 142 student participants in this study. Results indicated that there were no significant differences among participants in Section 1 and Section 2 for gender ($p > .05$), age ($p > .05$), and emphasis of study ($p > .05$).

Table 2.3

Demographic Data for All Participants in Both Sections

Demographic	Section 1	Section 2
Male, %	26.7	16.1
Female, %	73.3	83.9
Age 18-22, %	75.6	80.4
Biology Major, %	37.2	32.1
Pre-allied Health, %	47.7	53.6
Totals ($N = 142$)	$n = 86$	$n = 56$

Critical Thinking

After removing participants that did not complete both MicroALE No. 1 and 2 (initial) and MicroALE No. 6 and 7 (final), the sample size included 61% of all participants from Section 1 ($n = 48$) and 74% of all participants from Section 2 ($n = 37$). Although this diminished potential information available from the entire population, it was the most comprehensive data available for making inferential comparison between sections. HCTSR scores were normally distributed across both sections.

Results indicated that there was not a significant difference in critical thinking ability at the beginning of the semester between individual ($M = 2.49$, $SD = .66$) and collaborative ($M = 2.54$, $SD = .78$) treatments, $t(83) = -.326$, $p = .745$. Although 35.7% of participants in the individual cognitive processing section (Section 1) had positive critical

thinking gains, the initial mean score did not significantly differ from the final mean score ($p = .73$). Of the participants in the collaborative cognitive processing section (Section 2), 51.4% had positive critical thinking gains, and overall, they demonstrated a significantly higher mean critical thinking score on the final assessment compared to the initial ($p = .02$) (see Table 2.4). The effect size of this difference was $d = .42$. Finally, results indicated that there was not a significant difference in critical thinking scores on the final assessment at the end of the semester between the individual ($M = 2.53, SD = .81$) and collaborative ($M = 2.80, SD = .59$) treatment, $t(83) = -1.672, p = .09$.

Table 2.4

Critical Thinking Scores for Individual and Collaborative Groups

Variable	Initial M (SD)	Final M (SD)
Individual	2.49 (.66)	2.53 (.81)
Collaborative	2.54 (.77)	2.80* (.59)

Note. Significant difference is between initial (MicroALE No. 1 and No. 2) and final (MicroALE No. 6 and No. 7) mean scores of Section 2, collaborative student groups
* $p < .05$, two-tailed.

Learning

Results from item difficulty (P) and item discrimination (D) calculations are shown in Table 2.5. Since participants in this study were novice students of microbiology, it was reasonable to only consider the posttest data, as the pretest data was likely heavily influenced by their limited knowledge of microbiology, and thus, would

not be an accurate measure of performance discrepancies among participants per item. By considering posttest item analysis results, it was possible to estimate the effectiveness of each item at measuring knowledge. Additionally, by plotting P for both sections across all items, it was possible to visualize the distribution of knowledge at the end of the semester for participants in both groups.

Table 2.5

Item Difficulty Index, Item Discrimination Index and Concepts Addressed for Each Item on the Host-Pathogen Interaction Concept Inventory Pretest and Posttest

Item	<i>P</i>				<i>D</i>				Concept
	Section 1		Section 2		Section 1		Section 2		
	pre	post	pre	post	pre	post	pre	post	
1	0.25	0.07	0.25	0.10	0.18	-0.05	0.32	-0.25	9,10
2	0.51	0.65	0.52	0.56	0.47	0.36	0.49	0.63	10
3	0.21	0.24	0.10	0.23	0.21	0.23	0.23	0.25	3,4,10
4	0.41	0.49	0.48	0.56	0.48	0.33	0.25	0.05	2,11
5	0.29	0.46	0.31	0.50	0.46	0.36	0.25	0.13	12
6	0.13	0.40	0.13	0.35	0.27	0.06	0.22	0.10	3,4,10
7	0.07	0.22	0.10	0.17	0.14	0.45	0.40	0.40	2,3
8	0.19	0.29	0.23	0.29	0.43	0.51	0.09	0.33	6
9	0.12	0.21	0.06	0.19	0.39	0.40	0.19	0.14	13
10	0.43	0.74	0.48	0.65	0.37	0.25	0.51	0.65	10
11	0.07	0.10	0.08	0.08	0.05	0.48	0.24	0.31	12
12	0.47	0.46	0.48	0.40	0.56	0.45	0.42	-0.05	1,7,12
13	0.65	0.82	0.60	0.90	0.35	0.06	0.44	0.28	4,5,9,12
14	0.19	0.35	0.23	0.40	0.43	0.46	-0.01	0.18	8
15	0.07	0.31	0.17	0.21	0.07	0.29	0.45	0.27	3
16	0.07	0.18	0.25	0.15	0.03	0.08	0.14	0.05	7,9
17	0.09	0.25	0.15	0.23	0.21	0.24	0.39	0.12	10
18	0.44	0.68	0.52	0.60	0.17	0.32	0.16	0.31	13
19	0.49	0.57	0.44	0.77	0.57	0.30	0.53	0.34	3,4,10

Note. Only posttest data were considered for the decision to eliminate item 1 and 16. Pretest data is shown to provide the reader with context for this decision

A review of these values revealed that item 1 (Section 1, $P = .07$, $D = -.05$; Section 2, $P = .10$, $D = -.25$) and item 16 (Section 1, $P = .18$, $D = .08$; Section 2, $P = .15$, $D = .05$) had low P and D values. This suggested that these two items were difficult for all students, and that the items did not effectively discriminate high-performing students from low-performing students. As such, these items failed to accurately evaluate participants in this study for learning; therefore, items 1 and 16 were not considered for within or between group statistical comparisons. Because the HPI concept inventory was originally developed utilizing learning goals that were not used in the microbiology course from the context of this research, it was reasonable to eliminate these questions for evaluation of statistical differences in learning between Sections 1 and 2 in this study.

Comparing the syllabus of the course in this study to the concept list constructed by the authors of the HPI concept inventory showed that there was insufficient coverage of metabolism in the course of this study. This concept (9) was addressed in items 1 and 16 on the HPI concept inventory, thus validating the decision to remove these items from consideration of statistical analysis of differences. Notably, similar procedures have been utilized by others (e.g., Marbach-Ad et al., 2009). They determined that two items from the original HPI concept inventory revealed deficient coverage in the content of their microbiology courses. Subsequently, they did not use these items for statistical analysis, as they were not representative of what students could actually learn in their courses.

Results showed that 88% of the participants in Section 1 ($n = 68$) and 77% of the participants in Section 2 ($n = 48$) improved their performance to some degree on the HPI concept inventory as measured from the beginning of the semester (pretest) to the end of the semester (posttest). Each multiple-choice item was worth one point for a maximum

score of 17. Percent correct for each item on the posttest is sorted by section and displayed in Figure 2.1.

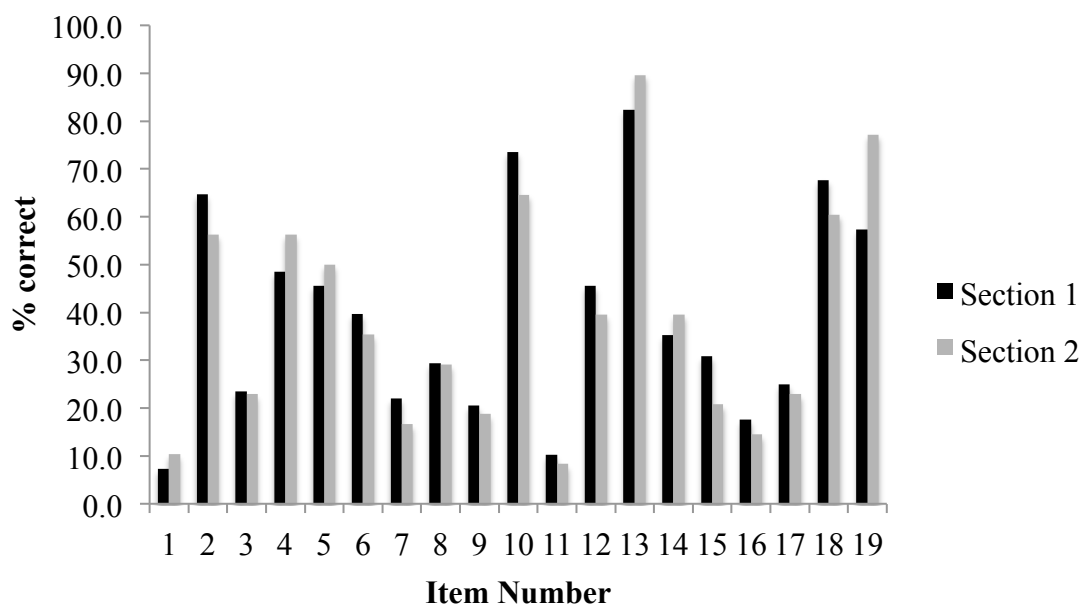


Figure 2.1. Percent correct for each item on the Host-Pathogen Concept Inventory posttest for Section 1 and Section 2.

Within group comparisons indicated that participant mean scores in both Section 1 ($p < .001$) and Section 2 ($p < .001$) were significantly higher on the posttest than on the pretest. Pretest mean scores between Section 1 ($M = 4.8$, $SD = 2.5$) and Section 2 ($M = 5.1$, $SD = 2.3$) did not significantly differ between the groups, $t(114) = -.534$, $p = .60$. Similarly, there was not a significant difference in posttest mean scores between Section 1 ($M = 7.22$, $SD = 2.5$) and Section 2 ($M = 7.1$, $SD = 2.0$), $t(114) = .312$, $p = .76$. Normalized learning gains were not significantly different between the individual ($M = .19$, $SD = .22$) and collaborative ($M = .12$, $SD = .30$) treatments, $t(114) = 1.373$, $p = .17$.

Results from this study were comparative to HPI concept inventory validation data conducted by Marbach-Ad et al. (2009) in Table 2.6.

Table 2.6

Mean Learning Gain Scores from Section 1 (Individual), Section 2 (Collaborative), and Host-Pathogen Interaction Concept Inventory Validation Data^b

Variable	<i>n</i>	<i>Pretest (SE)</i>	<i>Posttest (SE)</i>	Gain
Individual ^a	68	4.8 (.30)	7.2* (.31)	.19
Collaborative ^a	48	5.1 (.34)	7.1* (.29)	.12
Microbiology fall 2006 ^b	127	4.9 (—)	7.0* (—)	.19
Microbiology spring 2007 ^b	109	4.7 (—)	7.3* (—)	.23

Note. ^aHPI concept inventory score is determined by the number of correct responses out of 17 items. ^bData from “Assessing Student Understanding of Host Pathogen Interactions Using a Concept Inventory,” by G. Marbach-Ad et al., 2009, *Journal of Microbiology and Biology Education*, 10, p. 47.

* $p < .001$.

Epistemological Beliefs

The developers of the CLASS-Bio included a quality-check item that prompted students to respond with a specific answer (e.g., Please select agree, not strongly agree, for this question to preserve your answers). Based on a 5-point Likert scale, this item provided the researcher with an 80% chance of identifying participants that selected answers at random. Review of responses to the quality-check item revealed that two participants did not respond correctly; therefore, these participants were eliminated as

valid data points for statistical analysis. Also, the quality check item was not included in the statistical analyses.

Results from the overall instrument indicated that over the span of one semester, 52% of the participants in Section 1 ($n = 62$) demonstrated a positive shift toward more expert-like thinking. Similarly, 55% of the participants in Section 2 ($n = 43$) demonstrated a positive shift toward more expert-like thinking.

Analysis of CLASS-Bio pretest mean scores between groups indicated that participants in the individual ($M = 76.5$, $SD = 13.5$) treatment did not significantly differ from the collaborative ($M = 72.4$, $SD = 15.0$) treatment in their level of agreement with experts in the field at the beginning, $t(103) = 1.46$, $p = .148$. Similarly, a statistical comparison of posttest results indicated that the individual ($M = 76.3$, $SD = 14.0$) treatment did not significantly differ from the collaborative treatment ($M = 73.0$, $SD = 17.6$) in the level of agreement with experts in the field, $t(103) = 1.13$, $p = .259$. Additionally, comparison of pretest and posttest mean scores within group indicated no significant shifts along the novice-to-expert-like scale for either section. This held true for the overall instrument ($p > .05$) and for individual categories ($p > .01$). Results from between and within group comparisons for the overall instrument are shown in Figure 2.2. Mean gain score analysis between groups for the overall instrument indicated that no significant difference existed on agreement with experts between individual ($M = -.271$, $SD = 10.3$) and collaborative ($M = .319$, $SD = 15.0$) treatments, $t(103) = -.239$, $p = .811$. Finally, within group analyses for each of the seven sub-categories revealed no significant shifts in epistemological beliefs among participants as compared to experts in the field as shown in Table 2.7.

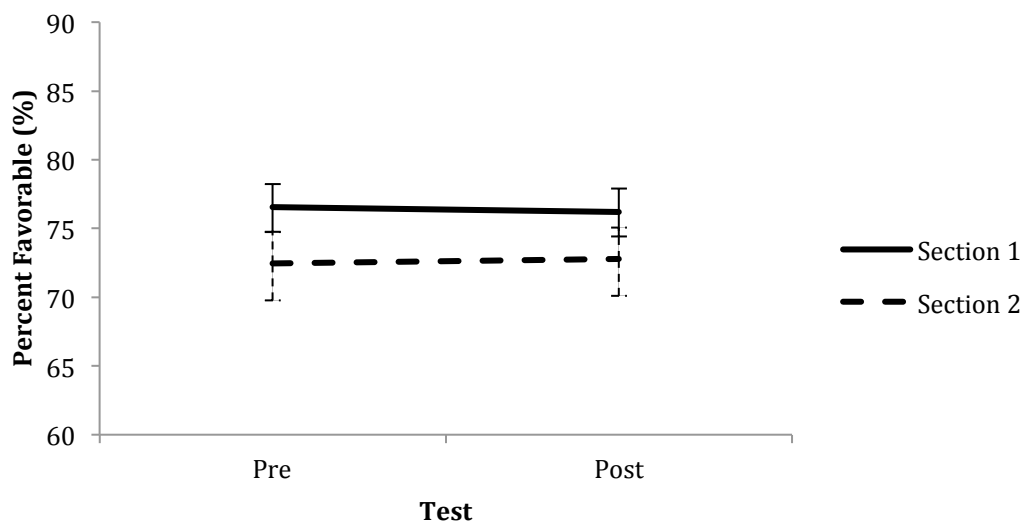


Figure 2.2. Overall performance on the CLASS-Bio for pretest and posttest responses in Section 1 and Section 2. Error bars represent standard errors.

Table 2.7

Match-paired Gains within Group on the CLASS-Bio for Section 1 and Section 2

Categories	Gain (SE)	
	Section 1	Section 2
Overall	-.27 (1.3)	.32 (2.3)
Real-world Connection	-.68 (2.2)	2.7 (3.3)
Problem-solving Difficulty	1.89 (2.9)	1.1 (3.7)
Enjoyment	1.88 (2.7)	2.4 (4.2)
Problem-solving Effort	.47 (2.4)	2.7 (3.8)
Conceptual Connections	-1.87 (2.3)	1.0 (3.1)
Problem-solving Strategies	.40 (2.3)	2.9 (4.3)
Reasoning	-3.2 (2.4)	-1.3 (3.4)

Discussion

This study was motivated by calls to reform biology education at the undergraduate level, and specifically by the publication *Vision and Change* (AAAS, 2011), which emphasized the importance of making post-secondary biology courses more student-centered and relevant to current students' needs. The purpose of this study was to compare the effect of two distinct instructional strategies when implementing a set of active-learning exercises designed for a microbiology course (MicroALEs). Both strategies were evaluated on three constructs of student performance and success: critical thinking, learning, and epistemological beliefs about biology. In addition to the research

reported here, the researcher was interested in describing an effort toward transforming the instructional model of a traditionally taught microbiology course from instructor-centered to a diversified model featuring student-centered, active-learning opportunities as called for in the literature.

Calls to reform science education, and specifically of interest here, post-secondary biology education, have persisted over the past several decades, yet there remains a lack of widespread adoption. AAAS (2011) stated that “biology faculty at campuses around the country are increasingly engaged in discussion about what and how they teach” (p. 21); however, they also report that faculty have expressed uncertainty regarding how to proceed when altering their traditional pedagogy to better serve their students. Given this uncertainty, the overarching goal of this study was to investigate the two distinct active-learning strategies in the context of a traditionally taught course in which the professor was interested in reform-based instructional strategies but uncertain of how to proceed. Furthermore, the researcher was interested in adding a nuanced perspective of individual versus collaborative active learning to the scholarship of DBER in science rather than to continue trends of comparing traditional versus reform-based pedagogies (e.g. Knight & Wood, 2005).

Although comparison of instructor-centered and reform-based pedagogies are important for highlighting the positive impacts of active learning, they have rarely attempted to distinguish specific components of active learning strategies that support these findings. A notable exception is Linton, Farmer, and Peterson (2014) who compared individual and collaborative active learning in a non-majors biology course and found that “peer interaction is necessary for optimal active learning” (p. 251). Their study

was particularly important for informing the design of the research presented here as this study sought to distinguish a similar difference in a biology course composed of students majoring in biology and pre-allied health fields.

The decision to compare individual versus collaborative student group completion of MicroALEs was grounded in Vygotsky's social learning theories and previous research demonstrating significant improvement in student performance, retention, and attitudes when collaborative group work is incorporated into traditional instruction (Tien, Roth, & Kampmeier, 2002). According to Handelsman, Miller, and Pfund (2007), "group problem solving can help students understand content better" (p. 31), and Walton and Baker (2009) found that "allied health students can actively learn science, communicate science information, and learn science from their peers" (p. 21) when engaged in collaborative group work. Although these results and others indicate collaborative learning is effective, Handelsman et al. (2007) stated that "active learning can take many forms, including both individual and group work" (p. 28).

Comparisons were made between individual and collaborative group completion of MicroALEs on students' demonstration of critical thinking, learning, and epistemological beliefs. Overall, the study revealed that there was no evidence of significant differences between the two implementation strategies utilizing MicroALEs in this particular case. There were, however, potentially important implications from the findings that merit discussion regarding critical thinking, learning, and epistemological beliefs about biology.

Critical Thinking

The purpose for utilizing the HCTSR was to evaluate students' ability to think critically about topics in microbiology following either individual or collaborative completion of MicroALEs. Critical thinking is a difficult construct to assess and should be distinctly evaluated on the thought process rather than the correctness of content knowledge (Saxton, Belanger, & Becker, 2012). The difficulty in assessment arises because the ability to think critically is linked with the ability to interpret knowledge in a logical pattern. The HCTSR was selected to assess critical thinking in this study because Facione and Facione (1994) purposefully designed the instrument to evaluate the reasoning processes (critical thinking) and not necessarily the correctness of content knowledge.

Sustained calls to reform general education frequently recommend the inclusion of opportunities for students to practice critical thinking skills in preparation for post-secondary education and professional careers (Schamber & Mahoney, 2006). Specific suggestions in science education recommend shifting the traditional instructional approach from instructor-centered to a diversified approach that features student-centered, inquiry-based activities that foster critical thinking (AAAS, 2011; Daly, 1998; Handelsman, Miller, & Pfund, 2008).

MicroALEs were intentionally designed to promote critical thinking related to concepts of microbiology. Specifically, the *summary question* prompted students to individually demonstrate their ability to analyze, synthesize, and evaluate knowledge (Crowe, Dirks, & Wenderoth, 2008). A goal of this study was to determine if the use of collaborative student groups to complete MicroALEs led to higher critical thinking skills.

Although no significant differences existed between groups at the end of the semester, results from within group comparisons suggested that participants completing MicroALEs individually did not significantly improve their critical thinking skills; however, participants completing them in collaborative groups significantly improved their critical thinking skills over the course of the semester. According to Cohen (1988), the effect size of this difference ($d = .42$) represents a medium effect, thus the finding could be considered practically significant as well.

Assessing critical thinking can be a challenging endeavor, and this holds true for this study. Due to the limited 4-point scale of the Holistic Critical Thinking Scoring Rubric, it is potentially problematic to estimate the presence or lack of statistically significant differences in critical thinking skills between sections or to make claims that either active-learning implementation strategy had a significant impact on students' ability to think critically about topics in microbiology. Therefore, it is appropriate to discuss meaningful differences between both active-learning strategies to more clearly relate their practical uses and potential outcomes. With 35% of students in Section 1 and 52% of students in Section 2 demonstrating positive gains in critical thinking scores, both implementation strategies should be considered successful for this particular study, and both represent a viable option for a professor selecting an instructional strategy for the purpose of improving students' abilities to think critically about the content.

