ASSESSING ASSESSMENT: HOW USE OF THE CONCEPT INVENTORY OF NATURAL SELECTION INFLUENCES THE INSTRUCTIONAL PRACTICES OF AN EXPERIENCED BIOLOGY PROFESSOR AND SUPPLEMENTAL INSTRUCTION LEADER

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by

BINABEN H. VANMALI

Dr. Marcelle Siegel, Dissertation Supervisor

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

ASSESSING ASSESSMENT: HOW USE OF THE CONCEPT INVENTORY OF NATURAL SELECTION INFLUENCES THE INSTRUCTIONAL PRACTICES OF AN EXPERIENCED BIOLOGY PROFESSOR AND SUPPLEMENTAL INSTRUCTION LEADER

Presented by Binaben H. Vanmali,

A candidate for the degree of Doctor of Philosophy,

And hereby certify that, in their opinion, it is worthy of acceptance.

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Professor Marcelle Siegel

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Professor Mark Volkmann

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Professor John David

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Professor Bonnie Zelenak

Dedicated with much love to my parents--my first teachers,

And to Dr. Sandra Abell—my mentor and dear friend.

Thank you for all the lessons! I will carry them forward.

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Binaben H. Vanmali
Dr. Marcelle Siegel, Dissertation Advisor

ABSTRACT

Assessment has garnered increased interest in recent years. It is seen as critical to enhancing student learning and understanding. Formative assessment tools such as concept inventories could be valuable in moving toward such goals. Concept inventories, a recent addition to biology education, hold much promise for helping faculty to understand the preconceptions their students hold and therefore, how to design lessons to better support students' conceptual change processes. While these are the hopes of the developers of concept inventories, no one has examined what professors and other academic professionals *actually do* with results of the concept inventories.

Likewise, academic support programs such as Supplemental Instruction have gained attention as mechanisms by which to help students improve understanding and increase achievement. Much research has touted the efficacy of Supplemental Instruction programs. However, little research has examined the mechanisms by which those learning gains are attained.

Do innovations such as concept inventories help improve teaching and learning? How are they used and what can we learn from the experiences of faculty and academic support professionals who use them? Would learning improve if concept inventories were utilized in an academic support environment such as Supplemental Instruction?

This study used interviews with an experienced biology professor and an experienced Supplemental Instruction Leader to examine how they used the collective results of the *Concept Inventory of Natural Selection* (used as a pre- and post-test) to design and implement lessons in a large lecture introductory biology course and in Supplemental Instruction sessions. Using observations and document analysis as supporting data, themes were identified that describe these educators' views of learning, knowledge of assessment principles, and knowledge of assessment interpretation and action taking. This study provides the *first* data for how concept inventories are interpreted by faculty and Supplemental Instruction Leaders and used to guide instructional planning and implementation.

Data analysis revealed that an experienced biology professor did not rely on the diagnostic pre-assessment tool (the *CINS*) to understand and act upon students' prior knowledge and misconceptions. Rather, she was already aware of common student misconceptions and prepared to help students modify their knowledge. Instead, she preferred to rely on such instruments as a tool to help students self-assess the status of their knowledge. Likewise, this experienced Supplemental Instruction Leader was also aware of students' misconceptions and prepared to work with students to revise their understandings prior to receiving the results of the *CINS* pre-assessment. She relied on a variety of formative assessment tasks to help students build their knowledge and periodically check their understandings in a *collaborative, small group* environment.

This study sheds light on areas of strength as well as needed professional development and education for faculty members and Supplemental Instruction Leaders. It provides the first data on how concept inventories may be used in the biology classroom and in Supplemental Instruction sessions. It also identifies areas of educator knowledge where more understanding and research is greatly needed by the teacher educator community.

CHAPTER ONE: INTRODUCTION

Educators across grade levels and across subject matter differ in many ways. However, the one thing all educators are interested in is improved learning outcomes. At the college level, faculty members at campuses across the country have resisted the idea of unifying curricula and using standardized tests. But as students in the US have fallen behind on international measures of science and math (i.e. TIMMS and PISA), cries for improved science and math education have been heard at all levels of education, K-16. Initiatives such as the National Science Education Standards (National Research Council, 1996) and AAAS's Project 2061 (American Academy for the Advancement of Sciences (1993) have identified and outlined the standards necessary to bring our students "up to par." Response to these standards at the college level has taken the form of examining classroom practices, curricular choices, and assessment practices. While the first two have been intensely studied for many years, the interest in assessment practices thus far has received less attention (Abell & Siegel, 2011).

Assessment research takes forms such as achievement testing (i.e. standardized tests) and classroom assessment (i.e. examining the purposes and uses of tests) (Shepard, 2000). Aligned with socio-cognitive views of learning that dominate learning research today, assessment research has moved toward the process and product of learning and assessment. That is, classroom assessment should evaluate higher order thinking skills, rather than rote memory. This means that teachers should adapt their teaching based on what helps their students learn, rather than "teaching to the test." Hence, it is important for teachers to understand the purpose and processes of assessment, or to develop assessment literacy (Abell & Siegel, 2011).

One aspect of assessment literacy is the ability to assess for conceptual understanding. In physics education, Hestenes and colleagues (1992) developed an inventory that invigorated the physics education community and has helped to reinvent how physics is taught at the college level. It has helped refocus physics instructors so that they teach for conceptual understanding rather than memorization (Klymkowsky, Garvin-Doxas, & Zeilik, 2003). Following in their successful footsteps, the development of biology concept inventories has slowly been gaining popularity. Thus far, seven concept inventories for biology topics have been written, tested, and found to be reliable and valid (Anderson, Fisher, & Norman, 2002; Klymkowsky & Garvin-Doxas, 2008; Wilson, Anderson, Heidemann, Merrill, Merritt, Richmond, Silbey, & Parker, 2008; Parker, Anderson, Heidemann, Merrill, Merritt, Richmond, & Urban-Lurain, 2012; Williams, Fisher, & Anderson, 2008; Odom & Barrow, 1995; Nehm & Schonfeld, 2008; Elrod, 2008), and at least four more are under development now (D'Avanzo, 2008). At the time of writing, none of these has been used in classrooms or other environments for strictly instructional purposes.

In addition to assessment, it is important to have a cadre of tools—strategies, programs, etc.—to support learning. One example of a program successfully implemented and shown to improve student achievement, as well as enhance study and learning skills, is Supplemental Instruction (SI) (Arendale, 1994, 1993). Supplemental Instruction is a peer-led academic support program that is based on the principles of collaborative learning. SI Leaders are undergraduates who have successfully completed the course with the faculty member and develop and lead collaborative learning based sessions for students.

What happens if teaching and learning tools such as a concept inventory and a Supplemental Instruction program are combined with experienced instructors and academic support professionals interested in student learning? How would an experienced biology faculty member use information about what her students do and do not understand to alter her practice? How would an SI Leader use this information?

Rationale and Purpose of Study

Because of the heightened interest in improving science education, new "educational innovations" of various sorts—programs, curricula, strategies, and assessments for example—have been developed, tested, validated, and distributed for faculty use. Programs such as SI have been around for 30+ years and research has shown significant improvements in student learning across disciplines at the post-secondary level, but the specifics of how lessons are designed and what happens to improve student achievement and enhance study skills have not been closely examined. What we do know is that SI Leaders are effective at helping to increase student achievement, study skills, and enhance conceptual understanding (Congos, Langsam, & Schoeps, 1997; Congos & Schoeps, 1993; Hodges & White, 2001; Ogden et al., 2003). There is still much to learn about creating active learning opportunities from the work of SI Leaders. Thus, SI sessions are an ideal environment in which to examine and understand what a skilled SI

Leader could do to enhance SI sessions when given valuable information about her students' conceptual understandings (and misunderstandings) prior to designing lesson plans.

As already mentioned, SI has been extensively studied for outcomes-based research (Arendale,1994; Arendale, 1993; Blanc, DeBuhr, & Martin, 1983; Congos, 2003; Hensen & Shelley, 2003; Van Lanen & Lockie, 1997). That is, we know much about the positive effects of SI on student achievement and on campus retention rates, as well as changes in study skills and learning habits. The assumption is that increased achievement means increased conceptual understanding. No one has empirically examined this assumption. This study provides one set of empirical data examining this potential assumption.

Like SI, concept inventories (CI)--a recent addition to the undergraduate biology education toolbox--hold much promise for helping faculty to understand better the preconceptions their students bring to the classroom. By knowing what their students' ideas are and wherein the faulty reasoning lies, faculty members can design lessons and activities to better support students' conceptual change processes and bring them to an understanding closer to that of the discipline. While these are the hopes of the developers of CIs, no one has examined what faculty members and other learning support professional *actually do* with the results of the CIs once they have them. This begs the question, do these innovations help improve teaching and student learning? How are they being used and what can we learn from the experiences of faculty who are using them?

Assessment of student learning has garnered increased interest in science education in recent years. Both the National Research Council (1996) and the American Association for the Advancement of Science (1993) have advocated a larger role for assessment in science education. They see the role of assessment as critical to enhancing student learning and understanding. To create environments that support learning, Donovan and Bransford (2005) call for classrooms that are learner-centered, knowledge-centered, assessment-centered, and community-centered. Formative assessment tools such as CIs could prove to be valuable in moving toward such classrooms.

The proposed study brings together all of the aforementioned pieces. That is, this study allows the researcher to examine the use of concept inventories in a real-world context--the biology classroom--and the collaborative learning-based SI sessions that support this course.

Theoretical Framework

Science Teacher Assessment Literacy

This study is informed by the Science Teacher Assessment Literacy model developed by Abell and Siegel (2011). The views (including values and principles) that teachers have about student learning and assessment guide their classroom assessment decisions. The core principles of effective assessment are based on the work of Abell and Volkmann (2006), Banta, Lund, Black, & Oblander (1996), and Siegel, Wissehr, and Halverson (2008) and include:

1. *Assessment is a process through which teachers can learn.* Teachers create a more complete picture of a student's conceptual profile by targeting different kinds of knowledge and levels of thinking at varied times (Abell & Siegel, 2011; Siegel & Wissehr, 2011; Shepard, 2000; Magnusson, Krajcik, & Borko, 1999).
2. *Assessment is a process from which students should learn*. Testing students in ways that requires higher levels of thinking and measuring *for* learning, rather than to measure it enables students to learn from the process (Abell & Siegel, 2011; Siegel & Wissehr, 2011; Shepard, 2000).
3. *Assessment should help students be metacognitive about their developing knowledge and skills in order to self-regulate their learning.* To help students develop metacognition about their learning, it is important to consider how assessment tasks are introduced to and used by students, how assessment data are interpreted by teachers, and how instruction is adapted in response to assessment data (Abell & Siegel, 2011; Siegel & Wissehr, 2011; Shepard, 2000).
4. *Assessment tasks need to be equitable for all learners.* Tasks should be designed to minimize the bias for all students (Abell & Siegel, 2011; Siegel, 2007; Siegel & Wissehr, 2007; Shepard, 2000; Magnusson, Krajcik, & Borko, 1999).

These four principles are the heart of teacher assessment literacy (Abell & Siegel, 2011).

Additionally, it is necessary for teachers to have knowledge specialized for teaching, i.e. teacher knowledge. According to Shulman (1986), the three forms of teacher knowledge necessary for effective teaching are content knowledge (or knowledge about the subject matter), pedagogical content knowledge (subject matter knowledge for teaching), and curricular knowledge (including knowledge for teaching subjects and topics at a given level and instructional materials). These are discussed in more detail a bit later.

The model of Science Teacher Assessment Literacy (Abell and Siegel, 2011) identifies teacher knowledge forms specific to effective assessment. These include:

1. *Knowledge of the Purposes of Assessment*, which relates to the purpose for assessing students. The main purposes can be grouped into four main types of assessments--*diagnostic* (occurs at the start of a unit of study), *formative* (occurs during instruction), *summative* (usually at the end of a unit), and *metacognitive* (helps students become aware of and monitor their own learning) (Abell & Siegel, 2011; Siegel & Wissehr, 2011; Shepard, 2000).
2. *Knowledge of What to Assess:* Teachers must know what to assess. This is tied to their curricular and learning goals (Abell & Siegel, 2011; Magnusson et al., 1999; Shulman, 1986).
3. *Knowledge of Assessment Strategies* refers to how a teacher assesses students on particular concepts, both formatively and summatively (Abell & Siegel, 2011; Magnusson et al., 1999).

4. *Knowledge of Assessment Interpretation and Action-Taking* pertains to what teachers believe about how students would respond to assessment tasks and how they interpret and adjust their instruction in response to this (Abell & Siegel, 2011; Siegel & Wissehr, 2011; Magnusson et al., 1999).

Little is known about how teachers interpret assessment data and act upon it (Abell & Siegel, 2011). What do teachers do with assessment data? How do they perceive assessment? What forms of teacher knowledge, beliefs, and values influence the interpretations they make of the results and how does that impact decision-making? That is, what decisions about teaching and learning will teachers make in response to assessment results regarding their students' understandings and misconceptions? What are the teaching and learning-related actions they choose?

The American Federation of Teachers (AFT), the National Education Association (NEA), and the National Council on Measurement in Education (NCME) wrote a set of "Standards for Teacher Competence in the Educational Assessment of Students" (AFT, NCME, NEA, 1990). The Standards outline seven areas of competency about assessment that teachers should have. Of these seven, the fourth Standard states that teachers should be able to use "assessment results when making decisions about individual students, planning instruction, developing curriculum, and improving schools" (p.31). Specifically, this means that teachers should be able to use aggregate assessment information to organize an instructional plan. Furthermore, teachers should be able to interpret results correctly using established rules of validity.