Even though within group comparisons of the collaborative group resulted in a significant improvement of critical thinking skills, the positive movement of average score on the pretest (2.53) to the posttest (2.80) HCTSR was not enough to categorize students as demonstrating acceptable critical thinking skills, a 3 on the HCTSR. Notably,

a 2 is considered an unacceptable critical thinking score by Facione and Facione (1994). Therefore, a seemingly practical goal of improving students' critical thinking skills from unacceptable to acceptable was not realized by using MicroALEs in either treatment, thus the question arises, why might the MicroALEs not have supported students in moving from an unacceptable range to an acceptable range? Two potential explanations address this concern.

A barrier to improving students' critical thinking skills may be the result of the instructor's goal for the course and instructional emphasis teaching students to think critically about the content. Critical thinking about microbiology concepts was not an explicit goal set forth by the faculty instructor in this study. Although MicroALEs are intended to foster critical thinking, they are merely a tool that promotes student-centered learning, but as with any tool, require effective utilization. Anecdotally, this effectiveness comes with experience and pedagogical knowledge. An emphasis of this study was the implementation of MicroALEs by a professor novice to RBIS. Therefore, the absence of movement to acceptable critical thinking scores are potentially the result of an instructor not emphasizing critical thinking and/or lacking the pedagogical knowledge and experience to illicit critical thinking from students. This is not a fault or represent a lack of effort by the instructor, but should be considered as a point of emphasis for potential professional development opportunities modeling RBIS to traditional faculty seeking to implement instructional change.

Overall, the findings in this study can be compared to previous studies exploring the effectiveness of collaborative or cooperative learning groups work for improving students' ability to think critically about scientific phenomenon. For example, Schamber

and Mahoney (2006) found that an emphasis on collaborative learning groups in class led to improvement of students' analytical skills demonstrated in group projects. Darland and Carmichael (2012) reported long-term retention of critical thinking skills (up to four years) for post-secondary students in a Developmental Biology course. These students completed collaborative in-class assignments followed by whole class discussion led by the instructor in a matter similar to the collaborative implementation of MicroALEs. Furthermore, they found positive correlations between student performance on summative assessments and critical thinking skills. Notably, Darland and Carmichael (2012) did not compare individual versus collaborative treatments, thus results from this current study not only reinforce the benefit of collaborative group work, but suggest that collaborative student-centered activities are potentially more effective at promoting critical thinking skills than students working individually on a student-centered activity.

Finally, Walton and Baker (2009) incorporated collaborative group projects into a public health microbiology course seeking to improve critical thinking in students enrolled in pre-nursing and allied health programs. They found that these students enjoyed working collaboratively and communicating science with their peers. Furthermore, these students demonstrated the ability to actively learn concepts related to host-pathogen interaction and learn from their peers. These studies, along with results presented here, provide evidence that active participation in lecture, particularly collaborative student group work, can potentially “develop habits of the mind to drive science” (Handelsman, Miller, & Pfund, 2007, p. 7), and is, therefore, a potentially meaningful endeavor for a novice to invest time and effort into for incorporating collaborative group work in student-centered reform initiatives. Additionally, research

efforts are needed to broaden the scope of this finding beyond MicroALE utilization during one semester and to develop a richer comparison of collaborative and individual student-centered activities. Furthermore, this research should continue to explore the impact of peer-to-peer interaction on students' ability to think critically about biological content.

Learning

The purpose for using the HPI concept inventory for this particular study was to compare student learning gains between collaborative student group and individual completion of MicroALEs over the span of one semester. Overall, there were no significant differences in learning gains between the two treatments. However, regardless of the active learning implementation strategy, participants in both treatments demonstrated significant learning gains over the course of the semester as measured by within group, match-paired pretest and posttest.

This particular result is not surprising as it is expected that the majority of students will gain knowledge as a result of completing the course, but the result is confirming that MicroALEs and, in particular, the diversified approach utilized for the first time by the faculty instructor did not negatively impact learning in that conceptual understanding did not decrease as a result of using MicroALEs. Thus, the results reported here can support the practical application of both the curriculum and either implementation strategy chosen for future use.

Although a goal of this study was to compare learning gains between treatment groups, a notable benefit for utilizing concept inventories in general and specifically for assessing the curriculum intervention here is that analyses of percent correct for each

item can be extrapolated. These analyses offer insight on particular concepts that were adequately addressed or that may need more emphasis in future iterations of the curriculum and implementation strategy. This particular use of the data supports the call to teach with a more scientific approach in that one can collect and analyze data to inform future instructional decisions that aligns with teaching and learning goals. For example, on the posttest items 10 (microbes adapt and respond to their environment) and 13 (immune response memory is specific) for both sections were answered correctly over 60% of the time, but items 3 (microbial evolution is subject to forces of natural selection) and 11 (Immune response has evolved to distinguish between self and non-self) were answered correctly less than 30% of the time. By reviewing this data one could adjust future iterations of MicroALEs or instruction to address weaknesses in understanding specific concepts.

Two particular concerns arise for interpreting the data collected using the HPI concept inventory here. First, due to the quasi-experimental design of this study, data does not reflect participants that did not receive MicroALEs as an instructional intervention, thus it is beyond the scope of this study to suggest learning improved when using MicroALEs versus a true control. However, as previously noted, multiple studies report on the positive impacts of active learning on constructs of student success, thus the decision was made here to accept this as theory and only investigate nuanced approaches to active-learning strategies.

Second, although the HPI concept inventory was specifically designed for the learning goals of a sequence of microbiology courses taught at the University of Maryland, review of the instrument indicated that it is generalizable for a post-secondary

introductory microbiology course and, in particular, targets most, if not all, of the topics covered in the microbiology course for this current study. However, because it was previously validated for the specific use of the developers, it was not validated for its particular use here. This is a potential problem with broad application of any concept inventory designed for specific learning goals; therefore, the researcher chose to include, as a comparison, mean scores collected from the validation of the HPI concept inventory, which in this case were similar to results obtained here.

The HPI concept inventory still proved useful for evaluating learning. An instructor seeking to measure learning using an existing concept inventory should be mindful of the meaningful interpretation that can be extrapolated from the data collected. It is recommend here that researchers and faculty that choose to utilize concept inventories consider validating one for their own particular use whether it is re-configuring an existing inventory or developing a new one.

Epistemological Beliefs

The purpose for using the CLASS-Bio was to compare the effect of collaborative student group and individual completion of MicroALEs on students' epistemological beliefs about the practice of biology as a science and the learning of biological content as compared to experts in the field (practicing biologists) (Semsar et al., 2011). Research in students' epistemological beliefs has been conducted in other post-secondary STEM disciplines including physics and chemistry; however, there is a lack of information regarding epistemological beliefs among students enrolled in undergraduate biology courses. Particularly, no research was found regarding the impact of collaborative versus individual cognitive processing on students' epistemological beliefs.

Although evidence from this study did not reveal significant differences in epistemological beliefs between the two treatments, the findings here contradict what has previously been reported on science majors' epistemological beliefs about biology. For example, past studies have reported novice-like shifts in post-secondary science students' beliefs after one semester of physics instruction (Adams, Perkins, Dubson, Finkelstein, & Wieman, 2004), chemistry instruction (Barbera, Perkins, Adams, & Wieman, 2006) and biology instruction (Ding & Mollohan, 2015). However, as reported here, participants in both Section 1 and Section 2 did not experience any novice-like shifts. In fact, more than 50% of all participants demonstrated shifts toward more expert-like beliefs.

The design of MicroALEs potentially supported the lack of digression toward novice-like beliefs. In particular, the active learning component of MicroALEs places a responsibility on the students regardless of collaborative or individual implementation that fosters introspective thought and prompts decision making. These aspects engage cognitive processes that are potentially absent from a traditional, didactic lecture in which notes are provided without emphasis on independent thought and decision making.

The lack of shift toward more novice-like beliefs is important when considering the goal of developing students as scientists. A curriculum or instructional strategy that can minimize the factors leading to novice-like shifts should be considered for promoting expert-like attitudes about the discipline. This should then support retention within the department and development of student attitudes that can serve them well as they enroll in upper division courses and pursue undergraduate research opportunities. These more expert-like attitudes will likely promote a positive experience when working and communicating with practicing scientists.

Limitations

This study had two primary limitations. First, the same professor taught two sections of a large lecture microbiology course in the same semester; however, the sections met in different classrooms. The collaborative treatment section met in a new classroom with mobile chairs and desks whereas the individual treatment section met in an older, stadium-style lecture hall. The two distinct classroom settings should be noted here as a potential confounding variable. As Kober (2015) discussed, mobile classroom arrangement is thought by some to enhance opportunities for active learning while others contend that, the lack of an ideal space for active learning is not necessary, as student-centered instruction is adaptable and still effective in traditional lecture hall designs.

Second, MicroALEs were used as the instructional intervention in both sections. These were developed and piloted in a previous semester; however, data were not collected during that time upon their usage. This study marks the first time in which the impact of MicroALEs was measured, therefore findings from this study are potentially limited by the quality of MicroALEs as an effective resource for implanting instructional change.

Implications and Future Research

Current literature is lacking, particularly in biology education research, that directly compares individual and collaborative active-learning strategies. Furthermore, the context of this study was purposeful in that the faculty participant was a novice to RBIS with long-term (21 years) experience teaching with a traditional pedagogy.

Navigating aspects of instructional change such as identifying appropriate reform-based curricular resources and establishing new instructional strategies can be

challenging for faculty with a traditional pedagogy. In particular for this study, the professor was tasked with formation of groups in the collaborative treatment group. This is a potentially daunting and inefficient task in large-lecture sections and especially for faculty that are accustomed to traditional classroom environments. Therefore, faculty seeking to implement RBIS are potentially discouraged at the prospect of organizing and directing student groups, whereas they may be more comfortable with individual learning and less organized chaos in the classroom.

This particular problem frames the general research question here. Is collaborative, student-centered instruction necessary for positive outcomes related to student performance and epistemological beliefs? This study was designed to address this question for the purpose of informing and alleviating aspects of uncertainty when traditional faculty attempt pedagogical reform. Implications from this study suggest that faculty with traditional pedagogies can effectively implement student-centered instruction utilizing an appropriate resource and without initially introducing collaborative student group work. However, as the faculty member becomes more experienced and familiar with RBIS, an instructor can broaden their instructional strategies to include student-centered strategies such as collaborative group work.

For all three measures of student performance in this study, there were arguably positive student outcomes associated with both implementation strategies of MicroALEs. Further research should consider longitudinal change over time as the faculty member pursues instructional change. With experience, the implementation of RBIS will potentially become more effective. Additionally, continued emphasis should be placed on

collaborative versus individual cognitive processing of student-centered active-learning activities.

Conclusion

The findings presented here add to the growing body of DBER that active learning is an effective instructional strategy. Although this study marked the first time this professor attempted to implement reform-based instructional strategies, his use of MicroALEs was not shown to negatively impact students' performance and epistemological beliefs. This is an important aspect to consider as past research suggests that initial approaches to adopt reformed teaching practices often lead to a digression back to old methods due to lack of success (Henderson, 2005). Further practice and experience gained by the professor in future use of MicroALEs will likely improve his efficacy utilizing reform-based instructional strategies.

Biology faculty with traditional instructional philosophies have expressed uncertainty with how to proceed with education reform. This current study fills a need in the literature by providing a rationale for faculty with novice RBIS experience to implement either individual or collaborative active learning as they attempt to reform their instructional model. The fact that few differences were documented when comparing the two strategies suggest that faculty can potentially proceed knowing that the benefit of a student-centered instructional strategy may be as simple as engaging students in peer-to-instructor discourse during class time. Further research should continue to evaluate differences that may arise between individual and collaborative learning. Additionally, the researcher welcomes the use of MicroALEs as an open-source active learning curriculum for others to use and evaluate.

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APPENDICES

APPENDIX 2.A

Example of a MicroALE

Scenario

We are heavily dependent on the western honeybee, *Apis mellifera* to pollinate our food crops and to produce the sweet nectar we collect from their hives. Since 2006, bee keepers have reported major losses in their bee populations, or colonies, which have led to increased concerns about the future of honeybees and the resulting impacts on agriculture. Concern has prompted an increase in the number of scientific studies investigating the cause of colony collapse disorder (CCD). Recent publications indicate multiple causes for the loss of honeybees including the Varroa mite, the gut pathogen *Nosema ceranae*, Tobacco Ringspot Virus (TRSV), and the presence of multiple pesticides (fungicides, insecticides, and herbicides) in individual bee colonies.

In the 1880s, the 1920s and again in the 1960s there have been reports of honeybees abandoning hives and essentially disappearing, but until recently there has not been significant work to identify the cause of disappearing honeybees. It is now thought that honeybees leave the hive before they die thus making it nearly impossible to locate deceased bees. Without the bee to study it is difficult to pinpoint the exact cause of death so scientist have focused their study on collecting data to assess colony population changes and the health of active hives. As a result several potential causes for CCD have emerged.

As a microbiologist you must investigate both the unknown and known in order to establish a clearer picture on the cause of CCD. For many reasons this has become critical research as time is of the essence. Even if you think you have determined the cause, you are responsible for publishing your findings and working with others outside of your field to address a solution. The efficiency of identifying the cause and the speed of implementing a plan of action is crucial in stopping CCD before society is faced with the loss of our most important pollinator. The sticky future of honey is ~~on~~ in your hands!

Expert Analysis Form

Group Members: _____

Analysis #1

Facilitator _____

As you are considering the cause of CCD, you should be familiar with the differences and similarities of viruses and bacteria. Make a table below to compare them based on characteristics such as: size, structure, DNA/RNA or both, pathogenic or not, reproduction, treatment, plus one more category that may be important for the study of CCD.

Analysis #2

Facilitator _____

The reading states that, “RNA viruses tend to be particularly dangerous because they lack the 3' → 5' proofreading function...”

To understand the potential aggressive nature of pathogenic microorganisms, you must be familiar with genetics and microevolution. Explain what a proofreading function is in DNA replication. According to the reading, why is the lack of a proofreading function dangerous?

Analysis #3

Facilitator _____

During DNA synthesis and transcription, the proofreading function prevents errors from occurring during replication and RNA synthesis. However, proofreading functions are not 100% effective plus environmental factors can lead to DNA mutations that can alter the base sequence leading to improper protein synthesis.

Define transcription:

Explain two types of mutations that can alter a DNA base sequence.

Analysis #4

Facilitator _____

There are potential multiple reason for CCD. Suppose you determined that a cocktail of pesticides found in multiple honeybee colonies were leading to CCD when the gut pathogen *Nosema ceranae* was also found in the colonies. You know that honeybees have a radius of 2 miles when in search of nectar and you know that *N. ceranae* is normal flora found in honeybees. Describe a plan for preventing CCD. How would you relate the importance of honeybees to the livelihood of the farmers who depend on pesticides to produce a crop every season?

Name: _____

Individual Question

Tobacco Ringspot Virus is transmitted from plant to plant as honeybees move infected pollen between plants. At one time scientist thought that viruses were not able to cause infection across the plant and the animal kingdom, that is a plant virus could not infect an animal. Based on the reading, what proof do we have that this is no longer considered accurate?

APPENDIX 2.B

Demographic Survey

INSTRUCTIONS: Answer the following demographic questions on the attached Scantron.

Demographic questions:

1. Please indicate your gender.
A. Female B. Male
2. Please indicate your age.
A. 18-20 B. 21-23 C. 24-26 D. 27 or older
3. Please indicate your GPA
A. Less than 2.0 B. 2.0-2.4 C. 2.5-2.9 D. 3.0-3.4 E. 3.5 and above
4. Please indicate your major
A. Biology B. Pre-Professional Health C. Both A and B D. Other
5. Have you previously taken this microbiology course?
A. Yes B. No
6. Have you previously taken a general biology course in college?
A. Yes B. No

APPENDIX 2.C

Critical Thinking Rubric



How to Use The Holistic Critical Thinking Scoring Rubric

1. Understand what the Rubric is intended to Address.

Critical thinking is the process of making purposeful, reflective and fair-minded judgments about what to believe or what to do. Individuals and groups use critical thinking in problem solving and decision making. This four level rubric treats this process as a set of cognitive skills supported by certain habits of mind. To reach a judicious, purposeful judgment a good critical thinker engages in analysis, interpretation, evaluation, inference, explanation, and reflection to monitor and, if needed, correct his or her thinking. The disposition to pursue open-mindedly and with intellectual integrity the reasons and evidence wherever they lead is crucial to reaching sound, objective decisions and resolutions to complex, high-stakes, ill-structured problems. So are the other critical thinking habits of mind, such as being inquisitive, systematic, confident in reasoning, anticipatory of possible consequences, prudent in making judgments. [For a deeper understanding of critical thinking, download your free copy of *Critical Thinking: What It Is and Why It Counts* and the research which grounds this concept: “*The Delphi Report*” - *Critical Thinking: An Expert Consensus* from www.insightassessment.com]

2. Differentiate and Focus.

Holistic scoring requires focus. Whatever one is evaluating, be it an essay, a presentation, a group decision making activity, or the thinking a person displays in a professional practice setting, many elements must come together for overall success: critical thinking, content knowledge, and technical skill (craftsmanship). Deficits or strengths in any of these can draw the attention of the rater. However, in scoring for any one of the three, one must attempt to focus the evaluation on that element to the exclusion of the other two. To use this rubric correctly, one must apply it with focus only on the critical thinking – that is the reasoning process used.

3. Practice, Coordinate and Reconcile.

Ideally, in a training session with other raters one will examine samples (documents, videotaped examples, etc.) which are paradigmatic representations of each of the four levels. Without prior knowledge of their level, novice raters will be asked to evaluate and assign ratings to these samples. After comparing these preliminary ratings, collaborative analysis with the other raters and the experienced trainer is used to achieve *consistency of expectations* among those who will be involved in rating the actual cases. Training, practice, and inter-rater reliability are the keys to a high quality assessment. This gives operational agreement, which is very important.

Usually, two raters will evaluate each essay, assignment, project, or performance. If they disagree there are three possible ways that resolution can be achieved: (a) by a conversation between the two raters regarding their evaluations, (b) by using an independent third rater, or (c) by taking the average of the two initial ratings. But, the averaging strategy is strongly discouraged. Discrepancies of more than one level between raters indicate that the raters must review together the evidence considered salient by each rater. This rubric is a **four** level scale, forced choice scale. Half point and “middle of the two” scoring is not possible. The only variation which would be consistent with this tool is to combine #1 and #2 so that this became a three level scale: Strong, Acceptable, Weak.

When working alone, or without paradigm samples, one can achieve a greater level of internal consistency by not assigning final ratings until a number of essays, projects, assignments, performances have been given preliminary ratings. Frequently natural clusters or groupings of similar quality soon come to be discernible. At that point one can be more confident in assigning a firmer critical thinking score using this four level rubric. After assigning preliminary ratings, a review of the entire set assures greater internal consistency and fairness in the final ratings.

www.insightassessment.com

The Holistic Critical Thinking Scoring Rubric - HCTSR

A Tool for Developing and Evaluating Critical Thinking

Peter A. & Noreen C. Facione

Strong 4 -- Consistently does all or almost all of the following:

- ✚ Accurately interprets evidence, statements, graphics, questions, etc.
- ✚ Identifies the most important arguments (reasons and claims) pro and con.
- ✚ Thoughtfully analyzes and evaluates major alternative points of view.
- ✚ Draws warranted, judicious, non-fallacious conclusions.
- ✚ Justifies key results and procedures, explains assumptions and reasons.
- ✚ Fair-mindedly follows where evidence and reasons lead.

Acceptable 3 -- Does most or many of the following:

- ✚ Accurately interprets evidence, statements, graphics, questions, etc.
- ✚ Identifies relevant arguments (reasons and claims) pro and con.
- ✚ Offers analyses and evaluations of obvious alternative points of view.
- ✚ Draws warranted, non-fallacious conclusions.
- ✚ Justifies some results or procedures, explains reasons.
- ✚ Fair-mindedly follows where evidence and reasons lead.

Unacceptable 2 -- Does most or many of the following:

- ✚ Misinterprets evidence, statements, graphics, questions, etc.
- ✚ Fails to identify strong, relevant counter-arguments.
- ✚ Ignores or superficially evaluates obvious alternative points of view.
- ✚ Draws unwarranted or fallacious conclusions.
- ✚ Justifies few results or procedures, seldom explains reasons.
- ✚ Regardless of the evidence or reasons, maintains or defends views based on self-interest or preconceptions.

Weak 1-- Consistently does all or almost all of the following:

- ✚ Offers biased interpretations of evidence, statements, graphics, questions, information or the points of view of others.
- ✚ Fails to identify or hastily dismisses strong, relevant counter-arguments.
- ✚ Ignores or superficially evaluates obvious alternative points of view.
- ✚ Argues using fallacious or irrelevant reasons, and unwarranted claims.
- ✚ Does not justify results or procedures, nor explain reasons.
- ✚ Regardless of the evidence or reasons, maintains or defends views based on self-interest or preconceptions.
- ✚ Exhibits close-mindedness or hostility to reason.

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APPENDIX 2.D

Concept Inventory



The HPI concept inventory is a two-tiered concept inventory developed and validated by the HPI Teaching Team at the University of Maryland

<http://hpiresearchteachingteam.umd.edu/hostpathogeninteractionteachinggroup>

The HPI-CI is a multiple choice test, coupled with requests for students to explain their response choice. The inventory targets students' misconceptions related to the 13 HPI concepts.

Host-Pathogen Interaction (HPI) concepts

1. The structural characteristics of a microbe are important in the pathogenicity of that microbe (see Question 11).
2. Diverse microbes use common themes to interact with the environment (host) (see Questions 3, 6).
3. Microbes respond to forces of natural selection. Important responses include changes in virulence and antibiotic resistance (see Questions 2, 5, 6, 14).
4. Microbes adapt/respond to environment by altering gene expression (see Questions 2,5,12).
5. Microbes have various strategies to cause disease (see Question 12).
6. Pathogens and host have evolved in a mutual fashion (see Question 7).
7. The cell wall and the cell membrane affect the bacterial response to the environment (see Questions 11, 15).
8. There is a distinction between a pathogen and a nonpathogen (see Question 13).
9. The environment will affect the phenotype (pathogenicity) of a bacterium (see Questions 9, 12, 15).
10. Microbes adapt/respond to the environment by altering their metabolism (see Questions 1, 2, 5, 9, 16).
11. Immune response has evolved to distinguish between self and nonself.

12. Immune response recognizes general properties (common themes vs. specific attributes: innate vs. adaptive) (see Questions 4, 10, 11, 12).
13. Immune response memory is specific (see Questions 8, 17).

The inventory was developed by our team using a collaborative stepwise process. We have used the inventory as a pre- test and a post-test in our HPI courses. The concept inventory allows analysis of student learning and gives insight into student misconceptions. The communal analysis of the data during team meetings has been a powerful faculty development tool and motivator for curriculum design projects.

The University of Maryland HPI teaching team has developed collaboration with the Virginia Tech Microbiology Teaching Team led by Professor Ann Stevens to use data generated by the HPI concept inventory to catalog student misconceptions. We consider the HPI-CI is most useful when the use of the inventory is coupled to review and discussion of the data among course instructors.

We generally deliver the inventory in an online format using a survey tool. Students respond by selecting one of the multiple choice options and providing a text explanation for their choice. Please see the articles below for discussion of analysis of data from the inventory.

Contact: Ann C. Smith, asmith@umd.edu
2100 Marie Mount Hall, University of Maryland, College Park MD
301.405.9165



Relevant Publications:

Smith, A.C. and Marbach-Ad, G. 2010. Learning Outcomes with Linked Assessments - an Essential Part of our Regular Teaching Practice. *Journal of Microbiology and Biology Education*; 11(2): 123-129. <http://jmbe.asm.org/index.php/jmbe/article/view/217>

Marbach-Ad, G., McAdams, K.C., Benson, S., Briken, V., Cathcart, L., Chase, M., El-Sayed, N.M., Frauwirth, K., Fredericksen, B., Joseph, S.W., Lee, V., McIver, K.S., Mosser, D., Quimby, B.B., Shields, P., Song, W., Stein, D.C., Stewart, R., Thompson, K.V., and Smith, A.C., 2010. "A model for using a concept inventory as a tool for students' assessment and faculty professional development". *CBE Life Sci Educ.* Winter; 9(4):408-16. <http://www.lifescied.org/cgi/content/full/9/4/408>

G. Marbach-Ad (2009). [From misconceptions to concept inventories](#). Focus on Microbiology Education, 15(2), 4-6.

Gili Marbach-Ad, Volker Briken, Najib El-Sayed, Kenneth Frauwirth, Brenda Fredericksen, Steven Hutcheson, Lian-Yong Gao, Sam Joseph, Vincent Lee, Kevin S. McIver, David Mosser, B. Booth Quimby, Patricia Shields, Wenxia Song, Daniel C. Stein, Robert T. Yuan and Ann C. Smith (2009). [Assessing Student Understanding of Host Pathogen Interactions Using a Concept Inventory" to consider for publication in the Journal of Microbiology & Biology Education](#). Journal of Microbiology and Biology Education, 10, 43-50.

Ann C. Smith, Gili Marbach-Ad, Volker Briken, Najib El-Sayed, Kenneth Frauwirth, Brenda Fredericksen, Steven Hutcheson, Lian-Yong Gao, Sam Joseph, Vincent Lee, Kevin S. McIver, David Mosser, B. Booth Quimby, Patricia Shields, Wenxia Song, Robert T. Yuan and Daniel C. Stein (2007) A Faculty Team Works to Develop a Concept Inventory that Measures Understanding of Microbiology Relevant to Host Pathogen Interactions. [Second Conceptual Assessment in Biology \(CAB II\) Conference](#).



1. Ciproflaxin is a broad spectrum antibiotic that kills most normal microbial inhabitants in the human gut. *Clostridium difficile* is found in small numbers in the normal flora of some healthy adults however this normal inhabitant of the gut is not affected by ciproflaxin. *Clostridium difficile* is innately resistant to ciproflaxin. After therapy with ciproflaxin patients who normally carry *Clostridium difficile* often exhibit *Clostridium difficile*-associated diarrhea. The change in ability of *Clostridium difficile* to cause disease would best be explained by the statement that [choose the statement below that you would argue is the best explanation, then provide support for your argument]
 - a. Ciproflaxin interacted with *Clostridium difficile* in a manner to make the organism more pathogenic
 - b. Ciproflaxin has killed the microbes that normally compete with *Clostridium difficile* in the gut allowing the microbe to grow uncontrolled
 - c. Ciproflaxin acted as a mutagen. Ciproflaxin induced a mutation in *Clostridium difficile* to make the organism more pathogenic.
 - d. I do not know the answer to this question.

Explain your response.

Concepts 9, 10

2. *Bacillus subtilis* is growing in a nutrient rich environment. If glucose is depleted, what would be the first response of *Bacillus subtilis* to the change in the environment?
 - a. utilization of another carbon source.
 - b. formation of an endospore.
 - c. alteration of a DNA sequence.
 - d. acceptance of DNA via gene transfer.
 - e. I don't know the answer to this question

Explain your response.

Concept 10

3. Which is *NOT* true about the evolution of antibiotic resistance in bacterial populations? It can be mediated by
- selective growth of bacteria capable of degrading antibiotics.
 - alterations of a bacterium's genetic material through mutation.
 - changes in gene expression that occur in the presence of antibiotics.
 - modification of a bacterium's genome through uptake of new genetic information.
 - I do not know the answer to this question.

Explain your response.

Concepts 3, 4, 10

4. A. The human immune response:
- has evolved to distinguish self from non-self.
 - has evolved so that it does not interact with the bacteria that live in our gut.
 - has evolved to recognize microbes but not human tissue.
 - has evolved so that all humans have the same antigenic specificity.
 - all of the above are equally correct.
 - I don't know the answer to this question

Explain your response.

Concept 2 and 11

5. The initial response (first day) of the immune system to *Streptococcus pneumoniae* is the same as the initial response of the immune system to *Escherichia coli* because
- both cause diarrhea.
 - both are rod-shaped.
 - the immune response to all bacteria is essentially the same.
 - both bacteria share one identical antigenic epitope.
 - both secrete the same toxin.
 - I don't know the answer to this question.

Explain your response.

Concept12.

6. Selection for antibiotic resistance (always) relies on distinguishing between differences in:
- genotype
 - phenotype
 - morphology.
 - physiology
 - I do not know the answer to this question.

Explain your response.

Concepts 3, 4, 10

7. Can both gram-positive bacteria and gram-negative bacteria use the same mechanism of resistance to an antibiotic that affects protein synthesis?
- yes, because they both have similar mechanisms of protein synthesis.
 - yes, because they both have similar cell wall structures.
 - no, because most antibiotics are bacterial species specific.
 - no, because gram-positive bacteria are intrinsically more resistant to antibiotics than gram-negative bacteria.
 - I do not know the answer to this question.

Explain your response.

Concepts 2, 3

8. Pathogens and hosts have co-evolved in mutual fashion over many centuries. This implies that bacteria that have co-evolved with hosts are more likely to
- cause severe disease symptoms.
 - be easier to grow in a lab setting (easier to culture).
 - be antibiotic resistant.
 - have a narrow host range.
 - I do not know the answer to this question.

Explain your response.

Concept 6

9. Patient A has been treated and recovered from a recent infection with *Streptococcus pneumoniae*. Patient B has never been infected with *Streptococcus pneumoniae*. Both patients are admitted to the ER with an infection caused by the same strain of *E. coli*. Which of the following would you expect regarding their symptoms?
- the symptoms of Patient A would be more severe because the previous immune response against *Streptococcus pneumoniae* would weaken the response to *E. coli*.
 - the memory response generated by *Streptococcus pneumoniae* infection will reduce the symptoms of *E. coli* in Patient A.
 - patient A will be more susceptible because antibiotic treatment for *Streptococcus pneumoniae* would weaken subsequent immune responses.
 - the patient's symptoms will be the same, despite their different history of *Streptococcus pneumoniae* infection.
 - patient B will have more severe symptoms for *E. coli* infection because his innate immune system has not been primed by a previous infection by *Streptococcus pneumoniae*.
 - I don't know the answer to this question.

Explain your response.

Concept 13

10. *Escherichia coli* is growing in a nutrient rich environment. If glucose is depleted, what would be the first response of *Escherichia coli* to the change in the environment?
- utilization of another carbon source.
 - formation of an endospore.
 - alteration of a DNA sequence.
 - acceptance of DNA via gene transfer.
 - I don't know the answer to this question

Explain your response.

Concept 10

11. Which of the following statements is most accurate about the adaptive immune response? A throat infection by *Staphylococcus* sp.
- will confer protection from infection by *Streptococcus* sp because *Staphylococcus* sp. induced a similar initial immune response.
 - will confer protection from infection by *Streptococcus* sp because *Staphylococcus* sp induced a cross-reactive antibody.
 - will confer protection from infection by *Streptococcus* sp because *Staphylococcus* sp induced a complement response.
 - will NOT confer protection from infection by *Streptococcus* sp because *Staphylococcus* sp. induced an insufficient level of cross-reactive antibodies.
 - will NOT confer protection from infection by *Streptococcus* sp because infection with *Staphylococcus* sp. suppressed the immune response.
 - I do not know the answer to this question.

Explain your response.

Concept 12

12. Which of the following is an early (first day) host cellular response to *Escherichia coli*?
- inflammatory response.
 - specific antibody response to teichoic acid.
 - antigen specific immune response.
 - specific antibody response to LPS.
 - I do not know the answer to this question.

Explain your response.

Concepts 1,7,12

13. A. Two roommates fall ill: one has an ear infection and one has pneumonia. Is it possible that the same causative agent is responsible for both types of disease?
- yes, because both individuals live in the same room and therefore the source of the infection has to be the same.
 - yes, because the same bacteria can adapt to different surroundings.
 - no, because each bacterium would cause one specific disease.
 - no, because one infection is in the lung while the other is in the ear.
 - I do not know the answer to this question.

Explain your response.

Concepts 4, 5, 9, 12

14. Feces from a patient with diarrhea is examined and found to have *E.coli*, *Bacteroides*, *Lactobacillus*, and *Bifidobacter*. What is the likely cause of the symptoms?
- E.coli*, because of the presence of LPS on its surface.
 - Lactobacillus*, because it is gram-positive.
 - the combination of all of these bacteria.
 - none of these bacteria can cause diarrhea.
 - not enough information is provided to determine.
 - I do not know the answer to this question.

Explain your response.

Concept 8

15. In a hospital environment where antibiotics are commonly used which bacterial trait will spread most rapidly?
- chromosomally encoded traits because they are spread through replication.
 - chromosomally encoded traits because they are spread through horizontal transfer (conjugation).
 - plasmid encoded traits because they are spread through replication.
 - plasmid encoded traits because they are spread through horizontal transfer (conjugation).
 - chromosomally encoded and plasmid encoded traits will spread with the same efficiency because they are both DNA.
 - I do not know the answer to this question.

Explain your response.

Concept 3

16. Transport of nutrients into a gram-negative cell is more complicated than transport into a gram-positive cell because:
- gram-negative bacteria have a thicker peptidoglycan layer.
 - gram-negative bacteria possess two membranes.
 - gram-negative bacteria contain more proteins on the cell surface.
 - the cell wall of gram-positive cells is more rigid.
 - the statement is false - transport is equally complicated for gram-positive and gram-negative bacteria.
 - I do not know the answer to this question.

Explain your response.

Concepts 7, 9

17. *Escherichia coli*, while growing on glucose, is treated with an uncoupler that eliminates the proton motive force for supporting ATP synthesis. The effect would be:
- the cells would die because they cannot make any ATP.
 - ATP is not essential for growth; the cells would continue to grow.
 - the cells would grow using ATP generated by fermentation.
 - the cells would generate ATP by fermentation, but would not grow as the amount of ATP generated would not be sufficient.
 - the cells could grow by anaerobic respiration using sulfate as a terminal electron acceptor.
 - I do not know the answer to this question.

Explain your response.

Concept 10

18. Two patients are treated in the ER for an infection caused by the same strain of *E. coli*. Patient A's symptoms are much more severe than patient B's symptoms. Which of the following could explain this?
- patient B has previously generated an immune response against *E. coli*.
 - patient A has recently recovered from a *Streptococcus pneumoniae* infection, which weakened her immune system.
 - patient B has recently recovered from a *Streptococcus pneumoniae* infection, which strengthened her immune system.
 - patient B was treated with antibiotics 1 month prior to the *E. coli* infection
 - because symptoms are only caused by innate immune responses, patient A must be immunocompromised
 - I do not know the answer to this question.

Explain your response.

Concept 13

19. A 0.1ml sample of a pure bacterial culture that contains 1×10^9 bacteria is transferred to two plates: Plate A contains growth media. Plate B contains growth media supplemented with the antibiotic ampicillin. After overnight incubation in the appropriate growth conditions, the plates are observed. Plate A has confluent growth, Plate B is observed to have 2 colonies growing on the plate. The colonies are tested and found to be resistant to the antibiotic ampicillin. **Why did 2 bacterial cells survive and produce colonies?**
- Antibiotics kill susceptible bacteria allowing resistant bacteria to survive and grow
 - Antibiotics induce changes in the DNA of a subset of susceptible bacteria allowing them to survive and grow
 - Antibiotics alter the structures or functions of susceptible bacteria allowing them to survive and grow
 - I do not know the answer to this question.

Explain your response.

Concepts 3, 4, 10

APPENDIX 2.E

CLASS-Bio Instrument

Select one of the choices that best expresses your feeling about the statement.

1. My curiosity about the living world led me to study biology.
 - Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
2. I think about the biology I experience in everyday life.
 - Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
3. After I study a topic in biology and feel that I understand it, I have difficulty applying that information to answer questions on the same topic.
 - Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
4. Knowledge in biology consists of many disconnected topics.
 - Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
5. When I am answering a biology question, I find it difficult to put what I know into my own words.
 - Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
6. I do not expect the rules of biological principles to help my understanding of the ideas.
 - Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree

7. To understand biology, I sometimes think about my personal experiences and relate them to the topic being analyzed.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
8. If I get stuck on answering a biology question on my first try, I usually try to figure out a different way that works.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
9. I want to study biology because I want to make a contribution to society.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
10. If I don't remember a particular approach needed for a question on an exam, there's nothing much I can do (legally!) to come up with it.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
11. If I want to apply a method or idea used for understanding one biological problem to another problem, the problems must involve very similar situations.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
12. I enjoy figuring out answers to biology questions.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree

13. It is important for the government to approve new scientific ideas before they can be widely accepted.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
14. Learning biology changes my ideas about how the natural world works.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
15. To learn biology, I only need to memorize facts and definitions.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
16. Reasoning skills used to understand biology can be helpful to my everyday life.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
17. It is a valuable use of my time to study the fundamental experiments behind biological ideas.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
18. If I had plenty of time, I would take a biology class outside of my major requirements just for fun.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
19. The subject of biology has little relation to what I experience in the real world.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree

20. There are times I think about or solve a biology question in more than one way to help my understanding.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
21. If I get stuck on a biology question, there is no chance I'll figure it out on my own.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
22. When studying biology, I relate the important information to what I already know rather than just memorizing it the way it is presented.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
23. There is usually only one correct approach to solving a biology problem.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
24. When I am not pressed for time, I will continue to work on a biology problem until I understand why something works the way it does.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
25. Learning biology that is not directly relevant to or applicable to human health is not worth my time.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree

26. Mathematical skills are important for understanding biology.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
27. I enjoy explaining biological ideas that I learn about to my friends.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
28. We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question to preserve your answers.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
29. The general public misunderstands many biological ideas.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
30. I do not spend more than a few minutes stuck on a biology question before giving up or seeking help from someone else.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
31. Biological principles are just to be memorized.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree

32. For me, biology is primarily about learning known facts as opposed to investigating the unknown.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
33. The use of MicroALEs made microbiology more interesting.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
34. The use of MicroALEs was helpful for learning microbiology.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree
35. The use of MicroALEs encouraged me to think critically about microbiology.
- Strongly Disagree
 - Disagree
 - Neutral
 - Agree
 - Strongly Agree

**CHAPTER THREE: PROCESS OF INSTRUCTIONAL CHANGE: A
QUALITATIVE CASE STUDY CHARACTERIZING THE PERCEPTION OF
ONE MICROBIOLOGY PROFESSOR'S SHIFT FROM A TRADITIONAL
INSTRUCTIONAL MODEL TO A DIVERSIFIED MODEL FEATURING
COLLABORATIVE, ACTIVE LEARNING**

Introduction

Calls to reform post-secondary science education suggest a need to shift the instructional model traditionally employed at the university level (American Association for the Advancement of Science [AAAS], 1989, 2011; National Research Council [NRC], 1999; National Science Board, 1986; Project Kaleidoscope, 1991). Specifically, there are appeals to increase student engagement and performance by implementing research-based pedagogy in undergraduate-level science courses that more purposefully aligns with current research on learning (Brewer & Smith, 2011; Hatfull et al., 2007; Woodin, Smith, & Allen, 2009). Research suggests the traditional, instructor-centered model, a stalwart in university-level science courses, is not aligned with how the brain processes information for long-term retention of knowledge (Brewer & Smith, 2011; Knight & Wood, 2005). Halpern and Hackel (2002) observed that, in regards to this traditional, lecture-only model, “it would be difficult to design an educational model that is more at odds with current research on human cognition” (p. 3). Although there is evidence of university science departments’ progress toward transforming this traditional pedagogy, there persists a particular concern that post-secondary biology education

continues to rely heavily on the traditional instructional model (Brownell & Tanner, 2012; Merkel, 2012; Miller, Pfund, Pribbenow, & Handelsman, 2008).

In a review of biology teaching and learning, Allen and Tanner (2005) suggested that the scholarship of teaching is pursued when “systematic inquiry and investigation” (p. 5) are used to understand what students are learning, how instructional materials and methods impact learning, and how teaching can be more effective. Recent emphasis on transforming biology education has led to a growing number of studies reporting encouraging evidence that reform-based pedagogies that incorporate active learning are positively impacting student learning and attitudes (Freeman et al., 2007; Linton, Farmer, & Peterson, 2014; Smith, Wood, Krauter, & Knight, 2011). According to Handelsman et al. (2004), student participation in active learning during the lecture portion of a course “develop[s] habits of the mind that drive science” (p. 521). These habits are those of a practicing scientist in which scientific inquiry and critical analyses are important constructs needed to advance scientific knowledge.

Emerging from these efforts to promote reform in biology education is an expanding selection of student-centered, research-based instructional resources and strategies that present alternatives to the traditional, instructor-centered model (Boucaud, Nabel, & Eggers, 2013; D’Avanzo, 2003; Prunuske, Batzli, Howell, & Miller, 2012; Rutledge, 2005; Wood, 2009). Mounting empirical evidence suggests these resources and strategies are working when they are utilized in the classroom; however, there is concern among education reformists that adoption of instructional change by traditional faculty is not happening as rapidly or as broadly as desired within undergraduate biology courses (Brownell & Tanner, 2012; Merkel, 2012; Miller et al., 2008). A notable obstacle for

adopting reform strategies was revealed by Andrews and Lemons (2015) who found that these traditional biology professors privilege personal evidence of success rather than empirical evidence when attempting reform.