Shulman (1986) described three forms of teacher knowledge—content knowledge (PK), curricular knowledge, and pedagogical content knowledge. Content knowledge includes the amount and organization of knowledge in the mind of the teacher about the subject matter. Curricular knowledge is knowledge about how subjects and topics are taught, including things such as instructional materials and the characteristics that make them useful at given times. Pedagogical content knowledge (PCK) is the knowledge that a teacher has about how to help students understand specific subject matter. It "includes knowledge of how particular subject matter topics, problems, and issues can be organized, represented, and adapted to the diverse interests and abilities of learners, and then presented for instruction"(Magnusson, Krajcik, & Borko, 1999, p. 96).

Magnusson, Krajcik, and Borko (1999) include the following as specific components of their model of PCK:

- Orientations toward science teaching
- Knowledge and beliefs about science curriculum
- Knowledge and beliefs about students' understanding of specific science topics
- Knowledge and beliefs about instructional strategies for teaching science
- Knowledge and beliefs about assessment in science (Magnusson et al., 1999, p. 97, 99-115).

Magnusson et al.'s (1999) concept of knowledge and beliefs about assessment in science includes an understanding of what aspects of science learning to assess and the methods to use when assessing student learning. Abell and Siegel's (2011) component of knowledge of how to interpret assessment results and take action on those results is missing from the Magnusson et al. model (1999) but has a central place in the current study.

These forms of teacher knowledge are used in conjunction with the beliefs and values that teachers hold about teaching and learning and the external pressures that compel them to action in certain forms (McMillan, 2001). Collectively, these factors all influence the decisions that teachers make regarding instructional choices and practices. These decisions include choices about further assessment, grading practices (McMillan, 2001), and strategies to use for teaching, such as questioning, explaining, listening, activities, and discussion, to name a few (Shavelson, 1973). In summary, how do teachers take their students' assessment results and use their knowledge, values, and beliefs to interpret, make decisions, and act on these results to help their students learn?

This study relied on Abell and Siegel's (2011) knowledge form #4—knowledge of assessment interpretation and action taking--as a lens by which to examine the interpretations and actions of SI Leaders and faculty members. The concepts of teacher knowledge, beliefs and values, and decision-making will also be considered. Specifically, the goal is to understand how professors and SI Leaders respond to information about student knowledge of specific concepts. For instance, are they aware of students' common alternative conceptions about specific concepts? How do they address these conceptions? Do they ignore them? What are their expectations of student conceptions after instruction? Will the data support their notions? Do professors and SI Leaders share those same misconceptions? Examining the interpretations and actions of the professor and SI Leader will allow the researcher to frame the findings in a context that permits generalization of the findings and forwards an area of assessment research that has received little attention.

Research Questions

This study will explore how an experienced biology professor and an experienced SI Leader for an introductory biology course for non-majors interpret their students' results on the Concept Inventory of Natural Selection and how they use these results to design and implement lessons. The overarching question guiding this study is: How do professors & SI Leaders respond to the results of concept inventories? This question is informed by the following sub-questions:

- In what ways do the professor's views of learning, understandings of principles of assessment, and knowledge of assessment interpretation and action taking skills interact?
- In what ways do the SI Leader's views of learning, understandings of principles of assessment, and knowledge of assessment interpretation and action taking interact?
- What are the similarities and differences between the interpretations and actions of the professor and SI Leader?
- In what ways does the CI inform the professor's efforts to support student learning?

- In what ways does the CI inform the SI Leader's efforts to support student learning?

Please see Appendix A for a detailed account of the data collected to answer each question.

CHAPTER TWO: REVIEW OF RESEARCH LITERATURE

This chapter introduces the primary bodies of research relevant to this study. First, the history of Supplemental Instruction and the research that has been conducted about Supplemental Instruction are discussed. Next, an introduction to concept inventories is provided, including descriptions of how test items are created and validated. Following that is an overview of the concept inventories currently in progress and/or available in the field of biology. An explanation of how the Concept Inventory of Natural Selection was chosen is provided, followed by a description of it.

Supplemental Instruction

Supplemental Instruction (SI) is a peer-based academic support and enhancement program that has traditionally targeted “high-risk” courses, not high-risk students. “High-risk” is defined as a course that traditionally has a history of high enrollment, high withdrawal rates, and high failure rates. The program is typically run through campus Learning Centers and is attached to courses in cooperation with the faculty member. Supplemental Instruction provides free, regularly scheduled sessions outside of class lectures several times per week, starting the first week of classes for all students enrolled in the course. The SI Leaders hold weekly office hours as well, giving students one-on-one time with a more knowledgeable peer. Studies have repeatedly shown that regular participation in SI increases students’ achievement and improve students’ learning and study skills and motivation, as well as their abilities to self-regulate and transfer metacognitive skills to other disciplines (Arendale,1994; Arendale, 1993; Blanc, DeBuhr,

& Martin, 1983; Congos, 2003; Hensen & Shelley, 2003; Van Lanen & Lockie, 1997). Additionally, SI has helped to improve retention rates and satisfaction with high-risk courses (Arendale, 1994; Congos, 2003).

Each course that implements SI has one Leader who attends lecture, holds multiple office hours weekly, and designs and leads between two and four SI sessions per week for students enrolled in the course. Because the SI Leader has previously taken and been successful in the course with the same instructor, he or she is able to identify the areas that are difficult for students to master. Through training in collaborative learning strategies, lesson and activity design, study strategies, learning and teaching styles, formative assessment, and other skills useful to facilitating successful collaborative learning environments, SI Leaders develop activities for and lead the SI sessions. The SI Leader is integral to the success attained by students.

Because SI is based on the principles of collaborative learning, SI participants are expected to engage actively in activities and discussions. Some hypothesize that this is why SI improves student performance and abilities. A small, collaborative, peer-based, and non-threatening environment allows for personal attention and interaction and encourages the organization of study groups outside of class. In addition, SI does not carry the stigma of being "remedial," since it targets courses and not students (Arendale, 1993). Moreover, because students acquire learning and study skills that are transferable to other courses, they find benefit in regular attendance at SI sessions (Ogden, Thompson, Russell, & Simons, 2003; Price & Rust, 1995; Ramirez, 1997).

Extensive research on the efficacy of SI has been conducted and indicates that SI participants typically earn at least one-half to one letter grade higher in a given course compared to non-attendees (Blanc et al., 1983; Collins, 1982; Congos, Langsam, & Schoeps, 1997; Congos & Schoeps, 1993; Hodges & White, 2001; Ogden et al., 2003; Shaya, Petty, & Petty,1993; Zaritsky & Toce, 2006). This holds true across disciplines and with diverse groups of students (Burmeister, 1994; Kenney & Kallison, 1994; Kenney, 1989; Lundeberg & Moch, 1995; Lundeberg, 1990; Lockie & Van Lanen, 1994; Pryor, 1989; Martin & Blanc, 1994). Some have suggested that SI participants are a self-selected group and that is why they performed better. That is, the students who participate in SI tend to be higher achievers and would have done better even without the support of SI. The research available however, has shown that SI is not comprised of self-selected higher achievers and that *all* students who participate in SI can earn higher grades (Congos & Shoeps, 1993; Congos et al., 1997; Gaddis, 2002; Shaya, 1993). Survey data has been collected about levels of students' motivation, satisfaction, and benefits in later courses from participation in SI.

However, little qualitative research of any area of SI has been conducted (Warner, 2008). Furthermore, while much of the SI literature has focused on assessing the effectiveness of the SI model and on the correlation between academic achievement of SI participants versus SI non-participants (Jacobs, Hurley, & Unite, 2008), very little attention has been given to understanding other aspects of the SI model (Jacobs et al, 2008; Grier, 2004). For instance, few studies have examined the actions of SI Leaders or the interactions among students and SI Leaders during SI sessions (Jacobs et al, 2008).

Likewise, there are no studies available on the relationship and communication that occurs between SI Leaders and the course professors. Neither is there research available on the use of diagnostic instruments with Supplemental Instruction.

The success of SI programs is often attributed to the emphasis on group work, and more specifically, collaborative learning (Arendale, 1993). Indeed, the research on collaborative learning in higher education is growing rapidly and is championed by educators such as Bruffee (1993), who argues that collaborative learning gives students practice in working together when the stakes are low, so that they are able to work together effectively when the stakes are high. They learn to depend on one another rather than depending on the authority of the instructor. They learn to construct knowledge in ways similar to knowledge construction in academic disciplines and professions…and they learn the craft of interdependence (p.1). Additionally, SI Leaders integrate study skills relevant to the course, another feature unique to SI (Arendale, 1993), and research has shown that SI programs that integrate study skills with course content are the most effective (Keimig, 1983).

Concept Inventories

Concept inventories (CI) are research-based conceptual assessment instruments that measure students' conceptual understanding of topics in various disciplines ((Klymkowsky & Garvin-Doxas, 2008). The topics assessed are those for which students often share common alternative or naïve conceptions and often incorporate students' misconceptions and language. Students' language refers to language that minimizes use of scientific jargon and instead incorporates students' everyday ways of talking and thinking. A useful concept inventory is able to inform faculty of the concepts his or her students do not understand, as well as to identify the incorrect mental constructs the students hold ((Klymkowsky & Garvin-Doxas, 2008, D'Avanzo, 2008).

Currently, many concept inventories are multiple-choice tests that can be scored objectively, which is an asset for implementing in larger classes (D'Avanzo, 2008). However, they differ from typical multiple-choice tests in several ways (Garvin-Doxas, Klymkowsky, & Elrod, 2007). The wrong answers, which are called *distracters* or *foils*: a.) are based on extensive research of student misconceptions; b.) are written using the language that students use, not scientific jargon; c.) diagnose a specific level of student conceptual understanding; and d.) reveal where student are having difficulties conceptually (D'Avanzo, 2008).

Distracter-driven multiple-choice questions allow researchers to combine qualitative research and quantitative assessment to measure change in students' concepts of carefully defined phenomena (Sadler, 1998). Interviews, which are a qualitative data source, are a powerful way to demonstrate students' mental models of concepts, as well as their reasoning. Multiple-choice tests, on the other hand, can be administered to a large group of students at one time. This increases the reliability of their results. Furthermore, thoughtful, well-designed questions can illustrate how many student responses match those of experts (D'Avanzo, 2008). It is important that we understand what biology faculty could do when armed with this knowledge about their students.

In the physics community, the Force Concept Inventory (Hestenes et al., 1992) has been widely adopted, “revolutionized the teaching of physics,” and “ushered in a new field of physics education” (Garvin-Doxas, Klymkowsky, & Elrod, 2007, p. 278). This is because widespread acceptance and use of even a single concept inventory also encourages the adoption of alternative means of learning assessment and program evaluation (Garvin-Doxas, Klymkowsky, & Elrod, 2007).

A concept inventory (CI) can reveal how many students do not understand a concept, as well as which conceptual view they hold instead. With this detailed information of how students’ views are different from the scientific one, instructors can address problem areas more effectively, using appropriate teaching techniques.

Concept Inventories available for Biology

The recent interest in concept inventories for the biology education community has resulted in the development and validation of at least seven different concept inventories (D’Avanzo, 2008). More are currently being developed and/or validated (D’Avanzo, 2008). In a 2008 paper, D’Avanzo (2008) provided an overview of the status of concept inventories for biology. The assessments she identified, their authors, and a basic description of them is found in Table 1. For D’Avanzo’s purposes, “validation” refers to confirming misconceptions and false positives via in-depth student interviews.

Table 1. Biology concept inventories available and/or under development.

Concept Inventory	Authors	Status and Conceptual Focus
Concept Inventory of Natural Selection	Anderson, D.L., Fisher, K.M., & Norman, G.J. (2002)	Published and validated; Examines concepts related to the process of natural selection
Biology Concept Inventory	Klymkowsky, M. & Garvin-Doxas, K. (2008)	Published and validated; "Focuses on random processes in biological systems" (authors)
Diagnostic Question Cluster: Matter and energy	Wilson C.D., Anderson C.W., Heidemann M., Merrill J.E., Merritt B.W., Richmond G., Silbey, D.F., Parker J.M. (2006)	In progress, including validation; "Multiple-choice questions that measure students' ability and inclination to trace matter through photosynthesis and cellular respiration" (authors)
Diagnostic Question Cluster: Photosynthesis	Parker, J., Anderson, C., Heidemann, M., Urban-Lurain, M., Merrill, J., Merritt, B., Richmond, G., & Sibley, D. (2012)	In progress, including validation; "Focused on students' abilities to apply basic concepts about photosynthesis by reasoning ...conservation of matter, conservation of energy, and the hierarchical nature of biological systems" (authors)
Cell Division Diagnostic Test	Williams, K., Fisher, K., & Anderson, D. (2008)	Unpublished but validated; Consists largely of two-tiered and simple multiple choice items; focuses on photosynthesis, decomposition, and energy and matter transformations
Natural Selection Diagnostic Test	Williams, K., Fisher, K., & Anderson, D. (2008)	Unpublished but validated; Modified questions from the CINS for two scenarios
Osmosis and Diffusion Test	Williams, K., Fisher, K., & Anderson, D. (2008)	Unpublished but validated; Selected items from Odom & Barrow's (1995) Osmosis and Diffusion Test; Consists of ten *two-tiered items*, twenty questions
Osmosis and Diffusion Diagnostic Test	Odom, A.L., & Barrow, L.H. (1995)	Published, not validated; Multiple-choice instrument that evaluates understanding of diffusion and osmosis
Natural	Nehm, R.H., &	Published, not validated;

Selection Instrument	Schoenfeld, (2008)	An open-response instrument to assess understandings about natural selection
Genetics Concept Inventory	Elrod, S. (2008)	In progress, not validated; Modeled after the Force Concept Inventory (Hestenes) but focuses on basic understandings of genetics
Diagnostics Tests on Energy and Matter and the Nature of Biology	Williams, K., Fisher, K., & Anderson, D. (2008)	In progress, not validated; -one will focus on photosynthesis, decomposition, and energy and matter transformations; multiple choice -other focuses on nature of science and will be mostly multiple choice questions

In choosing an assessment instrument for this study, several factors were considered. First, were the concepts assessed by the instrument included in the course objectives? Second, were the concepts assessed at a level appropriate to the level of detail expected of the course? Third, was the assessment one that the Professor of the course felt was appropriate for measuring conceptual learning in her course? After comparing each of the *validated* instruments above to these criteria, it was determined that the Concept Inventory of Natural Selection best fit the requirements for this study. In addition to meeting the criteria above, the CINS is an appropriate tool to use with a non-majors course. Finally, it focuses on one major idea—natural selection—and covers several important subthemes of natural selection.

Concept Inventory of Natural Selection

This study utilized the Concept Inventory of Natural Selection (CINS) (Anderson, Fisher, & Norman, 2002), which was one of the first CIs developed for biology (D'Avanzo, 2008). The authors describe the CINS as a "more realistic and comprehensive test for assessing conceptual understanding of natural selection" (Anderson et al., 2002, p. 953) because the context of the questions are specific evolutionary events that scientists are studying, such as the Galapagos finches. The 20 test items address how well students understand the five facts and three inferences that Mayr (1982) used to explain the logic of the theory of natural selection, as well as questions examining how well students understand the origin of variation and the origin of species. Collectively, 10 concepts related to the theory of natural selection are tested, with two questions per concept (Anderson et al., 2002). Each test item includes distracters that address common alternative conceptions about national selection. The table below describes the 10 main concepts covered in the assessment (Table 2).

Table 2. Ten Main Concepts of Natural Selection found in the CINS

Natural Selection Concepts	**Description of Concepts that appear in the CINS (from Anderson et al., 2002)**
Biotic potential	"All species have such great potential fertility that their population size would increase exponentially if all individuals that are born would again reproduce successfully"
Population stability	"Most populations are normally stable in size except for seasonal fluctuations"
Resources are limited	Natural resources are limited; All members of a species compete with one another for resources
Limited survival	"Production of more individuals than the environment can support leads to a struggle for existence"; only some will survive
Genetic variation	Organisms within a species differ from one another in inherited traits
Origin of variation	Variations arise through mutation and genetic recombination
Variation is inherited	Mutation and genetic recombination are random events that produce beneficial, neutral, or harmful traits. Much variation is inherited so the parents pass on their traits to their progeny.
Differential survival	Among offspring, those best suited to the environment tend to be most successful in producing young. Offspring that are less well suited to the environment are less likely to survive and less likely to produce offspring.
Change in Population	Through differential reproductive success, the frequency of different genetic types in the population can change with each succeeding generation. Populations change through changes in the frequencies of genetic types in the population.
Origin of Species	When two populations of a single species are separated for an extended period of time by a physical, behavioral, temporal, or other barrier, the populations may diverge to the extent that they become separate species.

One goal of the CINS was to be able to obtain information about student understandings that paralleled information obtained in interviews with students. At the same time, the results had to be efficiently collected, so that the test could be used with large classes. The results of the CINS show a positive correlation to interview results, suggesting that the CINS is a viable option for instructors to gain valid and reliable information about a large number of students' understandings of natural selection. The authors suggest that the CINS is best suited for assessing pre- and post-instruction knowledge of non-majors and pre-instruction knowledge of biology majors (Anderson et al., 2002).

Contributions of this Study to the Literature

This study is provides several novel contributions to the bodies of literature discussed above. It addresses gaps in the literature in two important areas of interest to the researcher—assessment practices and academic support programs.

First, this study explores the assessment practices of educators for conceptual understanding in undergraduate biology education. Specifically, this study describes the actions and assessment interpretations of an experienced professor and an experienced SI Leader in response to their students' collective results on a concept inventory. While concept inventories have been used and influential within the field of physics for 20 years (D'Avanzo, 2008), they are a relatively new phenomenon within the field of biology. Biology education researchers have developed and validated seven concept inventories thus far to assess various biological concepts (D'Avanzo, 2008), but no one has examined how these concept inventories are implemented in the undergraduate biology classroom. Furthermore, there is no data concerning how biology educators (instructors or academic support professionals) interpret their students' collective results on any concept inventory. Understanding this should be of value to the developers of concept inventories to enable them in constructing better assessment tools and providing adequate training and resource materials for those interested in using concept inventories in their work. This work should also interest researchers who study the assessment practices of undergraduate science faculty. It should also interest those who want to know more about the practices of Supplemental Instruction Leaders.

While the body of literature about the efficacy of Supplemental Instruction and its relationship to student achievement and retention is strong, very little research exists about what happens during SI sessions that leads to these results. That is, few studies have examined what happens during Supplemental Instruction sessions to support student learning and how those sessions are connected to the course that they serve. Moreover, there is a lack of data about the relationship between the SI Leader and the course professor. Finally, no one has examined *how much* SI Leaders know about their students' prior knowledge about course concepts and how these Leaders help students to address misconceptions. This study explores these areas and provides some of the first data about the qualitative aspects of what happens during Supplemental Instruction sessions and how SI Leaders carry out their work.

CHAPTER THREE: METHODS

Research Tradition

When conducting qualitative research, the validity of the research depends greatly on "the skill, competence, and rigor of the person doing the fieldwork" (Patton, 2002, p. 14). Hence, an understanding of the researcher's ontological, epistemological, and methodological assumptions is important when considering her data. This research was guided by a constructivist paradigm. It assumes a relativist ontological perspective, a subjectivist epistemology, and naturalistic methodological procedures (p. 21).

Ontological Assumptions

Constructivism argues that multiple realities exist, each of which are unique because they are constructed by the individuals who experience phenomena from their own vantage points (Hatch, 2002). Ontologically, the multiple realities of this study included the researcher's, biology professors', and SI Leaders' interpretations, instructional choices, and actions in response to their students' results on the concept inventory.

Epistemological Assumptions

The subjectivist epistemological views of this study relate to the constructivist design. The researcher and participants (the faculty and SI Leaders) co-constructed understandings about reality (Hatch, 2002). The researcher should not be distant and objective. Rather, mutual engagement between the researcher and participants constructs the subjective reality being studied (Hatch, 2002). From this perspective, the researcher had the opportunity to collect data and interpret her observations. Additionally, she was able to ask questions of the participants about their understandings and actions, as well as clarify her interpretations of these. Constructivism lends itself to writing case studies or rich narratives that describe the interpretations constructed as part of the research process" (Hatch, 2002).

Methodological assumptions

Qualitative research design is *naturalistic* in the sense that the researcher does not attempt to manipulate or control the research setting. It "has no predetermined course established by and for the researcher" (Patton, 2002, p.41). The goal of naturalistic inquiry is "to understand naturally occurring phenomena in their naturally occurring states" (p.41). Lincoln & Guba (1985) identify "naturalistic qualitative research methods [as] the data collection and analytic tools of the constructivist." The goal of this study was to explore and understand how a biology professor and SI Leader interpreted the results of the concept inventory and implemented instructional choices to enhance student learning. Naturalistic methods were appropriate for attaining this goal.

Context of Study

This study was conducted in the biology department at a large, mid-western university. The non-majors biology course is worth three credit hours and its goal is to introduce students to biology and its relevance to their lives. The course syllabus can be found in Appendix D.

In addition to the classes, the SI sessions attached to this course were also studied. This SI program was unique because it is housed within the Division of Biological Sciences at MU and not within a Learning Center. Hence, all staff and SI Leaders were housed in a biology building and therefore are able to interact more closely with SI professors.

Participants

The primary participants were the biology professor who taught the non-majors lecture under study and the SI Leader that facilitated the SI sessions for this course. Both individuals consented to participate in this study.

The Biology Professor—Professor Liberty

Professor Liberty was chosen for this study for multiple reasons. She was an experienced instructor for this course, having taught the course fourteen times before over a span of eleven years. In addition to general biology for non-majors, Professor Liberty had also taught other courses in the Division, including Botany (four times), Genetic Diseases (three times), and Infectious Diseases (five times). She had participated in the SI Program for the two semesters prior to this study for her non-majors biology course.

Significantly, Professor Liberty had an ongoing interest in improving student learning. She had given much time and thought to engaging students in the content and strategies for improving learning opportunities. She was very interested in formative assessment as one aspect of improving her course and thus saw this study as having potential for helping her to improve her course and learning opportunities for her students.

In addition, Professor Liberty changed the way she taught at least one concept (or set of concepts) in her course *every* semester, so that the material was "fresh" and aligned with the newest ways of teaching that had been shown to be effective in the research literature. She regularly conducted research on her own courses with the intent of collecting data that would allow her to improve them and create more learning opportunities for her students. Professor Liberty had also shared some of the findings on her class research at professional meetings such as AAAS and AIBS. She had even participated in workshops designed to help her conduct educational research and in professional development opportunities that helped her work on her teaching and learning efforts for the classroom.

Part of her recent teaching and research efforts had involved developing assessments that would elicit her students' prior knowledge and to assess for conceptual understanding after the lessons. Specifically, she had worked on assessments with colleagues that related to genetics, such as the structure and size relationships of genetic material. She had not developed any assessments related to evolution and specifically to natural selection, which were the focus of the concept inventory used in the present study.

Along with her interest in incorporating more assessment into her course and in educational research in general, she was dedicated to using active learning in her classroom, including her large lecture courses, and had been using these in her courses for many years.

Her efforts to improve as a teacher and an education researcher were noticed by her colleagues or her students. Professor Liberty had the reputation of being an excellent professor. She had earned the respect of her colleagues as an innovative, progressive, and dedicated *teacher*. Significantly, Professor Liberty had earned tenure on a teaching track in a biology department with a strong research focus.

In addition, Professor Liberty had earned several teaching awards and honors, including the campus's highest honor bestowed upon teachers. Colleagues would seek her out to discuss teaching and learning issues; she routinely made herself available to colleagues and graduate students to talk over issues and felt strongly that she still had much to learn about teaching and learning. New, inexperienced instructors and graduate students commonly sought her counsel on all aspects of course design and implementation.

Professor Liberty's students also thought highly of her. It was common for students to visit her office to talk over course materials or other topics, such as life and career plans. The researcher witnessed Professor Liberty's popularity with students firsthand, as students dropped by during the interviews and during other conversation between the Professor and researcher.

Because of Professor Liberty's unique interests and foci, she was an ideal participant for this study. She was not only an experienced teacher but had also shown great interest in enhancing student learning and her teaching practices through her research interests, which is uncommon at Research-1 universities (Park & Braxton, 2010; Schmidt, 2010). Professor Liberty's interests aligned well with those described as *valuable* in Boyer's influential study *Scholarship Reconsidered: Priorities of the Professoriate* (Boyer, 1990), although scholarship such as hers is not commonly regarded by peers with the same respect as traditional research is in the sciences (Boyer, 1990; Schmidt 2010). Boyer (1990) had called for an adjustment of academic priorities and suggested that scholarship of teaching methods should be valued as highly as the traditional scholarships of knowledge pursuit and theory generation and testing.

Scholarship of teaching has always taken a back seat to traditional research pursuits (Boyer, 1990; Schmidt, 2010), although scholars such as Professor Liberty illustrate what a teaching-centered scientist can accomplish in the classroom. Recently, Park and Braxton's research (2010) on latent teacher identities found that not much has changed in the 20 years since Boyer's study. That is, scholars who focus primarily on pedagogy are still in the minority, and they tend to stand apart from other faculty types. This focus correlates with increased likelihood that pedagogy-focused scholars choose to work at non-R1 institutions and instead spend their time at "teaching institutions" such as liberal arts colleges (Park & Braxton, 2010), where their work and scholarship is more likely to be valued.

Professor Liberty was *not* the typical scientist within the R1 biology department where she worked. Yet she was an active and vital member of that community, and her work and interests were valued by her colleagues. The ways in which she negotiated her role as a teaching track professor within research-focused science department (Lave & Wenger, 1998) allowed Professor Liberty to pursue her interests and feel supported in an environment that traditionally supported and placed priority on research in the sciences, not teaching. The researcher believed that there was a great deal that could be learned from observing Professor Liberty's teaching and specifically assessment practices.

The Supplemental Instruction Leader (SI)--Athena

Athena had previously led Supplemental Instruction sessions for two semesters for this course with Professor Liberty. She had earned a BA in science education (focused at the middle school level) and had developed a strong interest in collegiate academic support because of her work with the SI Program. In addition to her form education, Athena had received extensive training with the SI Program specifically in the theories and skills required of proficient SI Leaders, including collaborative learning strategies, lesson and activity design, study strategies, learning and teaching styles, formative assessment, and other skills useful to facilitating successful collaborative learning environments.

Like Professor Liberty, Athena had also spent much time thinking about how to incorporate more formative assessment strategies into her SI sessions because she believed it is important for improving student understanding. Part of Athena's interest in formative assessment arose from the knowledge that students come to science class with prior knowledge that does not always align with scientific views of concepts. Her science education program had exposed her to student misconceptions and their effects on learning, conceptual change theories, assessment practices, and even resources for using and/or creating formative assessment tasks such as Page Keeley's *Science Formative Assessment* (2008). Athena had actually recommended purchase of this resource for the SI Office.