According to Henderson et al. (2011), the solution to broad-based, sustainable reform is not as simple as creating innovative teaching resources, as their availability alone does not ensure reformed instructional practices. For example, effective resources and pedagogical strategies (e.g., *The National Center for Case Studies in Science* and active learning) may be available, but without an infrastructure in place to support selection and implementation, reform-based instructional strategies (RBIS) are potentially under-utilized, misused, or discarded. This may lead faculty to revert back to their previous traditional pedagogy (Brownell & Tanner, 2012).

Recognizing this, the current research attempted to model an effective change strategy (Henderson, 2011) with sustained, grass-roots implementation support to examine how a reform-based curricula can be effectively adopted by a professor accustomed to teaching in a traditional manner. According to Henderson et al. (2011), “effective change strategies must be aligned with or seek to change the beliefs of the individuals involved [and] change strategies need to involve longer-term interventions lasting a semester, a year, and longer” (p. 978). However, as Henderson noted, connections between faculty development researchers and practitioners are not occurring frequently enough to support change in post-secondary science education.

Considering a possible wide-variety of pedagogical knowledge and beliefs held among traditional biology faculty along with discipline-specific content within courses, there is potential for additional descriptive studies of instructional change to support

sustained reform of practice for a variety of settings. For example, Smith et al. (2005) presented an effective model for implementing active learning in a large-lecture, undergraduate microbiology course. However, the model included use of multiple instructors for one section and the use of graduate and undergraduate teaching assistants to carry out instructional change strategies. Although the study presented a descriptive model for change, it is not realistic for all post-secondary settings to expect multiple teaching assistants in a single course due to a general lack of in-class support staff available to professors. Consequently, to support broader adoption of reform-based instructional strategies there is a need for a diversity of practical strategies that apply to particular learning environments (e.g., Andrews & Lemons, 2015; Henderson, 2005). To be effective agents of change faculty should refer to applicable strategies that describe utilization of readily accessible resources, manageable instructional strategies, and meaningful practices that provide value to students in regards to learning and engagement during class (Henderson, 2012).

Statement of the Problem

There is currently a lack of research within the realm of biology education that characterizes, in an in-depth way, the process of instructional change from an instructor-centered approach to one that features student-centered components. Additionally, evidence suggests that professors in post-secondary biology courses continue to rely on traditional pedagogies (Brownell & Tanner, 2012).

A review of the literature suggested multiple obstacles that exist which slow faculty adoption of reform-based instructional strategies across STEM disciplines and, in particular, in biology. These include perceived or real lack of time, personal attitudes

regarding instructional innovations, instructional experience, and pedagogical knowledge (Andrews & Lemons, 2015; Brownell & Tanner, 2012; Henderson, Beach, & Finkelstein, 2011; Henderson, Dancy, & Niewiadomska-Bugaj, 2012). Additionally, evidence suggested broader instructional reform may not be occurring due to ineffective practices for disseminating curricular resources.

For example, Henderson and colleagues (2011) stated that disseminating resources is simply not enough to sustain pedagogical reform and that attempted top-down policy efforts to enact change among faculty utilizing traditional instruction is not effective. Particularly, there is limited guidance to support biology faculty seeking to transform their instructional model (Andrews & Lemons, 2015). To promote sustained adoption of recommended reform-based instructional strategies within post-secondary biology education there is a need for rich, descriptive accounts of traditional faculty attempting pedagogical reform based on effective change strategies.

Statement of Purpose

The purpose of this study was to characterize the perception of pedagogical change held by a microbiology professor attempting to implement a reform-based curriculum for the first time. Specifically, the participant sought to shift his instructional model from a traditional, lecture-only style to one that retained some direct-lecture but also incorporated components of a student-centered, active-learning instructional model. One pathway to pedagogical change potentially begins with an intrinsic motivation driven by discontent of current teaching and learning outcomes (Gess-Newsome, et al., 2003). Evidence for this was observable through questions posed by the author during informal conversations that led to the development of this study examining the perception

of instructional change. In particular, the participating faculty member was unhappy with student performance and engagement in his current course and was concerned that his traditional teaching methods were the problem.

The context of this study was grounded in a realistic scenario informed by a framework to support effective change (Henderson et al., 2011). That is, a veteran microbiology professor seeking to alter his instructional approach reflected on the process of change through a collaborative partnership with a biology education researcher experienced in development and implementation of active-learning resources and strategies in post-secondary biology courses. Throughout this collaboration, the researcher documented how the professor perceived the attempt to alter his instructional model for the first time in 21 years. This study was guided by the following research questions:

1. What motivated a veteran professor, with a traditional instructional model, to engage in the process of instructional change?
2. How did the professor experience the process of instructional change within the context of this study?

Significance of the Study

The desire to support reform of pedagogy utilized in biology education at the post-secondary level is continually expressed by science education researchers and funded by such organizations as the National Science Foundation, National Institutes of Health, NRC, and the Howard Hughes Medical Institute (AAAS, 2011; Brownell & Tanner, 2012; Tagg, 2012). In their review of biology teaching and learning, Allen and Tanner (2005) suggested that the scholarship of teaching is pursued when “systematic

inquiry and investigation” (p. 5) are used to understand what students are learning, how instructional materials and methods impact learning, and how teaching can be more effective.

This case study intended to explore the process of post-secondary biology education reform in the context of an undergraduate microbiology course. The researcher documented the process of change experienced by one professor with a traditional pedagogy who sought to implement research-based instructional strategies for the first time. The overarching goal of this study was to contribute to the specific effort of promoting and sustaining post-secondary biology education reform. The results of this work serve to: (a) inform future adopters of instructional reform as to what to expect when attempting pedagogical change; and (b) model an effective change strategy described by Henderson et al. (2011) with sustained, grass-roots implementation support to examine how a reform-based curricula can be effectively adopted by faculty without formal pedagogical training.

Conceptual Framework

Previous literature on instructional change theory served as the framework for this study. This included identifying a model to serve as a lens for determining the contextual elements that were present in this particular case, and a model for supporting the design of a sustained, grass-roots attempt at instructional reform.

Pedagogical discontentment. Pedagogical discontentment is acknowledged (e.g., Feldman, 2000; Southerland, Sowell, Blanchard, & Granger, 2011) as a significant motivating factor for pursuing instructional change. Gess-Newsome, Southerland, Johnston, and Woodbury (2003) stated that “change in practice requires dissatisfaction

with the teaching and learning goals established for students, beliefs about students and how they learn, and beliefs about the effectiveness of instructional practices used to meet newly established goals” (pp. 762-763).

In particular, the Teacher-centered Systemic Reform (TCSR) model for a college classroom developed by Gess-Newsome et al. (2003) served as a lens to view the particular problem in this study. According to this model, the professor represented a best-case scenario for attempting instructional reform in which contextual barriers (i.e., cultural, departmental, and classroom) were eased and pedagogical discontentment was acknowledged. After identifying the case as an ideal candidate, a model was identified to inform the effective dissemination of an instructional resource designed to foster an active, student-centered learning. This model is described next.

Change theory and professional development. This qualitative study was purposefully designed to capture the perception of change utilizing a model described by Henderson et al. (2011) to support effective instructional change. This particular model was selected as a theoretical proposition to support effective adoption of a reform-based curricula through a sustained, grass-roots implementation. Henderson et al. (2011) suggested that an effective change strategy is “to encourage and support reflective practices by individual instructors that lead to instructor-identified and defined change outcomes” (p. 961). The instructional change model in this study included a collaborative partnership in which the biology education researcher offered guidance on implementation outside of class and prompted the professor to reflect on implementation and the process of change. Furthermore, Henderson et al. (2011) argued that “[effective] change strategies involve long-term interventions, lasting a semester, a year, and longer”

(p. 978). The change strategy utilized by the professor in this study was individualistic and emergent. To document the perception of change under this model and within the context of this study, data were collected over the span of one semester in which a microbiology professor adopted a student-centered curriculum for the first time in his 21-year career as an undergraduate microbiology instructor.

Methodology

This study utilized a single case study design to describe a particular instance of instructional change by one professor in a post-secondary microbiology course. According to Yin (2014), the use of a single case study is appropriate when the researcher is attempting to capture the “circumstances and conditions” (p. 52) of a common situation. Heck (2006) stated, “Single case studies are appropriate in situations where one’s focus is on describing how a process works in a particular instance” (p. 379).

The purpose of this study was to explore the perception and experience over the span of one semester of a veteran professor attempting to change his instructional model. A single case study was chosen to explore his perception of change as it is a particularly useful approach for documenting such efforts of change over time (Yin, 2014). The nature of a single case study documents the experience of a specific case and is not intended to be statistically generalizable (Yin, 2014). However, this study utilized a professional development model for pedagogical reform that allowed for theoretically generalizability of results (Yin, 2014) to similar contexts in biology education and to a broader range of scientific disciplines. The goal was to promote and inform efforts toward sustainable and effective pedagogical reform.

University and Classroom Context

The context for this study was bound by one semester of one section of a general microbiology course taught by one professor at a large, public state university in the Southeastern United States that maintains doctoral programs. The university was composed of approximately 21,000 undergraduate students and 2,700 graduate students with 92.5% of all students classified as in-state residents. Within the biology department at this university, there were 561 full and part-time biology majors (36.9% male and 63.1% female).

The course of interest in this study consisted of 60 students and met three times per week on Monday, Wednesday and Friday for 55 minutes in a large-lecture room with stadium seating. Students enrolled in this class had taken, as a prerequisite, a two-semester introductory-level general biology course. These students were typically majoring in biology or preparing for a pre-allied health field (e.g., nursing, medicine, dentistry). In addition to the lecture course, all students were required to register for a 3-hour microbiology laboratory that met once per week. Although there were multiple laboratory instructors, all laboratory sections utilized the same curriculum and materials with weekly instructor meetings to control for instructional variation. Data were not collected from the laboratory.

As the primary investigator for this study, the researcher was not involved in the day-to-day classroom instruction or implementation of the curriculum resource; however, the professor and the researcher collaborated outside of class within the professional development model supporting reflective practice previously discussed. This included

meetings intended to prepare the professor for implementing the active learning exercises into his traditional lecture material.

Curriculum

Before data collection began, the participating professor and the biology education researcher informally discussed strategies for implementing student-centered learning into his traditional lecture course. The following is a description of the curricular resource that emerged from these conversations. To support instructional reform in this study, a novel set of inquiry-based, active learning exercises were developed specifically for an undergraduate-level microbiology course. Notably, the intent of this study was not to investigate this specific curriculum resource; however, it is described to provide an understanding of the resource and how it was utilized by the professor in this context.

The professor and the researcher engaged in a collaborative partnership to identify a resource he could utilize in the classroom to potentially address his concerns of declining student engagement and performance in his microbiology courses. The result of this was the creation of Microbiology Active-Learning Exercises (MicroALEs). The researcher designed MicroALEs to be used as a tool for incorporating student-centered, active learning into the traditional lecture (i.e., a diversified instructional model). Importantly, MicroALEs are generalizable for other instructors of microbiology in that they are based on curriculum guidelines outlined by the American Society for Microbiology (ASM) (Merkel, 2012). Additionally, the effort to create this resource responds to general calls from the NRC (2000, 2003) and the AAAS (2011) to increase the availability of high quality resources for improving curriculum and instruction across STEM disciplines, and to a more focused call from ASM (2012) to promote “concept-

based student-centered learning” (Merkel, 2012, p. 33) in university-level microbiology courses.

The researcher designed seven MicroALEs to engage students in the content of a microbiology course, fostering meaningful learning of important key concepts while prompting students to think critically about scientific evidence that is personally relevant to students’ academic and future professional careers. For each MicroALE, the professor lectured briefly before disseminating the day’s MicroALE. Students worked on the MicroALE in collaborative groups of three to four during class followed by whole class discussion led by the professor to clarify, correct, and elaborate on student group responses. The format, both in structure and implementation of the exercises, was adapted from a published set of active-learning exercises created and utilized by Rutledge (2005, 2008) who demonstrated that a collaborative, student-group implementation format was effective for diversifying a traditional instructional approach while improving student attitudes in the course (as compared to traditionally taught courses). MicroALEs were aligned with the current microbiology course content and the *ASM Recommended Curriculum Guidelines for Undergraduate Microbiology Education* (Merkel, 2012). Table 3.1 shows the topic for each MicroALE utilized in this study along with the date it was implemented. The components of a typical MicroALE are described in Table 3.2 along with the approximate amount of time the professor spent on each component in a 55-minute class period.

Table 3.1

MicroALEs Used for the Related Course Topic and Date of Implementation

MicroALE	Topic	Date
No. 1	Introduction to Pathogens	9/10
No. 2	Prokaryotic Cell	9/22
No. 3	Biotechnology	10/15
No. 4	Control of Microorganisms	10/27
No. 5	Epidemiology and Disease	11/10
No. 6	DNA and RNA Synthesis	11/24
No. 7	Epidemiology and Disease	12/1

Table 3.2

Components of a MicroALE in Order of Implementation

Component	Description	Time (minutes)
Scenario	Students complete a reading that relates to course content. The nature of this reading presents societal and/or scientific positions related to historical context or current events in microbiology. It serves as a hook that aims to prompt students to think about the relevance of content covered in lecture in relation to the field of microbiology.	5
Expert Analysis Form	Three to five inquiry-based questions in which students complete in collaborative groups of three to four. Questions prompt students to consider information from course content, general scientific knowledge, and personal beliefs. Possible responses include creating graphs, modeling, designing experiments to test claims, or making inferences based on provided evidence.	15
Debriefing	Instructor-led, whole class discourse where individual students are called on to present their group's answer. The role of the professor is not to provide explicit answers but to foster construction of knowledge through discussion.	10
Summary Question	Students work individually to complete an overarching question that prompts a demonstration of critical thinking skills by using sound reasoning to accurately interpret evidence, synthesizing knowledge, and evaluate points of view	5

Unit of Analysis and Participant Background

The case for this study was Dr. Robert (pseudonym), a tenured, research and teaching full professor in the Department of Biology. For the previous 21 years, he had taught multiple sections per semester of general microbiology using a traditional instructional approach. Dr. Robert was a formally trained microbiologist that was actively engaged in infectious disease research. Prior to the semester of interest, he claimed to

have no explicit knowledge of reform-based instructional strategies and described the incorporation of his notes into PowerPoint as the only aspect of instructional change in which he had engaged during his career. He did acknowledge shifting course material toward more relevant information as a strategy for making the content more interesting to students; however, he was uncertain of the effect (Pre-semester interview, 9/3/14, 18:30).

Dr. Robert described his instructional model as him lecturing while students sat quietly taking notes on which they would be tested at a later date. “I teach the way I was taught” (Pre-semester interview, 9/3/14, 3:15). He said, “My approach has been traditional. I talk and they write it down” (Pre-semester interview, 9/3/14, 13:15). Clearly, Dr. Robert was a novice in terms of reform-based instructional strategies. This aspect along with his background as an actively engaged scientist with a teaching assignment made him an ideal case for examining the process of instructional change experienced by traditional science faculty member with little experience with RBIS.

Data Collection

Data was collected under the approval of the university's Institutional Review Board (protocol #15-027). Multiple data sources were collected throughout the semester to triangulate findings. These included one-on-one interviews in the private office of Dr. Robert, reflective journal entries, and classroom observations. All interview data consisted of handwritten notes and audio recordings that were transcribed in full. Journal entries were recorded electronically in a secure format. Dr. Robert's reflections in the journal were prompted by questions posed by the researcher. Classroom observations were made on days that Dr. Robert implemented a MicroALE, and data consisted of handwritten notes and audio recordings that were transcribed as needed. Table 3.3 lists

specific data sources by their identifying title in the case study database and the date they were collected. The following is a detailed description of each data source.

Table 3.3

Record of Data Sources Collected Over One Semester Displayed in Chronological Order

Data Source	Collection Date
Pre-semester interview	9/3
Pre-MicroALE 1 interview	9/8 and 9/9
MicroALE 1 classroom observation	9/10
Post-MicroALE 1 reflective journal	9/12
Post-MicroALE 1 interview	9/17
MicroALE 2 classroom observation	9/22
Post-MicroALE 2 reflective journal	9/26
Post-MicroALE 2 interview	10/1
MicroALE 3 classroom observation	10/17
Post-MicroALE 3 reflective journal	10/24
Post-MicroALE 3 interview	10/24
MicroALE 4 classroom observation	10/27
Post-MicroALE 4 reflective journal	11/5
Post-MicroALE 4 interview	11/7
MicroALE 5 classroom observation	11/10
Post-MicroALE 5 reflective journal	11/18
Post-MicroALE 5 interview	11/20
MicroALE 6 classroom observation	11/24
Post-MicroALE 6 interview	12/1
MicroALE 7 classroom observation	12/1
Post-MicroALE 7 interview	12/3
Post-semester interview	12/17

Note. Classroom observation dates align with dates that a particular MicroALE was implemented.

Pre-semester interview. A one-on-one, semi-structured interview was conducted before the first day of class of the semester to establish the background of Dr. Robert's academic career, an understanding of his pedagogical knowledge, and his expectations for the implementation of a student-centered component into his traditional instruction. See Appendix 3.A for interview protocol. The pre-semester interview marked the beginning of formal data collection for the study (lower bound of the case study).

Post-semester interviews. A one-on-one, semi-structured interview was conducted after the final class meeting of the semester to summarize Dr. Robert's perception of instructional change, to understand his attitude toward future implementations of the active-learning curriculum provided to him, and to describe his intentions of future instructional change in general as a result of the experience during the semester. See Appendix 3.B for interview protocol. The post-semester interview concluded the data collection period of the study (the upper bound of the case study).

MicroALE interviews. A one-on-one, semi-structured interview was conducted after each class period in which Dr. Robert implemented a MicroALE to describe his perception of the curriculum resource and instructional strategy implemented. Additionally, the researcher utilized this time to clarify any written statements made in Dr. Robert's reflective journal entries (described next). See Appendix 3.C for the interview protocol.

Journal. A reflective journal was utilized to document the participant's perceptions following each implementation of a MicroALE. After each implementation, the researcher sent Dr. Robert an email (via the university email server) with question prompts to foster reflection on the implementation. Dr. Robert responded via email with

an electronic journal entry that was archived chronologically. In addition to being a data source, the journal entries were intended to prompt a reflective practice as recommended by Henderson et al. (2011) to facilitate instructional change. Notably, journal entries were discussed in weekly interviews, and reflections were clarified by the researcher for the purpose of describing the perception of change and validating the data through member checking.

Observations. Direct classroom observations were made during the entire class period that a MicroALE was implemented. Observations were not made during lectures that did not have a MicroALE component. The researcher collected field notes as a nonparticipant in the classroom using an observation protocol (see Appendix 3.D). Observations were archived in chronological order and paired with corresponding weekly interview data. Observation data included reflective notes taken by the researcher post-implementation to aid in theme development and data analysis.

In addition to written observational notes, an audio-recording device was utilized to document the entire class period. The audio data was not transcribed in its entirety as it served as a backup and direct quote reference to field notes as needed. The purpose for collecting classroom observation data was to corroborate Dr. Robert's implementation with his perceptions of implementation that were collected in the one-on-one interviews and journal entries. Notably, student commentary was not considered or collected as data during classroom observations or at any other time during for this study.

Data Analysis

Theoretical propositions based on previous research investigating the process of instructional change guided the analysis of data (Yin, 2014). All data sources were

assigned data codes and organized chronologically for the purpose of describing perception of change over the course of the semester. For example, interview data were transcribed and matched chronologically with reflective journal entries and classroom observation data so that the researcher was able to document evidence of perception at intervals throughout the semester and triangulate evidentiary claims at these time points.

A dual approach was utilized to analyze data (Yin, 2014). Initially, a deductive approach was used to select quotes from transcribed interview data and journal entries that were relevant to the research questions. The researcher identified emergent themes from the data, assigning each theme with a code in order to triangulate perception across sources and time. This work is presented in Appendix 3.E as a data matrix in which coded themes are listed in the first column organized into three encompassing categorical themes of motivation, perception of change, and experience. Subsequent columns to the right organize quotes by time collected (e.g., Pre-semester interview and Post-semester interview). Then, an inductive approach was applied to further refine evidence by documenting emerging themes from the quotes selected. A refined matrix was created to organize a rich account of perception of change over time by these emergent themes of motivation to engage and experience. The theme of experience was further refined to include the sub-themes: professional development, proof seeking, impediments to change, and proof.

A logic model (see Appendix 3.F) was created with these themes to evaluate the process of change. The TCSR model was used as a lens to document Dr. Robert's intrinsic motivation for change as a result of pedagogical discontentment (Gess-Newsome et. al, 2003). Henderson's et al. (2011) model of effective instructional change was used

as a lens to document Dr. Robert's participation in a sustained (one semester), informed intervention that was emergent and individualistic.