Athena was the most experienced SI Leader on staff at the time of the study. In addition to leading Professor Liberty's SI sessions, Athena was also the head SI Leader on staff. Her background in science education and experiences with the SI Program made her a standout in the biology department and even among SI Leaders. Similar to Professor Liberty, Athena focused her time and attention on teaching and learning, *not* traditional scientific research. Her non-scientist approach to science is what made her a competent and effective SI Leader. Her interest in academic support led Athena to decline a middle school teaching job during the year of the study, which was what she had prepared for during her undergraduate education. She is now pursuing a PhD in the Learning Sciences instead. Her goal is to run academic support programs such as Supplemental Instruction after she completes her doctoral studies. Because of the aforementioned qualities, Athena was an ideal candidate for participation in this study. There could be much learned from her work and her actions.

The Students Enrolled in General Biology

The students enrolled in the course served as sources of secondary data. While they were not the focus of this study, their responses to the CINS pre-test and post-test were necessary for this study. Their participation was voluntary and by consent. At the start of the semester, the researcher read a recruitment script to the class informing them about the purposes of the study and how their confidentially would be preserved. They chose whether to complete the concept inventory (see Appendix B) or not for the research study and indicated their consent or dissent by answering the questions attached to the concept inventory that elicited consent. Please see Appendix C for an example of how their consent was gained. Students completed the concept inventory (and the questions in Appendix C) twice, once at the start of the semester and a second time after the relevant lessons were taught, prior to completing the CINS questions as a post-test. For the post-test, Professor Liberty gave a regular course exam that she had written and attached the consent form and the CINS to the back of the exam. Students voluntarily chose whether to participate in the post-test by indicating consent and completing the CINS questions. Those who dissented were removed from the final data set before the interviews were conducted.

All students participated on a voluntary basis. Each primary participant (professor and SI Leader) read and signed a consent form that ensures that their participation is voluntary and would have no repercussions should they choose not to participate. All student responses to the concept inventory have been and will be kept confidential. Only the researcher knows which students consented and what their individual results were.

The collective results were provided to faculty member with no identifying information to ensure student privacy. All data collected from all participants was kept confidential and secure. Participation in this study presented no risks greater than those incurred in normal daily life.

Design

This naturalistic constructivism-guided study employed qualitative methods to understand the interpretations and actions of an experienced biology professor and SI Leader for an undergraduate introductory biology course for non-majors. Collected data included interviews with the primary participants (professor and SI Leader), selected classroom observations (and Tegrity recordings of lectures relevant to the concepts of interest as back-up data), pre- and post-tests of the concept inventory, and artifacts from the professor, SI Leader, and students.

Data Collection

Data were collected throughout the spring 2011 semester. To ensure that data collection methods were appropriate and that enough data was being collected, the researcher engaged in constant comparison while collecting data. That is, data was collected while simultaneously analyzing it, which helped to guide later data collection (Bogdan & Biklen, 2003; Hatch, 2002).

Pre-test and Post-test

The CINS focuses on natural selection and the ideas that support it. It is a 20-questions multiple-choice instrument and is intended to identify the conceptions that students hold about natural selection. The CINS was administered in full, but the instructor decided which and how many of the supporting concepts to revise instruction for.

The students' responses were summarized in collective form and provided to the professor and SI Leader to help design and implement lessons that address alternative and/or naïve conceptions and lead students toward scientific understandings. The concept inventory was administered twice, at the start of the semester and again after the concepts under study had been taught.

The professor and the SI Leader also took the CINS. This was meant to help identify if either held any of the misconceptions identified by the CINS. If they had held any misconceptions, this obviously would have affected their ability to help students learn the scientifically held conceptions about natural selection that they were trying to teach.

Interviews

Three interviews were conducted with the faculty member. Interview #1 occurred before the CINS was administered to learn of the faculty member's course and learning goals and her impressions of students' understandings for the concepts upon which she focused her instruction. Interview #2 occurred immediately after the concept inventory was administered and results were obtained. The researcher and instructor went through each question and the students' collective responses to gain the professor's impressions about the results and how she would use them to design and implement lessons for those concepts. Interview #3 occurred after the concepts under study were taught and all the relevant lessons had been taught and assessed in order to gain understanding of Professor Liberty's impressions of the students' learning experiences of those concepts. Furthermore, this interview elicited Professor's impressions of the concept inventory's usefulness in helping her with lesson planning and implementation and whether it helped her to improve students' learning experiences. Interviews 1, 2, and 3 described above were also conducted with the SI Leader to gain understanding of her perceptions. For all interviews, the principles outlined in the Assessment Literacy model aided in the development of questions and probes. (All Interview protocols can be found in Appendices E-G).

In addition to taking notes during each interview, all interviews were recorded and transcribed as needed for further analysis. The interviews were semi-structured, including both pre-determined questions and planned and spontaneous probes to get more details.

Document/Artifact analysis

Artifacts collected for this study included examples of any student homework and in-class work that involved the concepts chosen by the faculty member, as well as exams, quizzes, or other assessments related to pertinent content. Additionally, all lesson plans and assessments of the SI Leader and the faculty member related to those concepts for the spring 2011 semester were collected, as were the lesson plans and assessments for those concepts from previous semesters. This helped to understand better how the CINS contributed to revised instructional approaches (or if it did).

Field notes

The researcher observed all lecture meetings and SI sessions for the concepts chosen for revision by the faculty member. The observations were focused upon instructional approaches used by the professor or SI Leader to support student learning of the chosen concepts. Notes were collected on items including but not limited to: lecture content (representations, descriptions, etc.); methods for addressing alternate or naïve conceptions; and all forms of assessment, i.e. questions asked, written response prompts, quizzes, and dialogue.

Tegrity Recordings of lectures and SI sessions

In addition to collecting field notes, Tegrity video recordings for each lecture and SI session for the target concepts were downloaded as a secondary data source. These recordings were used only as “back up” for the field notes and not as a primary data source. For the SI sessions, Professor Liberty allowed Athena to use her Tegrity site to record her SI sessions. All Tegrity and video recordings are and will be kept confidential and secure.

Data Analysis

According to Marshall and Rossman (1989), data analysis is “the process of bringing order, structure, and meaning to the mass of collected data.” It is not a linear process (Marshall and Rossman, 1989), but a process that allows the researcher to handle qualitative data “so that what has been learned can be communicated to others” (Hatch, 2002).

All transcripts, field notes, expanded observation notes, documents, and surveys were utilized in data analysis. To ensure that data collection methods were appropriate and that enough data were being collected, the researcher engaged in constant comparison while collecting data. Gaining “repeated confirmations of potential explanatory patterns” (Hatch, 2002) ensures data are carefully being examined as “the researcher compares data with data, data with categories, and category with category” (Charmaz, 2005). By “beginning formal data analysis early,” researchers “improve the quality of the research” (Hatch, 2002).

According to LeCompte & Preissle (1993), typological analysis involves “dividing everything observed into groups or categories on the basis of some canon for disaggregating the whole phenomenon under study” (p. 257). Using Hatch’s (2002) explanation of typological analysis, data analysis begins by dividing the overall data set into categories or groups based on predetermined typologies. These typologies can be “generated from theory, common sense, and/or research objectives, and initial data processing happens within those typological groupings” (p. 152). That is, data are “reduced” (Marshall & Rossman, 1989) to certain patterns, categories, or themes and interpreted using the lens of teacher assessment literacy.

To analyze the data collected in this study, the researcher looked initially to the Model of Science Teacher Assessment Literacy described in Abell & Siegel (2011). The Model identifies assessment values and principles, divided into four categories. These categories are knowledge of assessment purposes, knowledge of what to assess, knowledge of assessment strategies, and knowledge of assessment interpretation and action taking. Specifically, the professor and SI Leader were provided with an assessment strategy--the concept inventory--and the study looked for themes of how they interpreted the results and “took action.” Categories for coding initially came from the science teacher assessment literacy model already presented and were supplemented by themes identified during data analysis. Some of the categories that were initially identified include:

- elements of the science teacher assessment literacy model (Abell & Siegel, 2011)
- student misconceptions identified by the CINS, the professor’s and/or SI Leader’s knowledge of those misconceptions
- the professor’s and/or SI Leader’s level and use of various forms of teacher knowledge (per Shulman, 1986) and beliefs (per McMillan, 2001)
- the various forms of interpretations of assessment results by the professor and SI Leader (NRC, 2001; AFT, NCME, NEA, 1990)
- the decisions they made (Otero, 2006; McMillan, 2001; Shavelson, 1973)

- the actions they took to help students learn (Abell & Siegel, 2011).

Not all themes that were identified were used in this study. During data analysis, the researcher organized the data categorically (using multiple coding schemes), reviewed it repeatedly, and coded simultaneously while collecting data and after collection was complete. Pervading themes are reported here (as suggested by Merriam, 1988) from which generalizations could be drawn (as suggested by Hatch, 2002).

Summary of Methods

Briefly, this was a descriptive case study of the professor and SI Leader. First, the researcher coded the Professor Liberty's data set. For her data, the researcher used the assessment categories plus other pre-determined and emerging themes as a guide for beginning to develop a profile. With Athena's data set, the researcher looked for themes of how Athena used the results of the concept inventory to adapt her SI sessions to serve student-learning needs. The researcher also looked for patterns of data that fit the themes identified in Professor Liberty's data set. Once Athena's data were coded, the researcher looked for examples of those themes in Professor Liberty's data set. By comparing the two sets with multiple sets of themes and viewpoints, the researcher saturated the themes and was able to develop profiles for both Professor Liberty and Athena. In addition, the descriptive profiles lent themselves to descriptions of the assessment literacy of the Professor and Athena and a comparison of the role of formative assessment in a large lecture course versus a smaller, collaborative learning environment.

Role of Researcher

The researcher was the primary data-gathering instrument in this study. She initiated contact with each of the primary participants and conducted the informed consent procedures with each of them. Additionally, she conducted the interviews with each participant, observed the lectures and SI sessions, and collected the artifacts and documents used in the study. She was also responsible for transcription of interviews, all data analysis, and the writing and reporting of these findings. Because constructivists see their role as to co-constructing data with the participants, the interviews "included more participation, more control of research processes, and more active sharing" (Hatch, 2002, p.110).

Trustworthiness

"How can an inquirer persuade his or her audiences (including self) that the findings of an inquiry are worth paying attention to, worth taking account of?" (Lincoln & Guba, 1985). It is essential to answer this important question when undertaking a research study under a qualitative, naturalistic paradigm. Several researchers (Guba & Lincoln, 2005; Lewis & Ritchie, 2003; Marshall & Rossman, 1989; Patton, 1990) refer to Lincoln and Guba's (1985) four criteria for trustworthy research--credibility, transferability, dependability, and confirmability--when discussing how to make a study trustworthy. Thus, it is important for this study to outline the methods by which these criteria were met. It is of import to note, however, that *the findings of this study are limited by the context of the study*.

First, to enhance credibility, Lincoln and Guba (1985) suggest prolonged engagement with the study participants(s), persistent observation, and data triangulation. The researcher interviewed each primary participant (faculty member and SI Leader) three times and observed her to gain insight into how her perceptions were enacted in the classroom or SI sessions. Additionally, data were collected via multiple methods and in multiple forms to enhance its credibility; that is, the data were triangulated (Lincoln & Guba, 1985; Marshall & Rossman, 1989; Silverman, 2000). These data included transcripts from interviews, field notes and expanded notes from observations, and pertinent information from documents. Finally, as a means of improving credibility, the participants were asked if the data the researcher collected and analyzed portrayed "adequate representations of their own (and multiple) realities" and asked them to react to them (Lincoln & Guba, 1985). That is, the researcher conducted member checks with each participant over the course of the study to ensure that the data were an accurate representation of the perspectives of the participants.

In addition to credibility, Lincoln and Guba (1985) cite transferability as being important to the trustworthiness of a project. Transferability means that the research findings must be transferable to other studies. However, the burden of transferability lies with the person seeking to use the data to make an application elsewhere, not the original investigator. To enhance the transferability of these findings, it was very important to provide as much thick, descriptive information as possible, which required the collection and analysis of much data and was built into this study.

The third and fourth criteria that Lincoln and Guba (1985) cite are dependability and confirmability, or whether or not the data are confirmable by different participants. To enhance both dependability and confirmability, Lincoln and Guba (1985) suggest the use of audit trails. That is, they recommend that an inquiry auditor examine the process and products of the study and attest to its dependability and confirmability. While this study did not formally employ an inquiry auditor, several people were involved during the course of the study in assessing the progress and trustworthiness of the study. These people included the researcher's doctoral advisor and committee members, as well as the participants themselves. While none of the aforementioned people formally served as "auditor," they all performed the functions of an auditor, which should help to make this study more dependable and confirmable.

Ethical Considerations

The confidentiality of the participants has received utmost priority. Participants' names were replaced by pseudonyms in any reports, conference presentations, and published articles. Additionally, the name and identifying information of the University will be disguised for reporting. The audio tapes produced during the interviews were heard and used only by the researcher for data analysis purposes and will not be used for any other purpose. This project does not involve any risks greater than those encountered in everyday life do.

CHAPTER FOUR: RESULTS

The findings of this study are rich descriptions (Patton, 1990) about how an experienced biology professor and an experienced Supplemental Instruction leader responded to their students' results on the Concept Inventory of Natural Selection. The first section describes the views of learning, knowledge of assessment, and knowledge of assessment interpretation and actions that Professor Liberty holds and how those relate to student learning. Professor Liberty's themes are identified with numbers (Themes #1-14). The second section describes the same constructs for Athena, the SI Leader. Athena's themes are identified with letters (Themes A-J). The third section is a comparison of these constructs between Professor Liberty and Athena. The final section examines the ways in which use of the CINS informed the Professor and Athena's efforts to support learning.

Professor Liberty's Views of Learning

The first question investigated was "In what ways do the professor's views of learning, understandings of principles of assessment, and knowledge of assessment interpretation and action taking skills interact? To answer this question, the researcher first identified Professor Liberty's views of learning, knowledge of principles of assessment, and knowledge of assessment interpretation and action-taking skills. Here, these elements and how they interact in relation to Professor Liberty are described.

Professor Liberty's views of learning are multi-faceted and connected closely with the other areas also examined in this study—knowledge of assessment and understandings of assessment interpretation and action. In this section, the four major themes identified through interviews with Professor Liberty and supported by her assignments, lectures, and other supporting materials are discussed. These themes include: 1) her goals for teaching; 2) her perceptions of the role of instructor; 3) her goals for students; and 4) strategies she values for helping students learn.

Theme #1: Goals for Teaching

Professor Liberty set goals and used them at every stage of course design and implementation. For instance, Professor Liberty's second goal for teaching was actually *to set goals*, "to know what outcomes are vital for your course" (see Excerpt 1). She said

> First, you have to know your students. By that, I mean that you have to know what they expect and want from the class, and what they already know coming in to your class. If you don't know your students, you can't expect to reach them, to help them learn. Second, you have to have goals-- to know what outcomes are vital for your course. You must have goals for your course *and use them* to plan your course. Third, and this is along the same lines and just as important, you must tie your course design and assessments back to the goals you set. They should inform your course at every step. If you don't, then there's no point to any of it. You have to know what your students should get out of the course and then build the

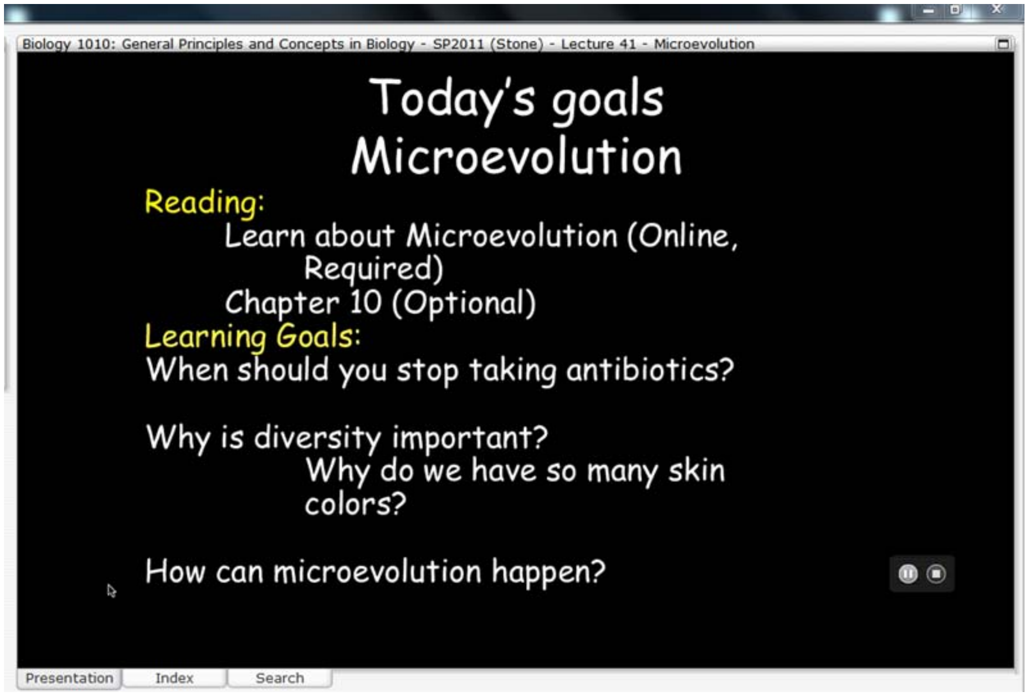
whole course around that. And you have to test your students' learning based on those goals and in ways that align with those goals. **(Excerpt 1)**.

In setting goals, it was important to Professor Liberty to know what her students expect and what knowledge and experiences they bring to class (goal 1). To gain understanding of her students' prior knowledge and experiences, Professor Liberty routinely used pre-tests, including those that she designed. This helped her to "know" her students better—what they know and what they want, so that the course goals matched both her expectations and theirs. She believes that these course goals should inform every step of course design and teaching.

Professor Liberty's third goal for teaching was to tie her "course design and assessments back to the goals [she] set." She looked to the course goals to design lessons, assignments, and assessments because the goals were important for "every step" of course design and implementation.

In developing course goals, Professor Liberty focused on both content and applicability. In terms of content goals, she said, "It's important when designing a course to identify the key concepts around which you'll base your course and focus on those. If you don't know explicitly what you expect your students to learn, then your students can't accomplish those goals." In the non-majors course, Professor Liberty emphasized specific 'learning goals' with the students at the start of each class. For example, on Day One of the Evolution unit, the topic was Microevolution. She began lecture by identifying and discussing specific learning goals with the class. The goals were stated in the form of questions presented on a PowerPoint slide (see Figure 1).

Figure 1. PowerPoint slide from a microevolution lecture displaying intermediate learning goals for students.



Learning goals for each lecture were presented in a similar fashion on a PowerPoint slide at the start of each lecture.

In addition to content-related goals, Professor Liberty also emphasized application- and relevance-based goals. This second type of goal dealt with how students would relate to and use what they learned in class, not just during that semester, but afterwards. Professor Liberty thought of such goals in this way:

> I'm always thinking to myself: "How can biology directly impact students' lives?" What do they really need to know? How are they going to use it? I try to help them think of them as "This will make your life easier goals." I hold that above content goals. Content is important, but usefulness is more important **(Excerpt 2).**

In addition to relating to students' lives, Professor Liberty wanted her students to connect to their lives and leave a lasting impression. She said

> Realistically, I want my students to get something from my class. I want them to find a few things they connect with & take away, so that later in life, they can look back & remember learning it in biology class. I want the things they learn to have some sort of application in their lives. But the truth is, for most, biology won't have as extensive an influence as I'd like it to **(Excerpt 3).**

Examination of Professor Liberty's course objectives further emphasized the mixture of content and application goals set for this non-majors course. The course objectives found in the syllabus included

COURSE OBJECTIVES

- Provide understanding of biological concepts to aid you in becoming a knowledgeable member of society.
- Develop inquiry and critical thinking skills that allow you to assess the validity and importance of scientific findings.
- Educate you on the human condition to provide you with health-related, decision-making skills.
- Help you understand how living things interact with each other and their environment and demonstrate how this interaction drives biological change.
- Develop life skills such as working in groups, following instructions, using online resources and seeking help (see Appendix D).

In thinking about goals as more than just content that needs to be covered and by sharing these sorts of goals with her students, Professor Liberty alluded to her first goal for teaching, which is to know her students and their expectations. Furthermore, she hoped that by teaching more than just biology concepts, her non-majors students would gain something from her class that they would retain and use again.

Theme #2: Role of Instructor

Professor Liberty sees the instructor's role as that of "a guide" and discusses this role using the analogy of an enzyme. She said, "We help our students learn science, help learning take place. We're not the reactants or the products. The reactants are the students and the content [material to be learned]. If one of the reactants—the students—are not ready to learn, then the product, the learning doesn't occur. We're guides but if the reactants aren't ready, the product won't happen. The reaction to create the product is sped up by the catalyst—the enzyme, which is the teacher."

Professor Liberty emphasized the importance of goal setting and implementation in fulfilling her role as an instructor. She asserted the importance of "know[ing] your students," and that among her goals for teaching, this is the first one (see Excerpt 1). While this idea overlaps with the previous theme, it closely relates to how Professor Liberty viewed her primary role. She thought, "It's about always putting the students first and knowing how they're going to use this information you present." In creating course goals, she thought about whether "realistically [her] students would be able to meet [given] learning objectives," and realizes that not all students can master all material. She recognized that "some [students] never get genetics."

Professor Liberty asserted the importance of using this method of course design and implementation for majors' biology courses as well as non-majors courses such as the one observed in this study. In asserting this, she also expanded on her views of how any science course should be prepared:

> I wish the majors' course in biology were designed this way too, that they used the students' learning needs and goals to design the course, rather than rely on tradition. [Interviewer: Tradition?] Yes-all lecture, few opportunities to practice, and no concern for or valuing of the students. It's important when designing a course to identify the key concepts around which you'll base your course and focus on those. If you don't know explicitly what you expect your students to learn, then your students can't accomplish those goals. The design won't allow for it **(Excerpt 4).**

For Professor Liberty, knowing her students was integral to her role as instructor, as well as careful design and implementation of her course. Inherent to this view is an understanding that she must reflect on her teaching and assess progress of her class and students. This will be further explored later, but next, Professor Liberty's views of learning about the goals she has for students in learning science will be further explored.

Theme #3: Goals for Students

Professor Liberty had clear ideas about what her role was in helping students learn biology. She also had expectations about her long-term goals for students in her non-majors biology course. She discussed her expectations in terms of the ideal student versus what she could realistically expect of her non-majors students:

> There is what I would like my students to do--the ideal student--and the *reality*-what I see in my students realistically and hope for. Ideally, I hope that my students would be critical listeners. [Interviewer: Please explain that.] I want my students to be critical of what they hear, to be critical consumers of information [pause], where they can analyze, judge evidence, and arguments and make decisions. I don't want students to take everything they hear or read at face value or superficially. They should explore ideas and apply them. Realistically, I want my students to get something from my class. I want them to find a few things they connect with and take away, so that later in life, they can look back and remember learning it in biology class. I want the things they learn to have some sort of application in their lives. But the truth is, for most, biology won't have as extensive an influence as I'd like it to **(Excerpt 5)**.

In thinking about what she hoped her students would learn in her class, she emphasized a need to learn to think critically and to question information they receive. She wanted her students to use the concepts and skills learned in her course to help them make decisions and to have value beyond the semester during which they took biology with Professor Liberty. Ideally, Professor Liberty's students would become "critical consumers of information," but thinking in realistic terms, she just hoped they would learn a few things that they could "connect with and take away" with them after the semester ended. The goal, whether speaking of the ideal or the realistic, was the same—she wanted the course to affect her students in positive ways that help them, whether by changing the way they think and approach the world (ideally) or by giving them some information that is applicable to their everyday lives (realistically). In this theme, Professor Liberty referred back to goals of making her non-majors biology course applicable and relevant to students' lives.

Theme #4: Strategies Professor Liberty values for Helping Students Learn and Succeed

Professor Liberty is an experienced professor who has developed a repertoire of teaching strategies and approaches for her non-majors biology course. She thinks that in order for students to meet her goals, they must be informed:

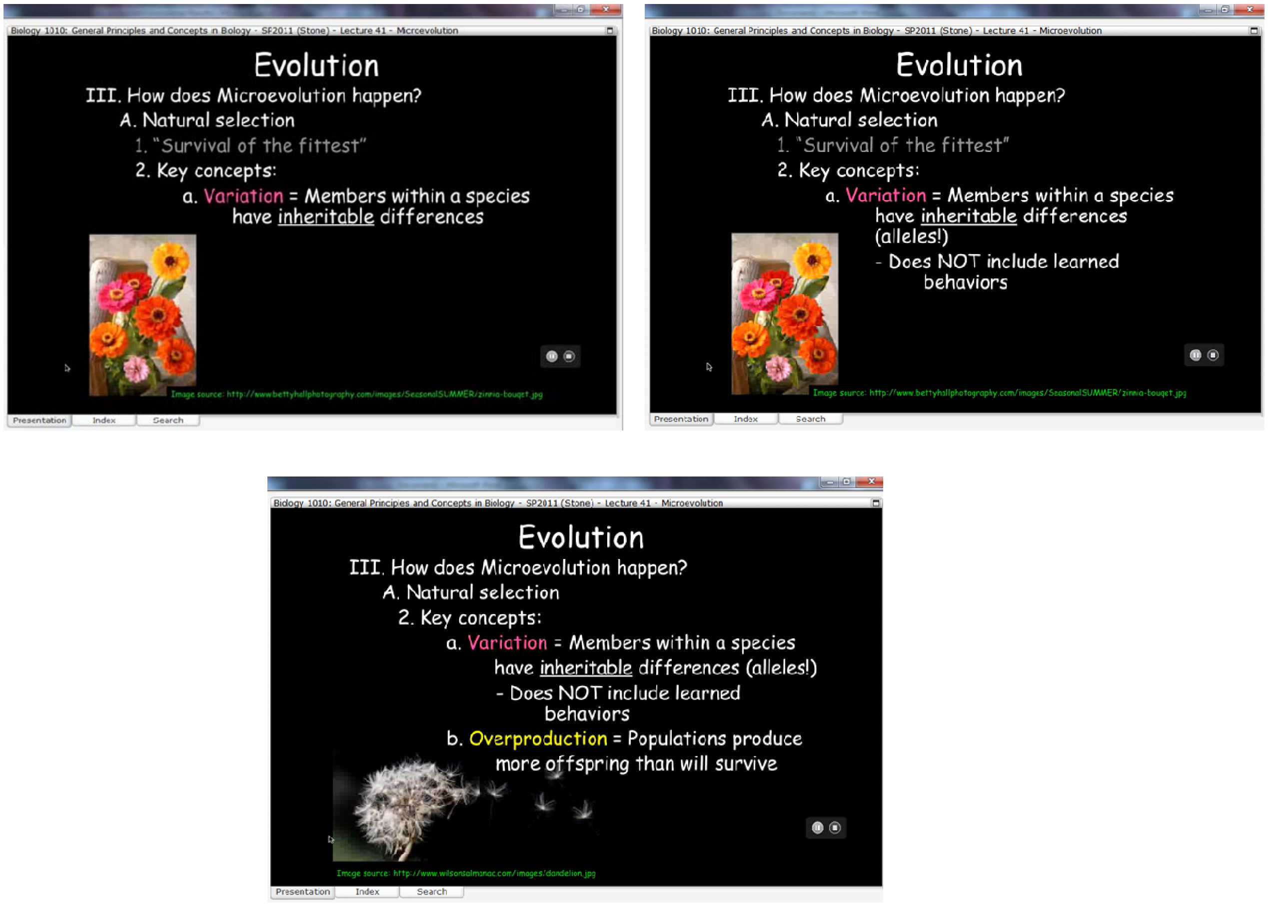
> First, you have to let your students know what the goals are. Hoping students have an attitude of figuring out what I want you to learn is not enough. We should constantly be reviewing goals with the students & updating them as the class progresses **(Excerpt 6).**

In Excerpt 2 from above (which was discussed at the same time as Excerpt 6), Professor Liberty talked about how she tried to relate course goals to their lives, using concepts that will make their lives easier. Telling students what they are expected to know, rather than letting them figure out it for themselves, increased the chances of them learning the proper material and succeeding in the course. Furthermore, as goals were updated, any changes were reviewed with students, so that they knew what they needed to accomplish. An example is shown in Figure 1, which is a PowerPoint slide Professor Liberty used to tell students of the intermediate learning goals they needed to master that day. Such slides were used at the start of each class period.