Limitations and Delimitations

Potential limitations included researcher and contextual bias. For example, the participant was fully aware of the background of the researcher potentially leading to participant bias when responding to questions. However, this is a potential problem with any ethnographic data source. To overcome this, the researcher continually reminded the professor that the nature of the study was to document his perception of change and that there were no correct answers to the questions posed.

Delimitations included the decision to use one participant bound by one semester of a post-secondary microbiology course implementing a student-centered instructional strategy and active-learning resource directed by the researcher. The boundaries of this case study were not intended to achieve statistical generalizability, but were intended to contextualize data so that they were potentially theoretically transferable to a broader setting of instructional change.

Trustworthiness

Acknowledging limitations, the researcher was mindful of attempting to not lead the participant toward particular answers regarding the use of a curriculum created by the researcher. The researcher sought to increase the methodological validity by triangulating data sources and utilizing multiple data collection methods. Additionally, inter-rater reliability was addressed by having peers and mentors review and provide input on thematic analysis and coding of data. Finally, a member check was utilized to control for researcher bias when interpreting Dr. Robert's perception of change. The researcher had

Dr. Robert review classroom observations and clarify his responses to questions posed during interviews and post-MicroALE reflective journal entries.

Results

Results are presented in narrative form to characterize Dr. Robert's perception of change. Evidence includes his motivation to engage, his experience utilizing RBIS for the first time, and his perception of the value for teaching and learning when implementing MicroALEs.

Motivation to Engage

Investigation of the process of change begins with revealing the circumstance leading to the decision to initiate change including contextual participant background information. Here, the researcher was interested in describing the motivations for this particular participant to pursue instructional change for the first time in his 21-year career. Results indicated these motivations were intrinsic and personal rather than extrinsic (e.g., departmental or institutional).

For example, in the summer of 2014 (prior to the bounded case), Dr. Robert informally approached the researcher with concern about lack of student engagement and performance in his microbiology course, but he was uncertain about how to proceed with impactful changes. During this conversation, he expressed that he was bored with the instructional approach he had used for the past two decades. In addition, he perceived students to be generally disinterested in attending lecture. He also suggested that student performance in his course had diminished over time even though he was teaching and evaluating in the same manner as he always had. Based on these concerns, his knowledge of the researcher's background in biology education research, and the researcher's

experience utilizing innovative teaching practices, he asked the researcher for help and ideas on improving his course. Dr. Robert was clearly discontent with his teaching and student performance. This sentiment led him to inquire, and eventually pursue, instructional change.

Documented at the beginning of the study, he described his intrinsic motivation to pursue instructional change because he accepted responsibility for his role as a teacher. For example, Dr. Robert stated, “I try to be responsible in my teaching” (Pre-semester interview, 9/3/14, 29:00). Recognizing this responsibility he offered further reflection on his current intrinsic motivation to change saying, “My teaching is stale. I want to do something different” (Pre-semester interview, 9/3/14, 32:00). Later in the semester, he recalled his traditional approach with a similar sentiment. “Class time can become somewhat stale when all you do is walk in and lecture and then walk out time after time for every class” (Post MicroALE 4 reflective journal, 11/5/14). When asked why he wanted to engage in pedagogical reform, he said, “My hope is that student attitude and performance will be better” (Pre-semester interview, 9/3/14, 35:45).

Notably, at the end of the study Dr. Robert restated his intrinsic motivation to change. “I have always felt there was a need to do something else to promote learning and scholarship, especially among the lower academic achieving portion of the class” (Post-semester interview, 12/17/14, 50:00). The “something else” to which Dr. Robert referred was the instructional strategy that he had used for the past 21-years. Dr. Robert described this strategy at the beginning of the study.

I think my teaching style is traditional. . . . Traditional teaching to me is when the professor stands in front of the students, provides factual information, expects the

students to write it down, and then later on will give them a test based upon the factual information that I gave them. (Pre-semester interview, 9/3/14, 2:58)

Furthermore, when the researcher asked him to describe his perception of an instructor-centered teaching model, he likened his model to an instructor-centered learning environment. “To me, that would mean that the classroom activity revolves around the instructor. If it is instructor-centered then classroom activities revolve around him or her. To me traditional would be an instructor-centered learning environment” (Pre-semester interview, 9/3/14, 14:23).

The researcher asked Dr. Robert to recall the origin and development of his teaching philosophy for the purpose of characterizing his background. He stated:

I teach the way I was taught. That is for several reasons. Number one, I don't know anything different. Number two, I felt that my education process was successful and the thought is that this traditional style will be successful as well. (Pre-semester interview, 9/3/14, 3:15)

Although this was not a study of origin, this sentiment was a potentially important factor to motivate Dr. Robert's pursuit of change. That is, 21 years of teaching without formal pedagogical training led to frustration and then uncertainty with regard to his given role as a teacher within his chosen career as a scientist.

Nowhere, anywhere in my career has anyone ever told me what to teach or how to teach what I teach, or said anything about how I could teach it. I think that is true of most scientists. I mean that's the kind of irony in secondary, elementary, and high school [education courses] you learn how to teach. [For] college professors there is no instruction, you don't learn how to teach. I mean the assumptions is

that if you have a Ph.D. I guess you can teach. I don't know. Never in my career has anyone ever told me how to teach something. (Pre-semester interview, 9/3/14, 30:35)

Finally, results indicated that a combination of intrinsic motivation and his uncertainty of how to enact change led him to seek help and ask questions related to alternative instructional strategies. For example, Dr. Robert stated, "I always wanted to talk and engage students, [but] I did not know how to do it or [how to] find the time" (Pre-semester interview, 9/3/14, 34:00). This sentiment from Dr. Robert was what initially led him to speak to the researcher about instructional alternatives. His interest in change began the process of planning for a semester in which he implemented RBIS for the first time. The following characterizes his perception of the experience to enact instructional reform for the first time in 21 years.

Experience Utilizing RBIS

Analysis of data revealed multiple, emergent themes that related to the experience of change. Throughout the span of one semester and across multiple data sources, Dr. Robert reflected on: past and present experiences learning about topics that addressed education and instructional strategies (professional development); his expectations for utilizing RBIS for the first time (proof seeking); his perceived barriers to reform (impediments); and finally, his perception about the value of utilization (proof). The following themes emerged from this data: professional development, proof seeking, impediments, and proof. These are described next in attempt to characterize Dr. Robert's experience implementing RBIS for the first time.

Professional development. A potential benefit for Dr. Robert participating in this study was the opportunity for professional development. The researcher was interested in Dr. Robert's perception about this opportunity in addition to his past experiences with professional development. The genesis of this study was Dr. Robert's intrinsic motivation to pursue change. He initially approached the researcher seeking to learn about alternatives to his traditional instructional model. To understand Dr. Robert's perception of professional development and to document his purpose for engaging in professional development, the researcher asked him to reflect on this current opportunity to learn about reform-based pedagogies.

I don't want to bury my head in the sand and pretend like none of this exists, or that I have no knowledge of it . . . I think when you've done the same thing for twenty years you become a little bit interested in changes that could make your job easier or better. (Pre-semester interview, 9/3/14, 32:15)

This further confirmed his intrinsic motivation to pursue change. This motivation led him to pursue knowledge of an alternative pedagogy. It is interesting that, as a faculty member with teaching responsibilities, he appeared to have not engaged in professional development in twenty years. Evidence suggested that Dr. Robert was not only a novice at implementation of RBIS, but he was also unaware of any alternatives to his traditional instructional model.

I have no knowledge of [RBIS]. In fact the university, what support the university has given, revolves around technology, it does not involve novel [teaching] approaches or anything like that. . . . I expect to learn something because I have never done this before . . . hopefully I will learn something and I may see ways to

gear [MicroALEs] even more specifically for my needs or [the students' needs].

(Pre-semester interview, 9/3/24, 18:10)

This self-evaluation about his past experience with professional development is potentially important toward structuring future professional development opportunities for professors in similar positions. Dr. Robert did not feel extrinsic support existed to improve his efficacy as a teacher, rather he claimed to only have training on classroom technology. He separated technology from pedagogy. This was a distinction that may not always be evident. That is, being able to use new technology in the classroom does not equate to alternative instructional strategies that positively impact student attitude and learning gains. This awareness was a notable factor that led Dr. Robert to seek an opportunity to learn. In this instance, this opportunity was a grass-roots approach to professional development in which he sought to learn from the experience of collaborating with a biology education researcher.

The researcher was interested in the development of Dr. Robert's pedagogical knowledge as a result of this particular professional development opportunity. Prior to this semester, Dr. Robert had not experienced any professional development that included explanations of alternative pedagogies; however, Dr. Robert appeared to adapt quickly to the alternative instructional strategy employed here. For example, during the implementation of MicroALE 1, the researcher observed that Dr. Robert seamlessly implemented the MicroALE into classroom instruction (MicroALE 1 classroom observation, 9/10). The researcher noted this to Dr. Robert in a follow up interview:

Researcher: Did you feel prepared for the first MicroALE?

Dr. Robert: Yes. Actually, pretty well. I was apprehensive but once it got going... the longer it went the more comfortable it felt. . . . [Implementation] just naturally occurred. (Post-MicroALE 1 interview, 9/17, 8:40)

After observing Dr. Robert utilize the first four MicroALEs, the researcher asked Dr. Robert to describe his understanding of active learning. “Having never been formally educated as to what active learning is, actually having never taken education classes. To me, active learning is when students participate, when students learn as a result of participation in some type of activity” (MicroALE 4 follow up interview, 11/7/14, 2:00). This description was an indication that Dr. Robert was learning terminology related to RBIS, and classroom observations were an indication that he was grasping the concept of effectively utilizing student-centered instruction.

The grass-roots professional development was effective for Dr. Robert. He engaged in the process of learning both terminology and practical applications of RBIS in the classroom. Although Dr. Robert was eager to participate in this opportunity, he was initially skeptical of the potential lack of impact on students and the effort needed on his part to change. During planning meetings and post-MicroALE implementation interviews, Dr. Robert described his expectations and hope for attempting reform. These reflections were themed *proof seeking* by the researcher and are presented next.

Proof seeking. Dr. Robert was forthcoming describing his initial expectations for implementing a student-centered pedagogy. There were instances during the pre-semester interview that he expressed excitement about trying something new. “Glad to try it and look at something new . . . The idea of having students learn on their own and then discuss it in class is interesting” (Pre-semester interview, 9/3/14, 34:00).

Analysis of data indicated Dr. Robert held expectations regarding potential benefits of utilization. For example, he was interested in identifying personal proof that the curricular resource (MicroALEs) and the implementation strategy (collaborative student groups) were beneficial to teaching and learning. In particular, Dr. Robert expressed hope regarding positive student outcomes as a result of utilizing MicroALEs in his course.

Hopefully it will provide [me] insight into ways to better engage the students more and thus to help the students. Hopefully if the students are more engaged they will do better in class so they aren't just sitting out in left field taking notes and going home. Hopefully, if I am able to engage the students it's going to engage, promote their interest and [promote] class performance. . . . My hope is that [student attitude and performance] will be better. Do I expect it? I don't know, but I hope it. I don't know if hope and expectation mean the same thing. I think probably part of it is you hope it gets better and then once you know that it works then you expect it to be better. I mean to me you can't expect it to be better until you know that it works, and I think what we are doing now is doing something hoping that it will [lead to] improvements then from then on you would expect it to work every time, I guess. (Pre-semester interview, 9/3, 34:24)

Here, hope was coded as proof seeking and presented as a beginning narrative of Dr. Robert's overall experience implementing a reform-based instructional strategy. It should be noted that researcher discretion was taken in labeling proof seeking as experience in pursuit of change rather than as motivation to pursue change. Recall, intrinsic motivation caused by pedagogical discontentment, as a construct, characterized his reason to pursue

change prior to the collaborative partnership formed with the researcher. Once he engaged in the process of change, proof-seeking was potentially a factor for sustaining the reform effort.

Dr. Robert was interested in improving student engagement and performance, but he was seeking personal proof that utilizing innovative strategies (i.e., student-centered resources and approaches) was both effective and viable for making teaching easier and less demanding.

I'm not opposed to [utilizing innovative instructional strategies]. I'm fully free to engage it. If I can be convinced that they work. You know the bad thing about innovative strategies is sometimes they aren't proven, and I think when someone can see that they work, [and] if you can show that innovative strategies makes my job easier then I think you are really on to something, or if you can convince the instructor that it is going to make their job easier you are on to something. (Pre-semester interview, 9/3, 21:35)

This sentiment was indication that, although he was attempting to implement a student-centered strategy, he was still maintaining an instructor-centered mindset. He was concerned about making his job easier and more efficient as opposed to promoting student-centered learning. Therefore, he was seeking proof that MicroALEs could potentially ease the burden of lecturing for entire class meetings. He expounded on what proof meant to him in regards to making his role as an instructor less demanding.

If you could engage innovative strategy to where perhaps a professor would not have to stand and talk for a full hour. I mean when you stand and talk for an hour and an hour and a half, that can be fatiguing particularly if you are older. If you

can show, if you engage these strategies and [students] can learn just as much if not more and you don't have to stand there on your feet and talk in a loud voice in a large room for 60 or 70 minutes straight, I think people would engage it, people would be more inclined to engage it. (Pre-semester interview, 9/3, 23:20)

To conclude his perception regarding proof seeking, it is necessary to consider a statement Dr. Robert made regarding effort and impact. From his initial inquiry about alternative instructional strategies, he expressed concern over the effort involved and the impact of the RBIS on his prescribed content coverage in the course. He stated, "My only concern is, I want it to be worth the effort. You know I guess my only concern is that it will detract from the amount of information [covered in the course]" (Pre-semester, 9/3, 39:50). Dr. Robert was expressing a reasonable concern based on personal knowledge of his available time as a professor with teaching and research commitments and historical context for what is traditionally covered in microbiology course. These are potential concerns that any professor attempting change may reasonably have. For Dr. Robert, seeking proof did not entirely revolve around proof that student performance and engagement improved; it also included evidence that utilizing RBIS would not alter his routine (i.e., time and content) of teaching the course.

Impediments to reform often include time. For Dr. Robert, this included the time to prepare for implementing MicroALEs and the time spent on MicroALEs during class which may detract from the amount of material he typically covers. The following section considers this concept of time and along with other factors Dr. Robert's perceived as impediments to reform.

Perceived impediments. To understand Dr. Robert's perceived impediments to change, the researcher asked him to describe what had previously deterred him from pursuing change.

I mean I really haven't engaged in [pedagogical reform] as much as I could or should mainly due to time. I mean, it takes time to learn new things, and I think [for] most professors that's their greatest resource is time because you are under pressure to do your research and publish papers, and you don't have quite as much time to engage in new education thought. (Pre-semester interview, 9/3, 32:40)

Dr. Robert clearly valued his time as a full professor responsible for teaching and running a research lab. He indicated that learning new pedagogical strategies is time consuming and that pressure to produce for any professor would take away from time to engage in reform. Although he perceived a benefit to engage, he had not prioritized instructional reform higher than publishing and conducting research.

The researcher noted in a classroom observation that the professor was placing less emphasis on the debriefing as it got noticeably shorter for MicroALE 3 (MicroALE 3 classroom observation, 10/17). The *debriefing* (i.e., whole class discussion led by the professor to facilitate peer-to-instructor interaction and active construction of knowledge) is a key component to MicroALEs, and in particular, active learning. The researcher asked Dr. Robert about his de-emphasis of the *debriefing* in a follow up interview. He said:

I think the debriefing is fun the first class or two. I think it is fun at first because of the novelty. I think the novelty has worn off a little bit [after three MicroALEs]

so I don't think they quite get much of a kick out of it. (Post-MicroALE 3 interview, 10/24, 12:20)

MicroALEs were new for Dr. Robert, and this was the first time in 21 years that he had attempted to add RBIS to his pedagogy. This experience for him was fun in the beginning based on this quote and observations the researcher made during implementation. In particular, Dr. Robert appeared to enjoy walking around the room interacting with students, but after the first two MicroALEs he began to minimize this component (i.e., the debriefing). He indicated in this quote that his decision to minimize was motivated by the perception that students were no longer interested in interacting (i.e., discussion) with him. In this case, lack of novelty was an impediment to efficacy of implementation. Furthermore, this indicated that he was prioritizing personal evidence over empirical evidence when making decisions about implementation. He was not consciously disregarding empirical evidence as his knowledge of implementing RBIS was limited. However, this novice-like response to improvise without the background to rely on experience or informed strategies will potentially impede sustainability of effective implementation of student-centered instruction.

The perceived value of RBIS is an important aspect to consider. The value, if considered significant by the agent of change (e.g., a professor seeking to adopt RBIS), may serve as motivation to overcome impediments. Dr. Robert's perceived value is presented next.

Proof. Throughout the semester Dr. Robert's perception of value in pursuing reform and adopting RBIS emerged. He specifically identified components of

MicroALEs that were interesting and useful to him. The following characterizes his perception of proof that RBIS added instructional value to his course.

As a result of using MicroALEs I did spend more time talking to the students this semester than I have historically . . . I never [historically] asked questions to the students. I never [historically] asked their opinion on anything. With the use of MicroALEs . . . that was the first time in 20 years that I actually walked out amongst the students, and talked to them about microbiology. As a result of doing the MicroALEs, I think the students were more receptive to talking to me, and I was certainly more receptive to talking to them. Use of the MicroALEs just broke down this imaginary wall that was between the instructor and the students. (Post-semester interview, 12/17, 3:35)

Dr. Robert valued the interaction with students that MicroALEs fostered. This was a new experience for him in which he carried on conversations with them about microbiology rather than lecturing to them. In classroom observations for each MicroALE implementation, the researcher noted that he was able to communicate his interest in microbiology to students. This appeared as excitement and intrigue that made his interest in microbiology seem more accessible to students. He freely moved around the classroom interacting with students and breaking the imaginary wall during the debriefing. The researcher asked him to consider where this wall originated.

Tradition. Well, it came from me (laughing). I mean I put up the imaginary wall on the first day of class. I say, "I'm [Dr. Robert] the instructor. I will give you lecture material then I am going to test you over it." I did not leave any room for suggesting that they be engaged in the learning. That's the way I was taught, that

there is an imaginary wall between the instructor and the students. (Post-semester interview, 12/17, 5:10)

This pedagogy that he described was the same traditional pedagogy that worked for him as a student. He laughed here as he made the connection between the imaginary wall he broke using MicroALEs and why the wall was there in the first place. The researcher asked him to discuss his perceived need for reform given that this traditional pedagogy worked for him. He said:

Any college professor in science should be open to change because science is constantly changing. The lecture material should not be 35 years old so therefore the way you teach should not be 35 years old too. If you are teaching history that is one thing but science is a dynamic changing field . . . Science is an evolving body of knowledge so why should not your teaching methods evolve along with it. (Post-semester interview, 12/17, 50:35)

Evidence here suggested that Dr. Robert perceived value in reform. He reasoned that the progressive nature of science should be taught utilizing current information in the subject. Furthering this thought, he made a meaningful connection between pedagogy and the practice of science. Science is evolving, therefore the way science is taught should also evolve.

Since Dr. Robert clearly perceived value in reform, it should be considered next what components he valued and his perceived value in using MicroALEs in the future. The researcher asked Dr. Robert to discuss this. He said, “I like this concept [RBIS using MicroALEs] and I think I will continue to have this as a component of lecture. . . . I think it really lends itself well to laboratory” (MicroALE 4 follow up interview, 11:00). After

completing four MicroALEs, Dr. Robert began thinking about how these could be used in the future and in other instructional environments (e.g., the laboratory). The concept to which he referred was student-centered, active learning that facilitated an opportunity for him to engage with students during lecture. MicroALEs were the component he referenced that fostered this form of RBIS.

The researcher was interested in advancing the idea of value in order to investigate whether Dr. Robert perceived value for himself, for the students, or for both after utilizing MicroALEs. He had previously discussed his interest in making teaching easier for himself, but based on his intrinsic motivation to pursue change, he was initially interested in the value or benefit for students. The researcher asked him to discuss the value in regards to students. He wrote in a journal entry, “I can see the benefit of engaging the students. . . . I see that active learning is something students enjoy doing and it is worth the effort” (Post-MicroALE 4 reflective journal, 11/18). His comment suggested that he was aware of potential value to students and that his perceived value was worth the effort.

Dr. Robert frequently utilized the term effort when discussing impediments and perceived value. In both cases, the term was used in regards to the effort needed to implement RBIS for the purpose of diversifying his traditional pedagogy. To further explore the relationship between perceived value and the effort he put forth to enact reform, the researcher asked Dr. Robert to elaborate on the effort to implement RBIS that was outside his traditional role in the classroom.