In addition to setting, discussing, and reviewing content and application goals with students, Professor Liberty focused on identifying key biological concepts and concentrated on those (see Excerpt 4). By spending time on the most important concepts to be mastered, chances of student success improved. Professor Liberty also emphasized the importance of knowing the misconceptions students hold about various biological concepts and on spending time helping students revise their ideas. In reference to CINS question #14, which a large number of students answered incorrectly, she said, "We will go over this because more students chose misconceptions than the correct answers. It's because of the wrong answers [that she will focus on this concept]." In reference to CINS #17, she said, "I target this one [concept] because there are so many questions and misconceptions." Clearly, knowing students' understandings of biological concepts and what to do with them was a priority for Professor Liberty.

To teach about heritable variation, Professor Liberty first introduced the idea of microevolution and explained that it happens via natural selection. She then discussed the concept of natural selection and used the idea of "survival of the fittest" to convey how natural selection works. She asked for five volunteers who like blow pops to choose between two flavors, either cherry or grape. These served as traits for which predators would select and the Professor suggested that predators preferred cherry (two of these) to grape (three pops), so students responded that they would want to be grape to increase chances of survival. This led to an introduction of the concept of fitness, which Professor Liberty explained by asking the class about how many offspring they had. She has two kids, and so she joked that she was pleased to be the fittest person in class, at least in biological terms. This led to a discussion of what variation is, the subject of CINS question #17. She presented the information on three slides that were a continuation of the concepts of microevolution, natural selection, and fitness. Variation was described as "inheritable differences" (Figure 2a) and "does not include learned behaviors" (Figure 2b). She then began talking about overproduction in nature (Figure 2c).

*Figure 2 (a-c).*PowerPoint slides displaying a sequence for lecturing about the basic definition of the concept of natural selection.



Professor Liberty emphasized that the instructor should create the connections among the content and the goals—both content and application-based-- in order to help students learn. For instance, when discussing what good science teaching looks like, she said,

> I try to connect the material & everything else, like assessments, activities, and lectures, to each other. And hopefully it also connects back to their lives, their needs, how this class will be useful to them **(Excerpt 7)**.

She also thought about the importance of creating connections when thinking about teaching specific biological concepts. For instance, when discussing how to help students learn specific parts of natural selection, she said that it is important to "emphasize the connection between genetics and evolution. It gives them a mechanism to help explain it [the concept for some. That connection helps it click. It gives some more examples" (see Table 3).

One of the many ways Professor Liberty created connections was by making ideas as visual as possible. That is, she actively sought out ways of making biological concepts more visual. She used pictures and diagrams on her PowerPoint slides and incorporated videos and animations into her lectures. Professor Liberty also discussed ways in which she might connect concepts to graphs so that they could *see* large changes over time, rather than just read about them. She recognized that many students understand and retain concepts better if they connect them to visual aids. Other examples she used provided examples, scenarios, and connections to things students were familiar with already.

Throughout discussions with Professor Liberty, she described various techniques she uses to help students learn and remember concepts. Table 3 provides a sample of quotes that illustrate how Professor Liberty approached various concepts and the types of approaches they represent.

Table 3. Examples of Strategies used by Professor Liberty to teach various concepts related to natural selection.

Quote (In relation to CINS Concept)	**CINS Concept**	**Strategies based on concept**
CINS 6: It's the same as a scenario about giraffe necks..We look at giraffes & talk about different scenarios.	Origin of variation	Using scenarios as examples for teaching concepts
CINS 4: Emphasize the connections between genetics & evolution…it gives them a mechanism to help explain it for some. That connection helps it click; it gives some more examples, but some never get genetics.	Change in a population	Emphasize connections across topics
CINS 3: I don't do much with population size, so I don't go through different scenarios & say, "With these resources, this will happen."	Population Stability	Use scenarios as examples
CINS 11: If there's time, I show how human population has grown over the last 1000 years. It shows the concept really well...So if I have time, I show the video."	Biotic Potential	Use video as a visual example
CINS 11: [population growth patterns]…something they can visualize. It would've been different if this was shown on a graph. Maybe then, it would help them see that as population size increases in an environment with unlimited resources, it would grow faster…		use visuals to show population growth
CINS 10: fitness as number offspring. "I present this idea as a joke, I ask students who has the most children. Usually I am the most fit. I will occasionally get a non-traditional student that has more kids than me."	Differential Survival	Use a joke to introduce idea
CINS 18: "...cause I usually frame it in reference to people. & fitness is usually equated with strength, speed, intelligence, & longevity. So age is too."	Differential Survival	Frame ideas in reference to people to help students learn
I made a big deal about fitness, so I'm not surprised that more students got this correct. I use the example of me being the fittest person in the class because I have 2 kids, & the fittest individuals have the most offspring. It's concrete & makes sense, so it		Use concrete examples to help concepts make sense

sticks. That helps with these sorts of questions and ideas.		
The # of correct responses actually doubled, which is great. The example I use seems to work, I guess. [Interviewer: What Example?] Of me being the most fit because I have the most kids.		Use concrete examples to help concepts make sense
CINS 16: "I don't discuss the differences between internal & external features. I do give very specific examples of one versus the other, i.e. camo v. non-camo."...I try to make the class visual so I focus on the external." [Population growth patterns]…something they can visualize. It would've been different if this was shown on a graph. Maybe then, it would help them see that as pop size increases in an environment with unlimited resources, it would grow faster…	Variation within a population	Give specific contrasting examples Use "visual" examples to help make concept clearer Use examples that provide good visuals Need to be sure that visuals include examples of every instance of the concept (or it may cause misconceptions)
I briefly mentioned internal differences among individuals in a population but used external differences as examples because it gives good visuals. Clearly, that isn't enough. I can think of internal examples for next time.		
Next time, I'll need to think about what I've done because I need to change it next time. Maybe I can find some internal differences that are concrete or visual enough to make sense & stick. Perhaps making it redundant-find ways to repeat the ideas throughout the natural selection lessons so it sticks. Increasing the use of visual aids would be beneficial to students' learning.		

Views of Learning Summary

Professor Liberty considered it essential to know her students so that the goals she set match their needs and expectations. She relied on those goals to put together the lectures, assignments, and assessments and used them as a tool to help students understand what they must master. Hence, for Professor Liberty, student learning takes place in a course where the instructor

- Has well-defined goals around which to build the course
- Designs course goals based on content and on the applications of the course to students' everyday lives
- Creates goals that match the needs and abilities of the students
- Uses the goals to design the course materials—lectures, assignments, and assessments (not the other way around)
- Designs the course based on the students' needs and expectations, as well as their prior knowledge
- Holds both ideal and realistic expectations of her students' abilities and accomplishments in her course, as well as what they take away from her course
- Explains the course goals to her students and updates them as goals are revised
- Reminds students of intermediate learning goals so that students know what they must master content-wise
- Relies on a variety of strategies to teach biology concepts and tailors those based on content

Professor Liberty's views of learning are complex and multi-layered, and the connections between the "layers" are themselves complex. Her views mirror those of experienced teachers.

The next section describes Professor Liberty's Knowledge of Assessment Principles, which is another construct in the Model of Science Teacher Literacy.

Professor Liberty's Knowledge of Assessment

Magnusson et al.'s (1999) model of PCK includes knowledge and beliefs about assessment in science. This includes a teacher's understanding about what to assess for student learning and how to assess it. The section provides a description of Professor Liberty's knowledge of assessment as described in the examples of how she used assessment in her classroom to support learning. Themes #5-9 provide detailed explanations.

Theme #5: Assessment as a Tool for Understanding Students' Prior Knowledge

Professor Liberty views assessment as a central part of course design. In Excerpt 1, she discussed the importance of assessing what her students know coming into her class, that is, their prior knowledge and misconceptions. Because Professor Liberty is an experienced professor with eleven years of teaching experiences, she was already aware of many of the misconceptions her students have when they start her course. In addition to her knowledge based on previous interactions with students of similar populations, Professor Liberty also commonly conducted pre-tests with her students. The pre-tests used in her course are often ones she had written herself or with others. In talking about how she used pre-tests to support learning, Professor Liberty said that

> If we had gone through the results immediately afterwards, if I said, "Okay, now put down your pencils, turn in your scan sheet. Now let's go through each of these questions. I'm gonna give you the answer. And then we're gonna go through lecture, we're gonna discuss why that's the answer." That might make them think. And that's what I do with a lot of pre-tests. When I'm actually doing pre-tests, it helps to refer back to the pre-test a lot. "Remember this question? That answer. That is actually the correct answer." And I might have, I'll put some information up. I'll share some information with them and discuss something. And then I'll say, "Okay, now here's a question from the pre-test. How would you answer it now?" But I didn't want to do that with this. Because I really didn't want to lecture at all to the instrument. I didn't want them to see those questions multiple times because I think that would have artificially inflated the post-test (**Excerpt 8**).

Professor Liberty had a great deal of practice with using pre- and post-tests. She used them routinely as part of her assessment of students so that she could tailor her course around their needs and abilities. And despite having done pre- and post-tests with her students for years, she said that

> I think it's always nice to put numbers to impressions and I like to learn what my students don't know. It would be really nice, if I were to do this study on my own in my classroom on misconceptions, and having to

> discuss it so I can tease out exactly what students are thinking. I always enjoy doing the pre-test & post-test (**Excerpt 9**).

Her enthusiasm for understanding her students—including what they know coming in to class--so that she can better support their learning experiences is an integral feature of Professor Liberty's knowledge of assessment.

Theme #6: Assessment should align with Course Goals and Design

In Excerpt 1, Professor Liberty discussed the importance of tying the course goals to every other part of course design and she specifically discussed assessments. She asserted the importance of knowing what she wants her students to get out of her course, and therefore, the importance of testing students based *on the course goals* and *in ways that align with those goals*. She gave the following example to describe this idea:

> And you have to test your students' learning based on those goals & in ways that align with those goals. [Interviewer: Can you give me an example?] If you want your students to apply concepts, asking definition questions doesn't make sense. You must ask them to apply the idea (**Excerpt 10**).

She also endeavored to "connect the material and everything else, i.e. assessments, activities, and lectures to each other. And hopefully it also connects back to their lives, their needs, how this class will be useful to them." This was important to her because

> So often, teachers start with the material and use that to write the assessments. They just hope that in there, concrete goals exist and can be

> achieved. I actually try to go in order-understand my students, identify my learning & course goals, & then design the course (**Excerpt 11**).

Thus, for Professor Liberty, the overarching principle was to create connections so that every part of her course, including the assessments, connected to every other part of the course in obvious and meaningful ways.

Theme #7: Using Assessment to Guide Learning

Throughout the interviews, Professor Liberty repeatedly asserted the importance of aligning course goals with other parts of course design. This theme carried over into formative assessment, not just summative assessment. Professor Liberty routinely included thought questions in her lectures to break up the lecture and "get students thinking.” She had actually introduced another form of formative assessment to her class the semester in which this study was carried out. She described it this way:

> I did, the in-class activity was new this semester. That was new because I was adding that because this semester I added a Monday where all of Monday's lecture would be dedicated to reviewing all content for all our discussions. A longer exercise that included some critical thinking exercise (**Excerpt 12**).

Despite the size of the class, Professor Liberty was dedicated to providing opportunities for student learning to occur in the classroom. These Monday exercises were meant to increase student participation and engagement with the material by creating opportunities to discuss ideas and critically consider them. As for the impact that these Monday activities had on student learning, Professor Liberty said

> I think that if they hadn't had these activities, which were a little bit more points & it was on Monday, I would've had lower attendance on Mondays. I think having those activities helped them to get there and do it. And think about biology once more a week [laughs] than they would have. On the whole, I think the activities were helpful and I don't think the evolution one was an exception (**Excerpt 13**).

In addition to in-class thought questions/exercise and critical thinking exercises, Professor Liberty provided learning opportunities outside of class. In addition to traditional homework assignments, she used the online course website (Blackboard) to provide opportunities for practice with the material (and as formative assessment for her to gauge learning). Online assignments included a variety of questions (multiple choice, short answer) which students could answer using notes, textbook, and discussions with other students or the Professor. In the syllabus, the questions are described: "Many of the questions are old exam questions, so they should give you a feel for your understanding of exam material and how I write exam questions." Professor Liberty also required students to participate in and complete a semester-long group project in order to work on two of the course goals discussed earlier. The first goal was to develop skills in working with others. The second was to learn about the scientific process by doing science. She also gave four unit summative exams. Assessments were woven through Professor Liberty's course design, providing a variety of ways for students to show their learning.

Theme #8: How an Assessment Question is written affects how Students Perceive It

Throughout the interviews, when discussing the content of the CINS, Professor Liberty explained the different ways in which the assessment questions themselves can create difficulties for students. Table 4 below provides several examples of questions and the types of difficulties they pose for students, according to Professor Liberty. The complete CINS inventory can be found in Appendix B. For the sake of brevity, quotes that exemplify more than one type of difficulty were used when possible.

Table 4. Examples of Student Difficulties with the Questions found on the Concept Inventory of Natural Selection.

CINS Question Number	**Quote**	**Type of Difficulty**
10	[The question] is a bit misleading because of the wording. So actually, I'm a bit surprised to see the increase in correct responses.	Word choice and phrasing affect outcomes
13	I didn't like this question because of the wording--finger on claw. I still don't know what that means. [laughs]	
14	It's a misleading question in that it says they eat a variety of insects and plants. I can see why so many students chose number 2. They eat a lot of variety, so the word 'likely' leaves a possibility that that isn't true in the students' minds. So 'there's likely to be enough food but there may not always be' is how I'd put it together as a student...I disagree with this question's point. It doesn't accurately reflect a misconception.	

16	1. The question is how to explain "need," how to lessen its use, so students know it's not choice D. And just using different words is not enough. If you change the word "needed" to "had to", for example, this is less accurate too. 2. If the word "mutations" was used [instead of "random genetic changes"], the number of correct responses would've increased.	
17	I have a question about [choice] D--claw versus finger. What do they mean? Claws on their fingers? [pause] We won't use this one. We address this concept in a different question. If we use it, I want to re-phrase it. Is the phrasing what made this question unclear? I saw this with an earlier question too.	
19	I suspect if you'd leave that one [choice 4] higher, it might've gotten some more hits. But they can't all be 4's...it would be interesting to re-order some of these and then give the pre-test again to a different group & see if some that were less become more common...I saw that with two versions of an exam. A really good distracter will be before the right answer in version 1 and after in the other version and I see this. I try to avoid that now because I don't want them to mess up on an exam. I don't want that to make a difference. But it took me a while to realize, "Why is version B getting that question wrong & A did okay on it?"...I re-order within the concept. The concepts still come in the same order. So there's not as much mixing [versus changing answer order within a question]. (**Excerpt 14**)	1. Use of distracters in multiple choice questions affects outcomes 2. Re-ordering answer choices may change outcomes 3. On different versions of same exam, re-order questions by topic rather than changing the order of answer choices
15	So would the other questions have different [#4?] responses if we'd used a word other than mutations? CINS 15: The other difference I'd like to see or try is how students would've responded if you'd added the phrase "based on need" to choices A or B. How would the # of responses for each answer have changed?... For instance, when presented with all of these, do students pick "need" or "mutation"?	Use of technical and scientific terminology affects outcomes
16	<u>Interviewer</u>: Why do you avoid using the word "adapt"?	Words with dual meanings

	Professor Liberty: Why do I? I think it's a non-descriptive word. Again, it's so easy for students to misuse it. It's sort of need-based, so like in everyday life, if you're thinking outside of science. "Oh, I wasn't happy with my environment, so I adapted. Or I wasn't doing well at my job, so I adapted." It's something you can personally do. And in evolution, it's not a personal choice. It's hard enough to explain w/o throwing yet another word that has mixed meaning into it. (**Excerpt 15)**	(everyday and scientific meanings) affect student understanding of question

Theme #9: Creative Ways of using Assessment

Professor Liberty not only has a robust understanding of assessment, but she has also integrated her use of assessment into her course in a variety of creative ways. Quotes such as those from Excerpts 1, 7, 9, 10, and 13 illustrate how Professor Liberty values assessment as an integral part of her course. Excerpt 8 shows how she commonly used pre-tests with her own with her students--as a tool to support student learning. She often used the questions and answer choices to illustrate ideas and provide examples for application of ideas. For the purposes of this study however, Professor Liberty refrained from using the questions from the CINS as teaching examples, since she did not want repeated exposure to inflate artificially the post-test scores.

Professor Liberty generally conducts some sort of educational research in her classroom. These self-assessments are done to help her learn about her teaching. Portions of the transcript from Interview #3 are below:

Professor: In doing exercises like this [this study], I mean, almost every semester I do some sort of research in my classroom. Either I have someone come in or I do it myself.

Interviewer: Why?

Professor: Cause you learn things about your word choice-what you thought was perfectly acceptable or perfectly clear suddenly become, you realize, "Oh, wait, there's a way they'll connect [to incorrect ideas]. [She laughs.] Oh my goodness. And here I've been using it."

Interviewer: Is that why you do the research every semester?

Professor: Sure. Yeah. And I'm always playing with different teaching strategies and so you find that they work or not. And so for all these reasons I do different studies to see 'Does this new strategy work better than the old or should I go back to the old?" (**Excerpt 16**)

From this excerpt, it is clear that Professor Liberty values her students and their ability to learn in her classroom. She wanted to learn more about her teaching and how it affects her students' learning. She sees clear use of language as one part of that, as described in the above excerpt. She spends time creating meaningful learning activities and is interested in their effects.

She takes this class data from each semester's study one step further by using it to show students in the next class how to learn more effectively. She said

One thing I like to do with my research too, is I share it with the next semester's students when I talk about the scientific process, I share these results. And then I explain why I do things the way I do. "These are the results I saw that semester for students that did this and didn’t do this. That's why I'm gonna encourage you to do this." (**Excerpt 17**)

By using actual results from students previously enrolled in her classes, she hoped to help each "current" semester get the most from participating in her biology class. Introducing this data during the lessons on scientific process allowed her to use actual class data to exemplify the scientific process (a content goal) and to teach students how to study more effectively (an application goal).

The next section discusses Professor Liberty’s Knowledge of Assessment Interpretation and Action-taking, which is the third construct from the Model of Science Teacher Assessment Literacy.

Professor Liberty's Knowledge of Assessment Interpretation and Action-taking

Knowledge of assessment interpretation and action-taking skills refers to what Professor Liberty believes about how students would react to assessment tasks and how she interprets and adjusts her teaching in response to those reactions. This section will describe Professor Liberty's interpretations about students' understanding of the CINS, her actions after the CINS pre-test and after the post-test, how she would modify the CINS, and her reflections of her work as an instructor. It includes Themes #10-14.

Theme #10: Professor Liberty's Understandings about what Students Know

As discussed earlier, Professor Liberty prioritized getting to know her students, including their abilities, their prior knowledge, their needs, and their expectations. After looking at the content covered by the CINS and the pre-test results, Professor Liberty wondered about which content from the CINS was most important and whether her students could master all of it. She said

> It's hard. Right now, they all look like important questions. Will I get to them over the next three days? Do I think realistically my students would be able to meet that learning objective? I'll have to figure it out. (**Excerpt 18**)

Professor Liberty's concern came from an understanding of students' content knowledge, their strengths and weaknesses. One common weakness for students was genetics, an area Professor Liberty referred to several times because she teaches evolution by

> Emphasizing the connections between genetics and evolution. It gives them a mechanism to help explain it for some. That connection helps it click; it gives some more examples, but some never get genetics. (**Excerpt 19**)

Professor Liberty identified a variety of student difficulties related to the composition and content of the CINS and assessments in general. Examples of such difficulties include misuse of everyday words such as "need" and "adapt" in a scientific context (see Excerpt 16 above). A list of examples of student difficulties can be found in Table 4 above.

In addition, Professor Liberty focused on other types of difficulties for non-majors biology students when discussing her thoughts about CINS question #18. She identified several possible misconceptions that students may hold about the concept of fitness, such as "who lived longer," size of territory, or fitness being equated with strength, speed, intelligence, and longevity." She also noted that often, students would select whichever choice "looked longer" or answers that referenced greater age or larger territory. She also mentioned that many students often have problems reading tables. She wondered "How many students don't know how to read a table?" because she felt that could affect the collective results for the particular question. (The complete CINS can be found in Appendix B).

Professor Liberty was able to describe a variety of misconceptions related to the questions on the CINS. In addition, she could often "see" what her students would think with the various questions. For instance, with CINS #14, she said

> Maybe we could include it, but it's a misleading question in that it says they eat a variety of insects and plants. I can see why so many students chose #2. They eat a lot of variety, so the word "likely" leaves a possibility that that isn't true in the students' minds. So "there's likely to be enough food but they may not always be" is how I'd put it together as a student, which could be true. It's two sides of the same point. A big of vagueness. (**Excerpt 20**)

The ability to think about how the phrasing of a question will be perceived by students allows Professor Liberty to connect concepts, content such as lecture materials and assignments, and assessments to each other. By doing this, she is able to assess student learning without concerns about whether students understand what the question asks or if they are confused by some aspect not related to the content, such as language issues. This maximizes her ability to help her students meet her course goals.

Theme #11: Understandings about Factors that Influence Student Performance

Professor Liberty prides herself on knowing her students. Hence, when discussing students' success and factors that affect their success, Professor Liberty described several factors that would affect student performance and the overall course GPA for the class included in this study. Please note that the evolution lessons were taught during the last week of the semester. She said

> I think the last week the classes are pretty fried. [Professor Liberty laughs.] And so I can't really judge how helpful anything was. But I would hope that, on the whole, over the entire semester, doing that. Honestly, this is an 8:00 a.m. section. I usually don't teach an 8:00 a.m. section. Every time I have taught an 8:00 a.m. section, my GPA's been horrible because they just don't come to class. And this semester was really no exception. So I think that if they hadn't had these activities, which were a little bit more points and it was on Mondays, I would've had lower attendance on Mondays. (**Excerpt 21**)

Professor Liberty was aware of the fatigue students experience at the end of a semester and of how it influences student performance. In addition, this class met on Mondays, Wednesdays, and Fridays at 8:00 a.m., a time that usually sees poor attendance by undergraduate students. Understanding students' exhaustion and lack of motivation led

Professor Liberty to develop and implement the critical thinking exercises each Monday that were discussed in Theme #7 and Excerpt 13.

When discussing the CINS as a pre-test, Professor Liberty noticed that as the end of the assessment neared, students' answers were "getting a lot more spread out…There's not a number of students that picked a strong majority." She wondered "if it's just because the students have become mentally exhausted by this point." She understood that on long assessment exercises, students' mental fatigue might lead to a decrease in performance as the assessment goes on.

When thinking about students' affective responses to the CINS, Professor Liberty noted that students were not aware of how the CINS related to the evolution unit during the evolution lessons. In fact, students generally were not attentive to pre-tests. She said

> I don't think that they were heavily aware, as we went through the unit. They don't know how much because of the time, so there was at least a week between the pre-test and starting the material. Um, and honestly, it wasn't like, I don't think they were thinking of it really as we were going through the lecture slides and saying, "Oh, now I know the answer to that question." I think that when they take a pre-test they're so baffled by the whole process, um, that they don't give it a lot more thought afterwards.
>
> (**Excerpt 22)**

Also, because a week passed between the time when the CINS was administered and when the evolution lessons started, students were even less aware, partially because

Professor Liberty did not use the pre-test to help teach the major concepts of the unit, unlike her normal use of pre-tests discussed in Theme #5 (and Excerpt 8).

Theme #12: How Professor Liberty would modify the CINS

Because Professor Liberty felt as though she understood how students thought about the questions on the CINS, she had ideas for how to make the assessment clearer and more suited to her course and her students. For instance, in Excerpt 14 Professor Liberty discusses ways in which assessment questions could be made fairer for all students, specifically when multiple versions of an exam are used. This includes keeping the order of answer choices consistent among exam versions, and specifically keeping distracters in the same location relative to the correct answer choice. Professor Liberty also emphasized that rather than re-ordering the answer choices within a question to create multiple exam versions, it is fairer to change the order of questions (but keeping them together by topic). One example of how this consideration is critical is represented when Professor Liberty discussed CINS question #15 (see Table 4). She said, "If we moved choice #4 in front of B, more than 109 students would've picked it."

In further discussing CINS question #15 (see Table 4), Professor Liberty also expressed concern over the use of technical and scientific terminology and the impact that could have on student understanding of the question and how to answer it. For Professor Liberty, concern over word choices and the use of dual meaning words (words with both everyday and scientific meaning) was also an important factor in writing good assessments.

Theme #13: Teachers Learn from Teaching

Professor Liberty believes that teachers are the "enzyme" that helps learning take place for students. In addition, she discussed how teachers "learn from the process" of teaching. She said

> We learn from the process. We learn from trying to guide our students. We learn about how they think, what they understand and don't, how they process the material. It makes us teach differently, change in response to what they need, to improve their learning of biology. (**Excerpt 23**)

Professor Liberty believed in the importance of not just preparing responsive lesson plans and knowing student misconceptions, but also of *reflecting* on her work and *constantly adjusting* it based on what she learned from those reflections. She re-asserted the importance of knowing her students—how they think, what their goals and needs are, and what they know (prior knowledge) and don't know. In addition, she believes that she must *use* that information to adjust her teaching, to change her materials, and to be open to those changes.

That statement also underscores other ideas Professor Liberty discussed, such as doing research on her teaching each semester so that she could better understand how her lessons affect student learning (see Excerpt 16). Her interest goes beyond just conducting classroom research though. In Excerpt 9, she discussed how she liked doing pre-tests and post-tests and using the results to "tease out exactly what students are thinking". It helped her to think about the material and how her students connected with it.