After having participated in it, I can see that there is great potential. I think the thing that kind of excites me a little bit now is the potential for active learning,

and getting the students more engaged in teaching themselves. . . . Something I am beginning to see now, if I can get the students engaged in teaching themselves some things then that takes pressure off of me actually. If you can get students to teach themselves some fundamental principles, it could actually free up the instructor. It came to me towards the end [of the semester] actually. I began to see how if you really went all out and engaged this active learning concept, you could free up the instructor. The instructor could potentially not have to spend so much time lecturing. Maybe you could use the lecture to summarize what they have taught themselves. You could use the lecture format to confirm what they have already taught themselves, and I think students are interested in teaching themselves. You might be able to even get by with fewer lectures, possibly. If you put a lot of effort into active learning you could conceivably get more done in less time. There is a lot of down time in traditional education. (Post-semester interview, 12/17, 21:50)

Evidence here suggested that Dr. Robert was placing value in RBIS as an approach to free up time spent lecturing. He indicated this time could be used to promote learning. He did not say that it would make his job easier, as he was seeking at the beginning of the semester. Rather he characterized RBIS as a means to foster peer-to-peer instruction, enable learning confirmation as the facilitator by reinforcing concepts covered in peer-to-peer discussion, and make lecture more efficient.

Dr. Robert frequently discussed his perceived value of active, student-centered learning on shifting the traditional role of students in the classroom.

The use of MicroALEs allowed the students [to] work together on something, which I had never previously done in any of my classes. . . . They worked together on things; they got to express an opinion on things. There may not be an absolute right or wrong answer [to MicroALEs] in some cases . . . they got to express an opinion based upon their knowledge and experience. . . . [Students] were working together to solve a common goal or problem, and I think they enjoyed that. (Post-semester interview, 12/17, 3:35)

This was the first time that Dr. Robert relinquished control of the learning process to students during class time. He sounded surprised during the interview that students were enjoying the process, and that they were engaged in the process of learning. He particularly liked the idea of students using critical thought to express opinions amongst their peers versus his traditional instruction that promoted memorization.

I like the question [MicroALE *expert analysis form*] where there might not be an absolute wrong or right answer. This is an opportunity for them to express an opinion and thoughts on answering questions. I like questions that are somewhat open-ended and there might be more than one right answer. It allows the students to formulate an answer. It allows them to get engaged in discussion. Historically, there are not a lot of options for discussion at this point [particular level of this microbiology course] and this [MicroALE] is an opportunity for them to discuss and that is desirable . . . because they have very little opportunity to do that [in biology]. I think it will help them learn it [material] and promote their interest in [the material]. (Post-MicroALE 4 interview, 11/7, 10:00)

Dr. Robert repeatedly made comments comparing his and the students' shifting roles in the classroom. He pointed out how traditional pedagogy leaves limited opportunities for students to learn from each other in class. Additionally, he was encouraged by student participation and interest in discussing MicroALEs. During a reflective journal entry, he elaborated further on the evolving roles in the classroom.

One of the main roles of the instructor is to present a sense of excitement about doing a MicroALE. The students will follow up on this. MicroALEs allow students to participate in the classroom activities in a role other than simply a note taker. This should be stressed to the students [that] this is their opportunity to express an opinion and put into practice some things they have learned. (Post-MicroALE 4 reflective journal, 11/5)

Dr. Robert acknowledged that part of his role was to show excitement about completing MicroALEs. Based on classroom observations, he embraced this new role as he promoted forth-coming MicroALEs and referred back to them during lecture on days following implementation of a MicroALE. He said, "We are still talking about the first MicroALE [several class periods after utilizing it]. Students are still [engaged] asking questions" (Post-MicroALE 1 interview, 9/17, 20:39).

One of the reasons Dr. Robert engaged in reform was to improve student interest in topics covered in class. He found value in MicroALEs because he felt their format encouraged students to engage in class. Dr. Robert often described his perception of the value that students placed on their role while completing MicroALEs, "I think the students were motivated to do this [active learning with MicroALEs]. My perception is they were motivated by the active learning [opportunity]" (Post-semester interview,

12/17, 18:30). After the first MicroALE he said, “I think they responded well. . . . clearly the majority of students were into it (Post-MicroALE 1 interview, 9/17, 11:00). Again after the third MicroALE he stated that “they really liked doing [MicroALEs]. . . . They worked on it to the end of the class, and they weren’t rushing to get done” (Post-MicroALE 3 interview, 10/24, 11:30).

Dr. Robert was excited that students worked effectively toward completing a MicroALE. He perceived relevance for utilizing MicroALEs by relating the act of completing them to students’ potential careers. For example, Dr. Robert instructed the students to complete MicroALE 2 saying, “You need to be efficient and accurate when making decisions and [completing the MicroALE]. . . . Nurses and doctors can’t take as long as they want, neither should you on these [MicroALEs]” (MicroALE 2 classroom observation, 9/22).

Overall, results indicated that Dr. Robert found value in the experience of implementing RBIS. He briefly discussed this and his fidelity of implementation in regards to how he improved over the span of the semester. He concluded by elaborating on how the students were able to adapt to a reform-based curriculum.

I think that now one main benefit is that I am comfortable doing it. I was very nervous about this at first. It is now apparent that I believe the students enjoy the MicroALEs for several reasons. The students enjoy the ability to express and have opinions about the subject material. Both them and myself also enjoy the change of pace. Class time can become somewhat stale when all you do is walk in and lecture and then walk out time after time for every class. I think I am better at this

and also of additional importance I think the students are better at doing the MicroALEs. (MicroALE 4 reflective journal, 11/5)

Finally, results indicated that Dr. Robert's perception of RBIS were altered over the span of one semester. When asked if he perceived a change in his opinion about innovative instructional strategies, he recalled his initial expectations and final perceived outcomes from implementing RBIS for the first time.

Yes. At the beginning of the semester I probably had low expectations. I did not have great expectations. I was not staying awake at night thinking about it. . . . I didn't have low, I just didn't have great expectations. I think the end result of this is that my expectations have been exceeded. I think there is a real possibility for this . . . active learning concept . . . there are viable alternatives to the instructor-centered approach. (Post-semester interview, 12/17, 18:30)

Although Dr. Robert pursued an alternative to his traditional pedagogy, he indicated at the end of the semester that he did not have high expectations when he initially engaged in RBIS. He was clearly surprised by the outcome and optimistic that active learning represented an alternative to his traditional, instructor-centered pedagogy.

Discussion

Currently there is a lack of research within the realm of biology education that characterizes, in an in-depth way, the process of instructional change from an instructor-centered approach to a one that features student-centered components. To support reform efforts there is a need for rich, descriptive accounts of the perception of change for the purpose of informing future adopters of what to expect when attempting to shift their own instructional model. The purpose of this study was to characterize the perception of

change when a professor with an instructor-centered pedagogy sought to implement RBIS for the first time. This case study explored the process of instructional change in the context of a post-secondary microbiology course. The following is a discussion of the results as they revealed Dr. Robert's intrinsic motivation to engage in reform and his experience of implementing RBIS for the first time.

Intrinsic Motivation

One pathway to pedagogical change begins with intrinsic motivation driven by pedagogical discontent (Gess-Newsome et al., 2003). This was particularly evident in Dr. Robert's case as he approached the biology education researcher about possible strategies to alter his traditional pedagogy. Dr. Robert lacked formal pedagogical knowledge and experience utilizing RBIS; however, his discontentment with the same instructional model for the past 21 years led him to inquire about viable alternatives. He acknowledged he was bored with his teaching, and thus, the students must be as well. He sensed from student behavior in class that they were disengaged. Dr. Robert associated this observation with decreasing student performance in his microbiology course.

Dr. Robert was discontent with his instructional model. He was concerned that his traditional approach was stale resulting in decreased student engagement, performance, and attendance. Because of his lack of formal pedagogical knowledge he was uncertain about what to do with his discontentment. Dr. Robert's decision to seek alternatives to his traditional pedagogy emerged gradually over his career. He claimed that he initially chose an instructor-centered approach at the beginning of his career because it worked for him as a student. Furthermore, he claimed to not know of any alternatives to this approach.

Dr. Robert described an imaginary wall that separated himself from the students in the classroom. Overtime, this imaginary wall fostered an environment in which he was bored. He told students at the beginning of each semester that he was Dr. Robert and he would give them information on which they would be tested at a point in the future. Just his recollection of declaring this in the classroom elicited thoughts of bored and disinterested students.

Although his traditional pedagogy had worked for him as a student and then as a professor, it was no longer satisfying. It was fostering discontentment in his job, and he was taking responsibility for poor student performance. He sensed students were no longer interested in the content of the course as a result of his teaching. Gess-Newsome et al. (2003) suggested that pedagogical and contextual discontentment was a leading factor toward motivating faculty to pursue reform. Discontentment in place but without knowledge of alternatives, Dr. Robert sought help from a biology education researcher.

Dr. Robert pursued instructional change as a result of intrinsic motivation rather than through departmental or university pressure. Previous research suggested that a top down approach to pedagogical reform is not effective and is difficult to sustain (Henderson et al., 2011). Specifically, within the biology education research community there is concern surrounding the lack of widespread, sustained use of reform-based pedagogies (Wood, 2009). In order to answer calls to reform biology education (e.g., *Vision and Change*) it is necessary to identify and act upon motivating factors that promote faculty to adopt strategies of reform. Gess-Newsome (2003) declared that to support efforts of reform we must focus on faculty discontentment and their efforts to mitigate this sentiment.

Finally, in regards to Dr. Robert taking the initiative to ask for help, was the presence of an accessible knowledgeable other. In this case, the source of knowledge was the researcher. Dr. Robert's awareness of the researcher's background opened the dialogue of change that was needed to enable reform. Therefore, an important point to consider is the value of an embedded biology education specialist within departments of biology for the purpose of introducing and sustaining reform.

Results from this study indicated that extrinsic forces such as department or university pressure did not motivate the participant to seek reform. Rather, intrinsic forces such as a personal conviction to be an effective teacher and willingness to engage led him to pursue change. The following is a discussion of the experience that resulted from his intrinsic motivation to pursue change.

Experience

Previous research indicates what has worked or not worked for sustaining instructional reform. According to Henderson et al. (2010), dissemination of RBIS is not adequate for promoting effective, sustained instructional reform. Therefore, simply providing Dr. Robert with an instructional resource intended to diversify his instructional approach with reform-based strategies would not likely have been successful. As a result, the biology education researcher agreed to create a set of active-learning exercise (MicroALEs) that Dr. Robert could use to foster student-centered learning during the traditional lecture period. To support sustained adoption, the researcher mentored Dr. Robert on implementing RBIS for the first time. This grassroots professional development experience presented an opportunity for the researcher to characterize Dr. Robert's experience utilizing RBIS for the first time.

Dr. Robert was seeking proof throughout the experience that utilizing MicroALEs would result in increased student performance. He was hopeful that implementing RBIS would aid in alleviating his feeling of staleness in his teaching. Also, Dr. Robert was hopeful that the student-centered component would have a positive impact on student engagement and performance in his microbiology course. His expectations clearly revolved around hope, rather than certainty that student-centered learning would result in improved student engagement and performance. This expectation of change was justified by him and potentially generalizable to other science professors that seek proof over promise. According to Andrews and Lemons (2013), Dr. Robert demonstrated a common desire for personal evidence that RBIS was effective as he was unfamiliar with empirical studies supporting the use of student-centered, active learning strategies.

Ultimately, Dr. Robert's expectations were grounded in proof. That is, he was expecting to uncover proof that student-centered learning worked or did not work. Seeking proof was likely a primary factor for supporting sustained reform. Proof was important to Dr. Robert and is potentially important for others attempting change. According to Dr. Robert, he wanted proof that RBIS was worth the effort for positively impacting students while alleviating the fatigue of continuous direct lecture. Finally, Dr. Robert was seeking proof that implementing MicroALEs would not detract from the normal amount of information he was accustomed to covering in his traditional pedagogy. Interestingly, proof-seeking for Dr. Robert remained both instructor-centered and student-centered. Although it is understandable that an instructor-centered mindset will persist throughout an initial effort at reform, clinging to instructor-centered goals will likely impede sustainable reform. Therefore, beyond discontent and willingness to

engage, altering the beliefs of the instructor is a potentially important factor to consider when attempting reform.

Woodbury and Gess-Newsome (2002) suggested two potential ineffective change strategies including: reform without altering the pedagogy of the instructor or the role of the student and reform without altering the beliefs of the instructor. For this study, attempts were made to address both of these. First, student-centered instruction was identified as a strategy to alter the role of Dr. Robert and the role of the students in the classroom. Second, the bounded study consisted of opportunities for Dr. Robert to attempt and reflect on reform-based practices. Henderson et al. (2011) identified reflective practice as an effective strategy for effective reform.

Results from this study show that at times Dr. Robert consciously changed his role in the classroom. He intentionally crossed the imaginary wall between the lectern and the students in order to foster dialogue about the content and MicroALE topics. Dr. Robert also observed students altering their role in the classroom for the first time in his teaching career. This included his observations of peer-to-peer and student-to-instructor discussions. His awareness of these changing roles were potentially important indicators of an effective pathway toward reform. When an instructor does not develop a curriculum that supports RBIS they will potentially struggle with making relevant connections between the strategy of engaging students in the process of learning and the content. The learning community, such as the one here between Dr. Robert and the researcher, was potentially important for scaffolding these connections to support effective adoption of active-learning activities that the participant did not develop.

As Dr. Robert's role changed in the classroom, it was interesting to observe whether he was effectively moving from lecturer to facilitator of active learning. That is, did Dr. Robert identify himself as playing a role in active learning or did he place the credit on the intervention? He was willing to implement the MicroALEs but was interested in RBIS making his job easier where he would not have to talk as much. He appeared to struggle at times with conceptualizing or accepting his role as integral to promoting student-centered learning. After all, instructional change is more than just providing students with an activity, it requires the instructor to facilitate active participation in the learning process. The activity is merely a tool to support this.

There were times though that he embraced the facilitator role by crossing the imaginary wall where he discussed microbiology rather than only lecture about it. Based on comments made in post-interviews and classroom observations, he frequently saw his role as giving students something to do as they teach themselves in the process of doing it (peer-learning). This is an important consideration when conceptualizing what is required for instructional change. There is a tool and there is the carpenter. Considering classroom observations, the participant was using the tool as it was designed. Although he lacked the experience with implementing RBIS, he was able to follow basic instructions on the technique and strategy. In addition, as he became more comfortable he developed a personal style in his implementation.

Fidelity of implementation is a product of time and experience with a tool as well as an understanding of the rationale for implementing/using particular aspects of that tool. Thus, Dr. Robert was actually acting as a facilitator of active learning, but the researcher perceived that he was not fully aware of his role. He was not recognizing the

value of his role as the facilitator. This was likely why he began to minimize the debriefing when the “novelty” of MicroALEs waned. The debriefing is a common and critical component of active learning. The inability to identify critical components of active learning can potentially result in a deficit of these critical components from the implementation, and thus, diminish the impact of student-centered, active learning as an instructional strategy. This deficit alone has the potential to stall and ultimately prohibit the process of instructional change. Without formal pedagogical knowledge and the experience utilizing RBIS, this scenario provides evidence of why sustained reform continues to impede progress of biology education reform. The grassroots professional development here can potentially serve to identify the critical components that are lost in implementation.

The Future of Sustainable Reform

Dr. Robert was a novice to RBIS. In his experience it took him 21 years before he pursued instructional reform. Effort and time to reform was clearly an impediment for him; however, it is interesting to consider underlying factors that stalled his reform efforts. For example, Dr. Robert may not have engaged in reform if it were not for becoming acquainted with the researcher. Recall Dr. Robert’s personal identity was a scientist in a biology department conducting research. He did not identify himself as a formally trained or even prepared teacher. His knowledge of teaching and learning was from his experience as a student which led to his pedagogical decisions when he began his career. Although Dr. Robert possessed the intrinsic motivation, he had not embarked on reforming his pedagogy. It required a facilitator (the researcher) to begin the process of reform.

Future research should consider opportunities to broaden academics' professional identity. By engaging in a grassroots reform effort, Dr. Robert broadened his professional identity by developing new pedagogical skills and expanding his experiences as a teacher. Brownell and Tanner (2012) suggest broadening professional identity in regards to science faculty pursuing a teaching identity as well as maintaining their scientific research identity; however, this could also be relevant for science education faculty. They too could broaden their professional identity by collaborating with science faculty in curriculum design and instruction. Cross-discipline collaborations present opportunities of expanding professional identities and are potentially incentives to promote reform efforts and sustain widespread change.

Conclusion

This study sought to describe the perception of instructional change experienced by a professor of microbiology. He sought help in an attempt to transform his traditionally taught microbiology course. Through a collaborative effort with a biology education researcher, the professor altered his traditional pedagogy by incorporating RBIS. Implications from this study include informing future adopters of RBIS on what to expect when attempting reform in post-secondary biology education. Additionally, this study sought to add to previous research on potential models for effective, sustained adoption of RBIS.

Further research should consider specifically what aspect of RBIS does a novice struggle to conceptualize. This answer could help to better understand specific barriers that cause adopters to revert back to traditional practices. Consider the scenario in which a professor has infinite time, resources, and personal motivation to change. Training and

professional development seminars that last from a day to a week are not able to capture the essence of the fidelity of implementation. Potentially a grassroots professional development, such as the one here, can support faculty in implementation where modeling instructional practices and active participation in the development is emphasized. This is ironically linked to calls for reform. For example, resources and information are provided in seminars much like an instructor-centered model to faculty without a pedagogical background and is provided passively and abstractly to specific learning goals of a course. Grassroots professional development can be structured to actively participate in the change process.

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APPENDICES

APPENDIX 3.A

Pre-semester Interview Protocol

Time and Date of interview:

Location:

Interviewer:

Interviewee:

Background, Understanding, and Selection of Teaching Strategy

1. How long have you been teaching microbiology?
2. How would you describe your teaching style?
3. Why do you teach the way you do? Discuss the development of your instructional style.
 - 4a. Are you aware of alternative and/or innovative teaching practices? Examples.
 - 4b. How did you become aware of these?
5. Describe your understanding of:
collaborative, active learning,
an instructor-centered instructional approach, and
a student-centered instructional approach?
6. Do you or have you read articles or journals pertaining to biology education? Why?
How often?
7. Have you ever attempted instructional change in the past? Examples.

Perceptions of the process of instructional change

8. What is your attitude toward innovative instructional practices and biology education?
9. Have you always felt this way?
10. Describe why you are interested in instructional change now?
11. What are your expectations for implementing a new instructional approach?
12. What are your expectations for students' attitude, perception, and performance as a result of this change?

Conversational notes: Explicit concerns and questions from the participant regarding instructional change

APPENDIX 3.B

Post-semester Interview Protocol

Time and Date of interview:

Location:

Interviewer:

Interviewee:

Background (for comparison)

1. After using MicroALEs, how would you describe your teaching style in the past compared to this past semester?

Understanding of the implemented teaching strategy

1. Describe your understanding of:

- a. collaborative, active learning,
- b. an instructor-centered instructional approach, and
- c. a student-centered instructional approach?

2. Have you read articles or journals over the course of this semester that pertains to biology education? Why? How often?

Perceptions of the process of instructional change

1. Do you perceive a change in your opinion of innovative instructional practices (e.g., collaborative, active-learning) and biology education since the beginning of the semester?

2. What have you learned as a consequence of implementing a collaborative, active-learning strategy?

3. Will you use this approach again? Why or Why not?

4. Will you seek out other research based practices to alter your instructional approach?
5. What were your expectations for implementing a new instructional approach?
6. Were your expectations met for implementing a new instructional approach?
7. How do you perceive the students' attitude, perception, and performance as a result of your instructional change?

Conversational notes:

1. Explicit concerns and questions from the participant regarding instructional change
2. If a professor teaches how they were taught, do you think a professor would implement active learning if they were taught in this method. What, if anything, would lead to a paradigm shift in undergraduate biology pedagogy?

APPENDIX 3.C

MicroALE Interview Protocol for the Participant

Time and Date of interview:

Location:

Interviewer:

Interviewee:

Post MicroALE No.:

Pre MicroALE No.:

Guiding questions:

How did the collaborative, active-learning implementation go?

Did you feel prepared?

Did you have enough time?

How did the students respond?

What will you do the same for the next implementation?

What will you do different for the next implementation?

Guiding topics

Discuss the participant's perception of students' responses to the individual question.

Discuss journal entry?

Discuss a date and preparation for the next implementation.

APPENDIX 3.D

Classroom Observation Recording Sheet

Guiding Questions:

At what point in the class period does the professor introduce the MicroALE?

How well does the professor communicate the use of the MicroALE?

Do students seem to understand what is expected?

How does the professor manage class time when implementing the MicroALE?

Does the professor seem confident in the use of the MicroALE?

Date of observation:

Section:

Time of observation:

MicroALE No.:

Observations of Teacher-centered Lecture Prior to Active-learning Implementation

Descriptive Notes:

Reflective Notes:

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Observations of Student-centered Active-learning Implementation

Introduction of scenario (stage 1):

Descriptive Notes:

Reflective Notes:

Collaborative groups or Individual (stage 2):

Descriptive Notes:

Reflective Notes:

Debriefing (stage 3):

Descriptive Notes:

Reflective Notes:

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Individual question (stage 4):

Descriptive Notes:

Reflective Notes:

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APPENDIX 3.E

Matrix

Description:

This document is a matrix for organizing data based on the analytical strategy for thematically coding data collected for this study. A dual approach was utilized to analyze data. A deductive approach was initially used based on the guiding research questions of this study and literature on instructional change; an inductive approach was applied to document emerging themes that were not initially considered (Yin, 2014). The combination of the two approaches led to new hypotheses for instructional change and the matrix shown here. The conceptual framework in the far left column shown here was the backbone of the matrix and served to frame the entire study by guiding the data analysis and interpretation for the findings presented in this study (Bloomberg & Volpe, 2012).

Legend for Categories and Codes:

Motivation to Change: Evidence that describe his motivation to change his instructional approach.

M1: Personal reasons to try something different in class. What is your perceived value for pursuing instructional change? Why are you interested in changing how you teach?

M2: Past experiences that led him to try something different. Do you have examples that motivated you to seek alternative instructional practices?

M3: His motivation to alter his traditional model is. Specifically, What do you feel is wrong with the traditional model?

M4: His motivation to change based on student needs, lack of performance, lack of engagement. Do you think student performance/engagement is suffering as a result of your current instructional model?

Experience (Perception of Change): Evidence that describes his perception of aspects related to instructional change:

Note. These may emerge chronologically as each MicroALE is utilized

P1: Instructional models. What is your perception or knowledge of instructional models?

P1A: Your instructional model. How would you describe the development your instructional model?

P1B: Your instructional model. How would you describe your current instructional model?

P1C: Traditional model. How would you describe a traditional, instructional-centered model?

P1D: Alternative practices. Do you have knowledge of alternative or innovative models?

P1E: Innovative instructional practices. What is your attitude about using innovated instructional practices?

P1F: Innovative instructional practices. What are your perceived impediments to implementing innovative instructional practices?

P2: A diversified model that incorporates a student-centered approach. What is your perception of a student-centered approach?

P2A: Active learning. Describe your understanding of collaborative or individual active learning?

P3: Implementation throughout the semester. Did the implementation go as planned? Was it successful or not? How do you determine it was successful or not?

P4: Student attitude when using MicroALEs. Did students enjoy this type of instruction?

P5: Student learning as a result of using MicroALEs. Did students learn with this type of instruction?

P6: Student engagement while using MicroALEs. Were students engaged (more/less) as a result of using this type of instruction?

P7: Instructor engagement while using MicroALEs. Were you engaged (more/less) as a result of using this type of instruction?

Value: Evidence that describes his overall perception of the experience of one semester in which he attempted instructional change.

E1: Perception of value of instructional change. Do you see value in this approach?

Compare value post-instruction to P1E pre-instruction.

E2: Perception of impediments to instructional change. Do you see obstacles preventing instructional change? This semester? The future? Generally for other professors?

E3: Perception of potential for future adoption. Do you see yourself continuing with this diversified instructional model? Do you have recommendations for future use?

Categories (Conceptual Framework)	Pre-Semester Interview 9/3/14	Post-Semester Interview 12/17/14	Reflective Journal
MOTIVATION TO CHANGE			
M1 Personal	<p>“I try to be responsible [in my teaching].” (29:00)</p> <p>R: Recalling a conversation had with the participant where he said, “my teaching is stale. I want to do something different.” (32:00)</p> <p>“You don’t necessarily have to employ it, you don’t have to engage it, but I think you have a responsibility to at least be aware of it. I don’t want to bury my head in the sand and pretend like none of this exists, or that I have no knowledge of it... I think when you’ve done the same thing for twenty years you become a little bit interested in changes that could make your job easier or better.” (32:20)</p> <p>“I expect to learn something because I have never done this before.... Hopefully I will learn something and I may see ways to gear it even more specifically for my needs or the [students’] needs. (34:24)</p> <p>“Glad to try [implementing MA] and look at something new. I liked something you mentioned.... The idea of having students learn on their own and then discuss it in class is interesting. I always wanted to talk and engage students. I did not know how to do it or find the time.” (34:00, pre-semester)</p>	<p>“Any college professor in science should be open to change because science is constantly changing. The lecture material should not be 35 years old so therefore the way you teach should not be 35 years old too. If you are teaching history that is one thing but science is a dynamic changing field.... Science is an evolving body of knowledge so why should not your teaching methods evolve along with it.” (52:00)</p>	
M2 Past Experience	<p>“No where, anywhere in my career has anyone ever told me what to teach or how to teach what I teach, or said anything about how I could teach it. I think that is true of most scientists. I mean that’s the kind of irony in secondary, elementary, and high school [education course] you learn how to teach. [For] college professors there is no instruction, you don’t learn how to teach. I mean the assumptions is that if you have a PhD I guess you can teach. I don’t know. Never in my career has anyone ever told me how to teach something.” (30:35)</p>	<p>“I have always felt there was a need to do something else to promote learning and scholarship, especially among the lower academic achieving portion of the class.” (50:00, Post-semester)</p>	<p>“Class time can become somewhat stale when all you do is walk in and lecture and then walk out time after time for every class.” (MA 4)</p>

M3 Traditional Model			
M4 Students	<p>“If you can get students to teach themselves the, where they can improve their test grades then you will have fewer students coming in complaining about their in ability to understand material. I mean a course like this I always have students coming by saying, you know they come in saying they got a 55 on a test and I don’t understand what I did wrong, and you know my reply is always well you know you didn’t study enough. And they say, well I did study. What am I doing wrong? I mean it is hard for me to say what they are doing wrong. Its just if some innovative [strategy] could be where students could teach themselves to do better on tests or understand the material better...or, have students understand what is important in the course.” (21:35)</p> <p>“Hopefully it will provide [me] insight into ways to better engage... the students more and thus to help the students. Hopefully if the students are more engaged they will do better in class... so they aren’t just sitting out in left field taking notes and going home. Hopefully, if I am able to engage the students it’s going to engage, promote their interest and class performance.” (34:24)</p> <p>My hope is that student attitude and performance will be better. Do I expect it? I don’t know but I hope it. I don’t know if hope and expectation mean the same thing. I think probably part of it is you hope it gets better and then once you know that it works then you expect it to be better. I mean to me you can’t expect it to be better until you know that it works, and I think what we are doing now is doing something hoping that it will [lead to] improvements then from then on you would expect it to work every time, I guess.” (36:00)</p>		
Experience (Perception of Change)			
P1 Traditional Model			

PIA Development	<p>“When I started teaching it I was supposed to use a particular textbook and then kind of developed the course content the way I saw fit.” (1:20)</p> <p>Topics to cover were agreed upon by all of the microbiology instructors, however, “ your [instructional] approach is up to the individual.” (1:50)</p> <p>“I teach the way I was taught. That is for several reasons. Number one I don’t know anything different. Number two I felt that my education process was successful and the thought is that this traditional style will be successful as well.” (3:15)</p>		
PIB Current Model	<p>“I think my teaching style is traditional.” (2:58)</p> <p>“My approach has been traditional. I talk and they write it down.” (13:15)</p> <p>R: “Have you been teaching this way ever since you started?” P: “Yes. I have not changed.” P: “...this course doesn’t have time, I mean this course I just do not have time to do that [use the internet to show media] if I am going to get to the most basic factual information.” (5:05)</p>	<p>R: Where do you think this imaginary wall came from? P: “Tradition. Well, it came from me (laughing). I mean I put up the imaginary wall first day of class. I say, ‘I’m Dr. Robert the instructor. I will give you lecture material then I am going to test you over it. I did not leave any room for suggesting that they be engaged in the learning. That’s the way I was taught, that there is an imaginary wall between the instructor and the students.” (5:10)</p>	
PIC Traditional Model	<p>“Traditional teaching to me is when the professor stands in front of the students, provides factual information, expects the students to write it down, and then later on will give them a test based upon the factual information that I gave them.” (4:40)</p> <p>“To me that would mean that the classroom activity revolves around the instructor. If it is instructor centered then classroom activities revolve around him or her.... To me traditional would be an instructor centered learning environment” (14:23)</p>	<p>“Instructor-centered implies when everything centers around the instructor. To me that is my traditional approach, an instructor-centered approach.” (11:10)</p>	
PID Alternative Model	<p>“No. I have no knowledge of anything. In fact the university, what support the university has given revolves around technology, it does not involve novel [teaching] approaches or anything like that.”</p> <p>“The university...have [sic] not</p>		

	<p>addressed teaching styles, innovative techniques or anything like that to my knowledge.”</p> <p>R: “Have you ever attempted instructional change in the past?” P: I have changed in terms of incorporating my notes into PowerPoint. There has been some technological change in that. Now in terms of course content, I make changes because I have learned there are some things in microbiology that student don’t relate to and there are other things they do relate to. So I have tried to gear the course toward factual information that I believe is important and also whatever I say I try to gear it to students for something to relate to. Like when I talk about structures, when I talk about structures in bacteria I try to talk about how this structures are important for bacteria to be able to cause disease and things like that. And I just try to get them to relate to, I think it is important if they can figure out a way to relate to what I am talking about. It helps rather than just presenting it as some abstract entity, I guess.” (18:30)</p>		
<p>PIE Innovative practices</p>	<p>“I’m not opposed to it. I’m fully free to engage it...if I can be convinced that they work. You know the bad thing about innovative strategies is sometimes they aren’t proven, and I think when someone can see that they work, [and] if you can show that innovative strategies makes my job easier then I think you are really on to something, or if you can convince the instructor that it is going to make their job easier you are on to something. If it is something that is going to take away from what they are currently doing, take time away from them, I think it is going to be harder to get someone to engage it. There are some people out there that might be opposed to innovative strategies, but I think most people would at least try it. You know I am certainly willing to try to engage that sort of thing.” (21:35)</p> <p>R: How would it make the instructor’s job easier? “If you could engage innovative</p>	<p>R: Have you read any journal articles pertaining to biology education over the course of the semester? P: “I have not actively sought that, no.” (13:10)</p> <p>R: Do you perceive a change in your opinion on innovative instructional practices? P: “Yes. At the beginning of the semester I probably had low expectations. I did not have great expectations. I was not staying awake at night thinking about it. (18:30)</p> <p>R: What have you learning this semester? P: “That there are viable alternatives to the instructor-centered approach.... The internet strongly supports the active learning strategy.” (27:30)</p> <p>R: What were your expectations for implementing a new instructional approach? Were they</p>	

	<p>strategy to where perhaps where a professor would not have to stand and talk for a full hour. I mean when you stand and talk for an hour and an hour and a half, that can be fatiguing particularly if you are older. If you can show, if you engage these strategies and [students] can learn just as much if not more and you don't have to stand there on your feet and talk in a loud voice in a large room for 60 or 70 minutes straight, I think people would engage it, people would be more inclined to engage it." (23:20)</p>	<p>met? P: "I didn't have low; I just didn't have great expectations. I think the end result of this is that my expectations have been exceeded. I think there is real a possibility for this flipped classroom, active learning concept." (33:30)</p>	
<p>PIF Impediments</p>	<p>"I think one of the disadvantages to an introductory course like this is, there is very little limited time for discussion and activity. I think there is a place for it but it is more limited than it would be in a very advanced course because at this point [introductory microbiology course] you are simply trying to get information into them so they can function in the area of microbiology. I mean you have got to have some basic data before you can function as a microbiologist but ah I'm all for independent thought, collaboration, and discussion. I'm all for it. It would be good, but you have to be innovative in how you do that because there is limited time." (25:40)</p> <p>"I mean I really haven't engaged in as much as I could or should mainly due to time. I mean, it takes time to learn new things, and I think [for] most professors that's their greatest resource is time because you are under pressure to do your research and publish papers, and you don't have quite as much time to engage in new education thought." (32:40)</p> <p>"My only concern is, I want it to be worth the effort. You know I guess my only concern is that it will detract from the amount of information...<i>will it detract from the amount of information I am able to get to the students using traditional methods?</i> (39:25) I don't have any real concern yet, I don't know enough about it. Maybe after I have</p>		

	done the first [MicroALE]...you know at this point I really don't have any concerns because I have never done this. So at this point we will just wait and see." (39:50)		
P2 Student-centered	<p>"The student centered instructional approach to me would be where a student learns as a result of some student activity." (15:15)</p> <p>R: "Have you used this in the classroom?" P: "No, not in microbiology."</p>	<p>"In active learning you can function in an individual unit or in a group setting." (8:20)</p> <p>'[Student-centered approach] revolves around the students. A student-centered approach would be active learning. That is where learning is centered around some student activity whether it is a MA or a laboratory experiment. When they are engaged in a laboratory activity and they are doing it themselves and they are learning how to take measurements, perform experiments; they are learning.'" (12:40)</p>	
P2A Active learning	<p>"I have no knowledge of what that is." (11:08)</p> <p>"I am familiar with the term collaboration in terms of research.... if I'm on a [research] project and I can see how a certain component can help I will call somebody and ask them if they want to collaborate." (11:18)</p> <p>"I think it would be appropriate for at least the students to become familiar with the concept of using collaboration [for research purposes]." (12:40)</p> <p>"In my classroom, at least in the classroom environment, there has been no collaboration." (13:12)</p>	<p>"To me, collaborative and active learning mean two different things. Collaborative refers to students working together. Active learning, to me, would refer to when students are actually engaged in the learning. Active learning refers to when students are reading something, obtaining information on their own. As a result of obtaining information on their own they are actively learning something. I am not feeding them the information they are getting it themselves.... Even if I give them something [content] and they are processing that information themselves then they are actively teaching themselves. That to me would be what active learning would refer to." (7:35)</p> <p>R: What about collaborative groups, are students engaged? P: "Yes, that's a form of active learning. But, active learning refers to when the students are engaged inadvertently almost teaching themselves as a result of working on something." (8:00)</p>	<p>"I see that active learning is something students enjoy doing and it is worth the effort." (MA 4)</p>
P3 Implementation		<p>"Debriefing is a broader aspect of active learning." (10:40)</p>	<p>"I was favorably impressed with this for several reasons.... it gave me a chance to interact with the students... it was a good break or change of pace from our usual class routine." (MA 1)</p>

		<p>“I generally liked the idea of students working together in groups rather than working alone to answer the questions.” (MA 1)</p> <p>“I think it went well but actually... there was not a great deal of time left for discussion.” (MA 1)</p> <p>“We really did not have time to discuss each question, but I don’t know if this was that important.” (MA 1)</p> <p>“I think this went well.” (MA 2)</p> <p>“Something to consider in future MA is to ask yourself, ‘how can the student directly relate to the material?’ If they can do this I think it will immediately promote more interest.” (MA 2) <i>Interpretation:</i> Dr. Robert is telling me how to construct future MA rather than considering how he can facilitate active engagement through his approach of using MA.</p> <p>R: What do you feel is the most important aspect of the implementation? P: I do not think any of the components should be eliminated.... The debriefing component is also important. It is something new and promotes interaction between the instructor and the class. I see 3 different parts—the reading material [scenario], the questions to be answered in class [expert analysis form], and the debriefing. These are the components. In terms of aspect—or component—all 3 are important. You could get by without the debriefing but it should be kept in place if possible.” (MA 3) <i>Interpretation:</i> It is interesting that Dr. Robert verges on the perception that the debriefing could be eliminated because this is the instructor opportunity to facilitate active learning. Prior to the debriefing, when students are responding to the expert analysis form, students are actively engaged with an activity (i.e. a MA). What differences does Dr. Robert see between a traditional model and a</p>
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			<p>student-centered model? It appears he is not making the connection between MA as a tool for the professor to use to facilitate active learning. <i>Continue checking other sources to determine if he value the debriefing or links it to active learning and his role in changing his instructional model.</i></p> <p>R: What do you perceive you are doing better than when you began implementing MA?</p> <p>P: "I think that now one main benefit is that I am comfortable doing it. I was very nervous about this at first. It is now apparent that I believe the students enjoy the MA for several reasons. The students enjoy the ability to express and have opinions about the subject material. Both them and myself also enjoy the change of pace. Class time can become somewhat stale when all you do is walk in and lecture and then walk out time after time for every class. I think I am better at this and also of additional importance I think the students are better at doing the MA." (MA 4)</p> <p>R: Describe your role as the instructor while students are working on MA.</p> <p>P: One of the main roles of the instructor is to present a sense of excitement about doing a MA. The students will follow up on this. MA allow students to participate in the classroom activities in a role other than simply a note taker. This should be stressed to the students [that] 'this is their opportunity to express an opinion and put into practice some things they have learned.'" (MA 4)</p>
P4 Student Attitude		<p>"[Students] were working together to solve a common goal or problem, and I think they enjoyed that." (5:45)</p> <p>I think the students were motivated to do this [active learning with MA]. My perception is they were motivated by the active learning [opportunity]. (18:30)</p>	<p>"I believe students enjoyed talking to each other about the work." (MA 1)</p> <p>"I believe students enjoyed this because they could relate to it in the sense much of this information related to lecture material." (MA 2)</p> <p>"It is now apparent that I believe the students enjoy the MA for</p>

		<p>“They were very interested in this because it affected their grade. I think they enjoyed the active learning concept. They enjoyed the participation in it... They enjoyed it for the change of pace. They enjoyed it for their ability to be engaged with each other. They enjoyed the engagement with the teacher when we did the debriefing. It is an alternative way for them to demonstrate their knowledge. It is an alternative way for them to express their thinking. It is a way to express novel idea, and I think they like that.” (39:00)</p>	<p>several reasons. The students enjoy the ability to express and have opinions about the subject material.” (MA 4)</p>
P5 Student Learning		<p>“[Students] can learn more from the debriefing. Debriefing fosters learning, but some of the learning has already occurred prior to the debriefing. Debriefing can enhance what has already been learned. Debriefing is an opportunity to look at different aspect of a problem or issue. Debriefing served to enhance or promote learning that had already occurred.” (10:40)</p> <p>“I do think they did learn something doing this. It wasn’t just a curve. I think it raised their grades and they learned something in the process. I don’t think it was a gift. I think they learned something in the process of doing it. They learned something they would not have learned.” (47:20)</p> <p>R: Do you feel that student test performance indicates learning? P: “It means they have memorized. It means they know something. It means they are interested... In order to do well you have to have some interest in the material as a result of some factor... The more familiar you are with the material the less stress [incurred by the student]. The MAs give the students the opportunity to demonstrate knowledge in another way.” (58:20)</p>	
P6 Student Engagement			<p>“I believe students were interested in this because... they are interested in the disease process.” (MA 1)</p> <p>“[MA] served to engage students in</p>

			<p>the course material.” (post-semester reflection)</p> <p>“They [students] seemed to stay more focused on the work before them.” (MA 3)</p> <p>“It has promoted interest in the subject material.” (MA 4)</p>
P7 Instructor Engagement			“I can see the benefit of engaging the students.” (MA 4)
Experience			
E1 Value		<p>“As a result of using MicroALEs I did spend more time talking to the students this semester than I have historically. . . . I never [historically] asked questions to the students. I never [historically] asked their opinion on anything. With the use of MicroALEs. . . that was the first time in twenty years that I actually walked out amongst the students, and talked to them about microbiology. As a result of doing the MicroALEs, I think the students were more receptive to talking to me, and I was certainly more receptive to talking to them. Use of the MA just broke down this imaginary wall that was between the instructor and the students.” (3:35)</p> <p>“The use of MA allowed the students [to]... work together on something, which I had never previously done in any of my classes. . . . They [students] worked together on things; they got to express an opinion on things. There may not be an absolute right or wrong answer [to MA] in some cases. . . they got to express an opinion based upon their knowledge and experience.” (5:10)</p> <p>“After having participated in it, I can see that there is great potential. I think the thing that kind of excites me a little bit now is the potential for active learning, and getting the students more engaged in teaching themselves. . . . Something I am beginning to see now, if I can get the students engaged in teaching themselves some things then that takes pressure off of me actually. If you can get students to teach themselves some fundamental</p>	<p>“I see that active learning is something students enjoy doing and it is worth the effort.” (MA 4)</p> <p>“I can see the benefit of engaging the students.” (MA 4)</p>

		<p>principles, it could actually free up the instructor.”</p> <p>R: Did you see that in the beginning or did that emerge along the way?</p> <p>P: It came to me towards the end [of the semester] actually. I began to see how if you really went all out and engaged this active learning concept, you could free up the instructor. The instructor could potentially not have to spend so much time lecturing. Maybe you could use the lecture to summarize what they have taught themselves. You could use the lecture format to confirm what they have already taught themselves, and I think students are interested in teaching themselves. You might be able to even get by with fewer lectures, possibly. If you put a lot of effort into active learning you could conceivably get more done in less time. There is a lot of down time in traditional education. (21:50)</p> <p>“I think I would enjoy it [MA] more in a smaller class. (42:20)</p> <p>“If this can support retention in any way they [department] are going to be interested in it. If it can reduce the number of lectures required, if it promotes students with better knowledge, I see no reason why a department would not support something like this...I see value in it with retention, and even from just this semester, there are students that passed the course that wouldn't have passed. There are a few students that probably got into nursing school that would not have gotten in.” (47:20)</p> <p>R: It is possible it broke down a barrier between you and the students?</p> <p>P: “They are not interested in the material. They don't like to sit there and be talked to day after day, hour after hour. They don't want to just sit there and be lectured to. This might be a way of breaking that habit of rebelling against [traditional] lecture day after day, hour after hour. If they can come to class and express themselves and be noticed [with RBIS] maybe their performance</p>	
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		would be better, so this could be a way for them to express themselves.” (49:00)	
E2 Impediments		The only problem is when you have a really large class.” (28:25) “I personally do not want to go out and develop these things [RBIS] myself. It is all about time. (32:00) “Would probably be more difficult in larger classes. I’m not saying it would be impossible, just a little more difficult. It is certainly doable. It is completely doable. I mean we did it with a large class.” (42:20)	
E3 Future adoption		<p>“I would like to use it [MA] more.” (3:35)</p> <p>R: Explain example of freeing up time.</p> <p>P: Have students explore what is important about cell structure. Then in class have them tell me. You could potentially eliminate one day of lecture per week. Instead of hour lectures they could be 30 minutes. <i>Note these are not direct quotes. Refer back to (25:10) if example of flipping the classroom is needed.</i></p> <p>R: Would you see yourself using this approach again?</p> <p>P: “Yes. I have kept all of the MA. I will do some more on my own. I will do this some more.... In the summer when I only have 24 students I think I will for sure be using [MA]. I think it is very appropriate to do these in labs. I will use these to some degree. I will do it again.” (28:25)</p> <p>R: Do you see yourself altering them?</p> <p>P: “I think I will use the ones I already have. I am already familiar with them. I mean I like stuff that is already put together. So I will use the ones I already have in my possession. Some professors might enjoy creating their own but my preference is to use ones already made.” (29:00)</p> <p>R: Will you seek out other alternative instructional approaches?</p> <p>P: “Possibly. I am interested in the flipped classroom concept. But like I said, I am going to be more</p>	

		<p>inclined to use it if I am instructed on how to use it. For instance if there is a seminar, a speaker, if someone comes here and talks about using the flipped classroom and has specific lesson plans then I am going to be more inclined to use it.... Yes, that is what I want is for someone to do the work for me.” (32:00)</p> <p>“It would not be a bad idea to have MA on a test.” (39:00)</p> <p>R: If a student in this class this semester goes on to be a professor, do you think that student would teach with active learning?</p> <p>P: “I would think so, yes. If a student learns with active learning and they go into education they are going to educate using active learning. That is pretty clear.” (52:45)</p> <p>“I think I will give them a MA as a take home assignment and then discuss it in class. Keep that active learning component in class. I was happy with it. I will use MAs [in the future] to some degree.” (58:30)</p>	
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Categories (Conceptual Framework)	Prep/Follow-up Interviews	Classroom Observations
MOTIVATION TO CHANGE		
M1 Personal		
M2 Past Experience		
M3 Traditional Model		
M4 Students		
PERCEPTION OF CHANGE		
P1 Traditional Model		
PIA Development		
PIB Current Model		
PIC Traditional Model		
PID Alternative Model		
PIE Innovative practices		
PIF Impediments		
P2		

Student-centered		
P2A Active learning	<p>R: How did you perceive the collaborative active learning for the first implementation?</p> <p>P: “I think that went really well. Looking at the students they seemed to be talking quite a bit, talking about the subject material. They just weren’t killing time.... It is nice that the students interacted with each other [compared to the other section].” (MicroALE 2 prep and follow up for MicroALE 1.mp3, 9/17/14, 7:00)</p> <p>“Having never been formally educated as to what active learning is, actually having never taken education classes. To me, active learning is when students participate, when students learn as a result of participation in some type of activity.” (MicroALE 4 follow up.mp3, 11/7/14, 2:00) <i>Interpretation:</i> After four opportunities to implement a RBIS, the participant is able to clearing conceptualize what active learning is to him; however, is he able to identify key aspects of active learning related to his instruction?</p> <p>“More engaged in the learning process. To me, having groups and coming up with group answers is more active than individuals answering the questions. In fact when you do it individually that might even be almost passive.... Clearly [in the collaborative treatment] you could see the energy level was different [higher] because you had groups of people working together and talking about it.... I had more questions from the groups [than the individual treatment]. People working individual just don’t generate the energy that a group does.” (MicroALE 4 follow up.mp3, 11/7/14, 6:00) <i>Interpretation:</i> He appears no longer certain that individual completion of MA is active learning (thus, just participating in an activity does not equate to active learning). This is a relatively advanced view of what constitutes active learning, thus this demonstrates his progress toward implementing RBIS.</p> <p>R: Would you consider the debriefing active learning?</p> <p>P: “Yes. That would be active learning. The debriefing, I think it is good, but to me.... when you do it in groups you have more time as opposed to individually when every student has to answer every question.” (MicroALE 4 follow up.mp3, 11/7/14, 7:45)</p> <p>“I like the question [MA expert analysis form] where there might not be an absolute wrong or right answer. This is an opportunity for them to express an opinion and thoughts on answering questions. I like questions that are somewhat open-ended and there might be more than one right answer. It allows the students to formulate an answer. It allows them to get</p>	

	<p>engaged in discussion. Historically, there are not a lot of options for discussion at this point [particular level of this microbiology course] and this [MA] is an opportunity for them to discuss and that is desirable... because they have very little opportunity to do that [in biology]. I think it will help them learn it [material] and promote their interest in it [material] (MicroALE 4 follow up.mp3, 11/7/14, 10:00) <i>Interpretation:</i> Dr. Robert finds value in the addition of discussion as there is typically not a place for this type of learning.</p>	
<p>P3 Implementation</p>	<p>R: Did you feel prepared for the first MA?</p> <p>P: Yes. Actually, pretty well. I was apprehensive but once it got going... the longer it went the more comfortable it felt. (MicroALE 2 prep and MicroALE 1 follow up interview.mp3, 9/17/14, 8:40)</p> <p>R: On seamless implementation into classroom instruction.</p> <p>P: "It just naturally occurred." (MicroALE 2 prep and MicroALE 1 follow up interview.mp3, 9/17/14, 9:20)</p> <p>"I would have enjoyed more time walking around, interacting with the students.... Maybe if we reduce the number of questions [MA expert analysis form] it would give me more time to interact.... Yea [it was a valuable time], I don't get a chance [often] to talk to the student and joke around with them." (MicroALE 2 prep and follow up for MicroALE 1.mp3, 9/17/14, 9:53.)</p> <p>R: How much time did you spend getting prepared?</p> <p>P: "Two or three minutes." (MicroALE 2 prep and follow up for MicroALE 1.mp3, 9/17/14, 8:50)</p> <p>MA were not getting in the way of the amount of lecture covered; however, too much time was being spent on one MA. The researcher made the suggestion to re-think how MA were being implemented so that more MA could be utilized throughout the semester. The participant suggested the following:</p> <p>"I need to get them down to a half-hour." (MicroALE 3 Prep II.mp3, 10/13/14, 5:15) <i>Interpretation:</i> The participant is adapting the implementation to accommodate future active learning opportunities, additional MA.</p>	<p>R: The participant seamlessly implemented the MA into classroom instruction. (MicroALE 1 classroom observation, 9/17/14)</p> <p>R: Noted that the participant spent less time on the debriefing for MA 3</p>

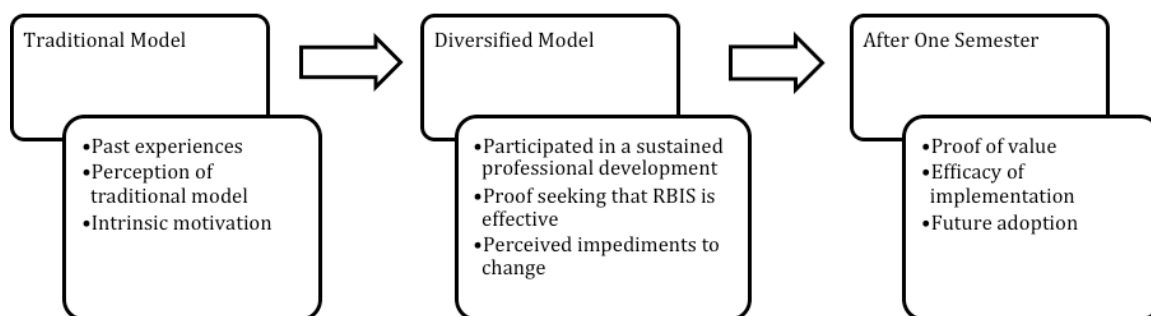
	<p>R: On thirty minutes used for implementing MA 3</p> <p>“You just don’t have as much time for debriefing. The thing is, it is actually kind of different because they work in groups in section 2 and I think they get done a lot quicker than if they do it all individually.” (MicroALE 4 prep and follow up for MA3.mp3, 10/24/14, 3:40) <i>Interpretation:</i> The participant perceives the group collaboration leads to more efficient completion of active learning tasks, that is less time spent on task as compared to individual completion. This would allow for more time for whole class discussion (student-instructor interaction) in the collaborative treatment.</p> <p>R: On chronic and acute infections which are not actually in his traditional lecture note but are of interest when learning about pathogens</p> <p>“I don’t have any information on chronic and acute. I don’t talk about that, so if you have any information maybe you could send me something on that.” (MicroALE 4 prep and follow up for MA3.mp3, 10/24/14, 8:30) <i>Interpretation:</i> Difficulty with adopting a new instructional strategy that includes a curriculum that the adopter did not create. This potentially leads to a deficit of relevance that the instructor sees in the approach.</p> <p>R: Classroom observation on debriefing getting shorter for MA 3</p> <p>“In the second class there is just not that much time because they are doing them individually.” (MicroALE 4 prep and follow up for MA3.mp3, 10/24/14, 12:20)</p> <p>The students and Dr. Robert are more in tune after the first couple of uses as to how MA work so they go faster. (MicroALE 5 follow up, 11/20/14, 6:00)</p>	
P4 Student Attitude	(They were enjoying the change of pace. They enjoyed the subject material [of MA], and I think they enjoyed the discussion” (MicroALE 2 prep and follow up for MicroALE 1.mp3, 9/17/14, 11:50)	
P5 Student Learning		
P6 Student Engagement	<p>“I think they responded well.... Clearly the majority of students were into it.” (MicroALE 2 prep and follow up for MicroALE 1 follow up interview, 9/17/14, 11:00)</p> <p>“They really liked doing it [MA].... They worked on it to the end of the class, and they weren’t rushing to get done.” (MicroALE 4 prep and follow up for MicroALE 3 follow up</p>	

	<p>interview, 10/24/14, 11:30)</p> <p>“We are still talking about the first MA [several class periods after utilizing it]. Students are still asking questions” (MicroALE 2 prep and follow up for MicroALE 1 follow up interview, 9/17/14, 20:39)</p> <p>R: Classroom observation on debriefing getting shorter for MA 3</p> <p>“I think the debriefing is fun the first class or two. I think it is fun at first because of the novelty. I think the novelty has worn off a little bit [after three MA] so I don’t think they quite get much of a kick out of it. (MicroALE 4 prep and follow up for MA3.mp3, 10/24/14, 12:20) <i>Interpretation:</i> Views the debriefing as a novelty rather than a teaching strategy to engage the students in the process of learning. This resulted in the participant de-emphasizing the debriefing period. This is potentially a point of concern for adopters; they lack the experience and knowledge to decipher value from specific, yet crucial component of RBIS. What aspects or components of RBIS do adopters fail to conceptualize as key components of shifting their instructional model to include more student-centered learning?</p> <p>You get comments that let’s you know the students are thinking about it [concepts of microbiology].” (MicroALE 4 follow up.mp3, 11/7/14, 10:39)</p>	
<p>P7</p> <p>Instructor Engagement</p>	<p>The participant was cognizant of who he called on in order to illicit good whole class discussion. (MicroALE 2 prep and follow up for MicroALE 1.mp3, 9/17/14, 13:40)</p> <p>R: Dr. Robert wants to have fun with the implementation</p> <p>P: “What I thought about doing that would be fun, you know try to make a big deal about this. Like, say for the next MA, [as if he is talking to the students] I want everyone to be here at your best. The thought is that if I show up on Monday [for the next MA] with a suit and tie on (laughing)... and to use a microphone.... just to make it fun and different” (MicroALE 2 prep and follow up for MicroALE 1.mp3, 9/17/14, 16:30)</p> <p>“Some professors might not like this, but I enjoyed going around talking to students. I would have liked to have more time to interact with them.” (MicroALE 2 prep and follow up for MicroALE 1.mp3, 9/17/14, 24:00)</p>	<p>R: Noted that Dr. Robert interacted only once during the collaborative group time. (MA 1) <i>Interpretation:</i> He appeared to be apprehensive about the implementation such as unsure of his role during the MA. Support from a learning community could readily address concerns such as this.</p> <p>R: Noted that the participant spent less time on the debriefing for MA 3</p> <p>R: Noted the participant prompting the students on use of MA</p> <p>To the students on completing MA, “You need to be efficient and accurate when making decisions and [completing the MA].... nurses and doctors can’t take as long as they want, neither should you on these [MA].” (MA 3) <i>Interpretation:</i> The participant is demonstrating the relevance of</p>

		the instructional intervention.
EXPERIENCE		
E1 Value	<p>“I like this concept [RBIS using MA] and I think I will continue to have this as a component of lecture.... I think it really lends itself well to laboratory.” (MicroALE 4 follow up interview, 11/7/14, 11:00) <i>Interpretation:</i> To promote discussion in lab where students typically get out early so there would be time to work with MA. Also, these would promote discussion in lab which is often non-existent in terms of discussion the implications of the experiments.</p> <p>“I think if you wanted to take this somewhere would be for you to have a book of MA for different subject areas so a professor could just pull one out and run with it. (MicroALE 5 follow up, 11/20/14, :20)</p>	
E2 Impediments	<p>“Professors don’t won’t to make these things [RBIS] up especially if they are not familiar.... It is a time thing. It is all about time, really.” (MicroALE 5 follow up, 11/20/14, :40)</p>	
E3 Future adoption		

APPENDIX 3.F

Logic Model



CHAPTER FOUR: CONCLUSION

A collaborative partnership was formed between a professor with a traditional pedagogy and a biology education researcher in order to enact reform in a post-secondary microbiology class. In this grassroots professional development effort, a student-centered, active learning strategy was selected for the professor to use as a tool to diversify his instructional approach.

The professor had taught this course for the past 21 years using the same traditional, instructor-centered instructional model. The utilization of active learning that occurred during this study marked the professor's initial experience for implementing reform-based instructional strategies (RBIS). A single-case qualitative study documenting this experience is presented in Chapter Three. The professor described his traditional pedagogy as direct lecture with minimal interaction or discourse between himself and the students either before or after class. According to the professor, this imaginary wall was not purposeful, but it developed as a consequence of his content delivery mechanism. The professor was discontent with his current pedagogy and blamed it on fading student interest and poor student performance in his class.

In attempt to break the imaginary wall, the professor and the researcher identified an RBIS he could utilize as a tool in lecture to potentially address his aforementioned concerns. The result of this was MicroALEs, active-learning exercises designed for the purpose of incorporating student-centered, active learning into the traditional lecture (i.e., a diversified instructional model). Importantly, MicroALEs are generalizable for other instructors of microbiology in that they are based on curriculum guidelines outlined by

the American Society for Microbiology (ASM) (Merkel, 2012). Also, the effort to create this resource responded to general calls from the National Research Council (2000, 2003) and the American Association for the Advancement of Science (2011) to increase the availability of high quality resources for improving curriculum and instruction across science disciplines. It also addressed a more focused call from ASM to promote “concept-based student-centered learning” (Merkel, 2012, p. 33) in university-level microbiology courses. The two studies in this dissertation allowed for an exploration of the faculty members attempt to implement this active-learning strategy and its impact upon a few critical outcome variables.

First, Chapter Two compared the effect of collaborative versus individual completion of MicroALEs. This was an important distinction to consider as the professor was attempting to implement RBIS without prior experience. Formation of collaborative groups can be difficult in a large lecture setting such as the context here. Therefore, the research sought to determine if the implementation of MicroALEs differentially influenced student learning, critical thinking, and epistemological beliefs. Overall, results indicated that method of implementation did not statistically impact any of the measures when comparing collaborative versus individual completion of the MicroALEs.

As this was the first time the professor implemented RBIS, the fidelity of implementation must be considered when interpreting results. His inexperience with RBIS likely affected the impact of utilizing MicroALEs. For example, his role in the classroom shifted from a traditional lecturer to a facilitator of active learning. This facilitator role required him to break the imaginary wall between him and his students and move around the classroom as he engaged with students about microbiology. Also, to

be an effective facilitator of active learning, it was necessary to relinquish control of the conversation in the classroom. In an active learning environment, students are talking to each other and to the instructor rather than the instructor only talking to the students. Inexperience will alter the ability to shift between lecturer and facilitator seamlessly. This was observed in classroom observations and post-implementation interviews and journal entries that were documented in Chapter Three of this dissertation.

The second part of this dissertation investigated the perception of instructional change experienced by the professor. In this study, the professor demonstrated an initial excitement about trying something new, but later admitted he had little hope that utilizing MicroALEs would impact his students. In fact, he was mostly concerned that utilizing RBIS would limit the amount of material he traditionally covered. Ultimately, the professor was surprised at the positive reaction from students and was encouraged by the minimal effort it required to enact change. He enjoyed his role as facilitator although he often minimized this role. As a novice, it is likely he did not value or conceptualize the importance of his role since he was no longer the only source of information in the classroom.

As a result of this semester long study, the professor gained experience in utilizing RBIS. Toward the conclusion of the semester, the professor utilized terms such as active learning and student-centered. Furthermore, he reflected on future use stating that he would use RBIS and could see benefit for MicroALEs in the laboratory portion of the microbiology course. One semester was not long enough for the professor to become an expert, but it was potentially long enough to support sustained reform. Further

research should consider a longitudinal study to determine the lasting effect of a one semester, grassroots professional development intended to support instructional reform.

In this study, the process of change was initiated as a result of intrinsic motivation. The professor was dissatisfied with student performance and their engagement in his class. He was vaguely aware of alternative teaching practices beyond his traditional pedagogy, but without formal pedagogical training, he was uncertain of where to begin the processes for reform. This dissertation described this attempt at reform and investigated the implementation of the tool used to enact it.

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APPENDICES

APPENDIX A

Institutional Review Board Letter of Approval



8/19/2014

Investigator(s): Jeffery W. Bonner, Dr. Michael Rutledge
Department: Biology
Investigator(s) Email Address: jwb5i@mtmail.mtsu.edu, michael.rutledge@mtsu.edu

Protocol Title: Diversifying the instructional model in a microbiology course

Protocol Number: #15-027

Dear Investigator(s),

Your study has been designated to be exempt. The exemption is pursuant to 45 CFR 46.101(b)(1) Evaluation/Comparison of Instructional Strategies/ Curricula.

We will contact you annually on the status of your project. If it is completed, we will close it out of our system. You do not need to complete a progress report and you will not need to complete a final report. It is important to note that your study is approved for the life of the project and does not have an expiration date.

The following changes must be reported to the Office of Compliance before they are initiated:

- Adding new subject population
- Adding a new investigator
- Adding new procedures (e.g., new survey; new questions to your survey)
- A change in funding source
- Any change that makes the study no longer eligible for exemption.

The following changes do not need to be reported to the Office of Compliance:

- Editorial or administrative revisions to the consent or other study documents
- Increasing or decreasing the number of subjects from your proposed population

If you encounter any serious unanticipated problems to participants, or if you have any questions as you conduct your research, please do not hesitate to contact us.

Sincerely,

Kellie Hilker, Compliance Officer
Office of Compliance
615-494-8918