She gave specific examples of her reflections, such as with CINS question #16. After seeing the pre-test results, Professor Liberty was interested in seeing if her lecture and readings--which provided many external (visible trait) examples about variation within a population—would reinforce misconceptions about this topic or if the external examples were enough to help students master the concept. She wanted to use the material she had already planned, rather than change the materials to target the concept in a way different from what she was already doing. She was eager to see the post-test results and disappointed to see that the number of correct responses actually decreased by seven students. She said

> Next time, I'll need to think about what I've done because I need to change it next time. Maybe I can find some internal differences that are concrete or visual enough to make sense and stick. Perhaps making it redundant, find ways to repeat the ideas throughout the natural selection lessons so it sticks. Increasing the use of visual aids would be beneficial to students' learning. (**Excerpt 24**)

This clearly illustrates Professor Liberty's interest in understanding how her efforts affected student learning and how to improve upon her lessons.

Theme #14: How Professor Liberty will use the Results of the CINS

Professor Liberty was excited to participate in this study because of her ever-present desire to improve her class and help her students learn more. While she often relied on pre- and post-tests that she wrote herself, she thought, "it's good to use somebody else's, cause you get to see what other concepts you don't think about regularly." Throughout the interviews, she discussed the results of the CINS pre-test and post-test and what, if anything, she would change for her non-majors biology course. In reflecting on what she learned from the pre-test results and how that affected her teaching of natural selection during the study, she said

> None of the responses on here surprise me a whole lot. I didn't end up changing a whole lot. I changed, I mentioned verbally the internal differences. It hasn't been a huge hang-up for me. I didn't, and I don't know if I've ever mentioned that distinction. I didn't change enough to make a slide about it. I still introduced evolution the same way-antibiotic resistance. I don't think I ended up changing a whole lot. (**Excerpt 25**)

Hence, for this study, Professor Liberty did not modify many of her lessons, lectures, or assignments based on the pre-test results. She felt that her plans were adequate for addressing students' misconceptions identified in the pre-test and for building on the things that they already knew coming into class.

After looking at the post-test results, Professor Liberty was satisfied overall with the way the evolution lessons were taught. She discussed the effects of the weekly critical thinking exercises that she had implemented for that semester (see Excerpts 12 and 13) and how they affected learning and attendance. She also talked about what else she was planning to do with the complete set of pre-test and post-test results to help with planning the evolution lessons for the next class. She said

> Now that I know the results, I might go back through that document and see if there's anything where I can say, "I'll target that." I'll definitely change it to target that--mutations. And see if there's anything else that could've reinforced, like the internal differences, the misconception that went up...In the middle of lecture, you always think, "Okay I need to do that differently." (**Excerpt 26**)

In terms of content, Professor Liberty planned to look at how she taught mutations and re-think the related lectures and activities. She felt that "they still have strong misconceptions…[She] doesn't know if it was targeted correctly." She "didn't want to give up talking about mutations…[she] just need[ed] to figure out how to target this more aggressively." She also intended to revisit her lessons on variations and her use of external (visual) versus internal examples. Overall, though, she did not feel that she had much work to do for next time "because the results were as [she] expected them to be. The content choices and pedagogical choices didn't really change student learning much and nothing got worse."

In fact, if Professor Liberty could add more time to the course, she would not change much in regards to the evolution courses. She might "weave [evolution] through other discussions". But instead of adding more content on evolution, she would actually add lectures on global climate change. If she could add one more class period to evolution specifically, rather than adding more content, she would actually "change a couple of little things. [She would add] five to ten minutes of lecture, but [she] would add a lot more critical thinking exercises" and give them "a lot more problems to work through".

Athena's Views of Learning

This section describes Athena's views of learning. Athena's views of learning indicate formal education in educational theories and an understanding of pedagogical content knowledge, as well as a deep interest in student learning and a practical, active learning approach to teaching. There is some overlap with the other constructs examined in this study—knowledge of assessment and understandings of assessment interpretation and action. In this section, the major findings about Athena's views of learning are identified through interviews with Athena and supported by her SI sessions, activities, and other supporting materials are discussed. There are five themes identified, labeled A-E to differentiate between Athena's and Professor Liberty's views of learning, which are numbered. Athena's themes include: A) her goals for teaching; B) her perceptions of the role of instructor; C) her goals for students; D) strategies she values for helping students learn, and E) students learn from interactions.

Theme A: Goals for Teaching

When thinking about her goals as an SI Leader, and for teaching in general, Athena's ideas varied. For instance, she felt that science teaching should allow for learning to be exploratory rather than a presentation of facts, and that it should focus on the individual learners rather than aimed at a whole group. She said

> I think regardless of what classroom you're working with, like what size, science education should be a more exploratory event. You know, it

> should be focused on the actual learner, as opposed to the class as a whole and just info out there. (**Excerpt A**)

Along the same lines, Athena also sought for her non-majors biology students to be able to apply their scientific knowledge in their everyday lives, and hence saw science teaching as a way to provide students with a foundation of knowledge to take with them. She described these ideas as:

> You want them to be able to use their knowledge that they already have about science and scientific processes to acquire new scientific knowledge that more relates to their day-to-day or whatever career they end up in. So you're just kind of giving them like, a foundation to take with them outside of the classroom. (**Excerpt B**)

For students to be able to use science in their everyday lives, Athena believed that students need guidance and support to help them develop their knowledge. Students need to see how scientists *think* about questions and problems. For instance,

> Especially with helping them to be science thinkers, would be, to provide them with enough, like guidance and modeling, during the class activities, that it can help them formulate their own knowledge, but at the same time doesn't leave them feeling overwhelmed by not knowing how to tackle things. (**Excerpt C**)

One method of helping students build their knowledge was by supporting open discussions where the students were the main actors. In addition, while Athena felt it important to allow students to discuss, ask and answer questions for themselves, and learn from each other, she also thought it important to step in with the correct information at times. For instance, when talking about discussions in her SI sessions, she pointed out that

> You're always there to jump in on, uh, anytime when there's a large misconception that continues through a discussion, if other students start agreeing [laughs] because they typically look to this particular person for answers. So, I mean, I guess there's kind of a point in time where you do offer up, you know, as a kind of expert knowledge, but generally speaking, um, you're kind of there to just get them talking with each other. (**Excerpt D**)

Examples of these ideas were evident during her SI sessions. For example, Athena began one session by asking students to write questions about confusing or unclear material from lecture. She then told them to crumple their papers up and proceed to have a "snowball fight" in order to exchange their questions anonymously. One by one, students unfolded their new papers and read out the question. Athena stepped to the board to write the questions and then waited for students to discuss and answer each of the questions. Unless it was clear that they were headed toward unscientific answers, Athena stood quietly and listened to the conversations about each question. If students "got stuck," Athena would ask questions to help students build on what they knew and move toward scientific understandings. She let students explore ideas and build their knowledge, supporting these processes without direct instruction.

Theme B: Role of Instructor

Athena felt a great deal of pride about her role as an SI Leader. She felt that she served an important purpose in helping students learn biology and was excited about that. She had specific ideas about what her role was and how she could best help students learn. In describing her duties as an SI Leader, she said she acted

> As mostly a facilitator, in order to foster interactions as opposed to, like a typical instructor, where you're there just imparting knowledge & hoping they remember something from it. (**Excerpt E)**

Athena saw her role as that of a facilitator who should promote interactions and discussions among students in SI, as opposed to lecturing from the front of the classroom. In thinking about promoting discussions, she said her role was

> To, you know, encourage a focused discourse instead of just saying, and "Talk about whatever questions you have." You know, providing them a meaningful route or activity in which discussion is structured. (**Excerpt F**)

That is, the discussions she fostered in SI sessions needed to focus on specific concepts and provide a *meaningful* opportunity for student learning to take place, rather than an unstructured 'free-for-all'. Furthermore, as discussed in Excerpt D, she participated in discussions to guide and support the students, but not lead them or lecture to them. She also spoke of her role as of a 'motivator' for students. She said

> I think it's a really fine line, especially when working with unmotivated students. You want to give them enough to help them, to make it accessible to them, but you don't wanna spoon-feed them either. And so,

there's some balance between their, um, try to find, in order to boost their confidence and to give them enough guidance, but yet they're still doing things on their own. (**Excerpt G**)

Specifically, she saw the need to assist unmotivated students, but not to make things too easy. There needed to be balance between boosting students' confidence and providing guidance but ensuring that they are making some effort and actually working.

Theme #C: Goals for Students

Athena's goals for her students were simple statements with laudable intentions. Athena wanted her students to be scientifically literate. Her overarching goal was for her students to be able to learn scientific ideas without an expert present to tell them what to think. She said

> Um, but I think providing students with tools probably through more in-depth assignments, uh, but a means of developing their own scientific knowledge without like, the brain in the room could be the other really big thing because you don't want them to just walk out and be done with science. They're gonna encounter science all throughout life and you want them to be able to be scientifically literate. (**Excerpt H**)

Furthermore, Athena wanted to ensure students had a "foundation" of biological knowledge they could use beyond the course. She was focused on helping her students learn about biology and how to use it (see Excerpt B). Specifically, she hoped that her students would leave the course and SI with the ability to use what they had learned and build on that by continuing to learn new scientific information. The idea of a strong foundation that was constantly built upon by her students appealed to Athena.

Theme D: Strategies Athena Values for helping Students Learn

Athena values the experiences that SI provides for her students. She emphasized the importance of activities and collaboration to learning science and that was evident in her sessions. Athena emphasized that science education "should be more of a physical doing, um, regardless of what setting you're in. Now, the extent to the doing becomes limited whenever you're in larger and larger groups." She felt that SI sessions were more conducive to learning than large lecture halls because their small size allowed for extensive interactions among students.

During the SI sessions, students interacted in a variety of ways. For instance, at the start of one session, students did a "brain dump." Athena instructed the students to "Make a list, sentences, whatever—everything you're thinking about evolution—for one minute." After, she took up all the papers and handed them out so that no one got his or her own paper back. She then said, "Look at the paper in front of you. Make sure there are no problems, nothing incorrect." Then, one by one, the students read the papers they had aloud and amended them as necessary, discussing concepts of microevolution targeted in lecture. Athena promoted discussion by seeking more information and examples of statements students read.

Throughout the SI sessions, students were active participants, talking, sharing, asking and answering questions, and fully engaging in the activities Athena designed. Athena promoted the conversations in a variety of ways, and discussed *why* she did so:

> That's why I think that discussions between them are so important and useful. Because they're the ones doing the learning, not me. I mean, I don't wanna talk about something that I know about that I've been talking about for years. That's not necessarily going to help them, just hearing about it. But being a part of, like an activity or a discussion about a concept. That is where they will learn things. (**Excerpt I**)

That Athena valued student discourse was evident from observations and even from the way she discussed planning lessons. When talking about how different biological concepts could be made more "active," Athena described evolution as being more 'procedural' and difficult to engage students in conversation about. On the other hand, she could see other biological topics, such as climate change, being ideal for the SI environment. She said

> Something that's open-ended like global warming. You know, there are numerous sides to that. Who knows if it's a real thing? And then if it is, you know, what's causing it? How do we change it? That's something you can debate, that you can discuss, that you can have differing opinions on that can all be valid and you can actually have, you know, a meaningful conversation or like mini-project on that because there are, there is not one definitive answer. So I think those types of things really lend themselves

> more to that inquiry, problem-based sorts of things, sorts of instruction.
> (**Excerpt J**)

According to Athena, a major reason for students' misconceptions about natural selection was having a segmented understanding of the major parts of the concept. She discussed the importance of helping students connect ideas to each as the most important goal. She said

> Umm, the most important thing, I would say, is understanding how different main concepts or main topics relate to each other. That they're not like, their own little island. For instance, with evolution, I think a lot of students struggle with evolution because they see it as a separate entity from everything else that we've ever talked about in science, instead of seeing it, as you know, heavily embedded in genetics and inheritance. Then everything makes so much more sense if you look at it from that perspective and realize how inter-related and dependent those two concepts are together. Yeah, this is probably like the biggest thing is connecting the dots.

Athena had also thought about how specific content should be handled with students. For instance, when discussing the various questions from the CINS and the relevant content, Athena referred to "creating connections" frequently. She saw a need for creating connections between conceptual areas such as genetics and evolution to enhance learning for students. She said

> For those still struggling, I think making the connection overt between the genetic side of things and what that actually looks like in the environment would help. (**Excerpt K**)

Also, she suggested that

> They want to focus on the genetics aspect, that these [traits] are controlled by alleles which relates back to genetics discussions. Genetics aren't determined by environment but by parents. If you could get those two ideas connected in their minds, a unit on evolution would go so much more smoothly. (**Excerpt L**)

Athena felt that if students could 'connect' the main principles of inheritance to the process of natural selection, it would aid in their understanding of the processes.

Athena had also spent time thinking about active ways for helping students create these connections. She mentioned that this was an area of focus for both her and Professor Liberty. They had both used concept mapping as a tool for helping student connect concepts. Athena also discussed arranging and 'grouping' concepts with students in SI. For example,

> Um, and as far as making the connections between concepts, I mean, the possibilities of working on that seem almost limitless. We've spent a lot of time on doing that with students, you know, whether it be concept mapping, or um, making like, sorting main concepts and main ideas in groups together, and re-grouping, and other sorts of activities that are pinpointing related concepts and why they're related. (**Excerpt M**)

Athena also described other activities that she used in SI with her students to help create those connections and make them stick. For instance,

> Here's one, one activity that went really well, um, was Odd One Out, which really I would equate it to Sesame Street's One of These Things is not like the Other. Um, and we'd have, like, a short list of words and they would all go together in some way except for one of the words. And sometimes there would be numerous combinations like, oh, all these words are about natural selection and this one is about sexual selection, or, but then having to pinpoint which word didn't belong and then having to describe that, um, as well as saying why the other ones went together. That was an activity that we ended up doing like, for every test unit cause that went really well and they really seemed to get a lot out of it. [Making concepts relate...] Or, are these just words that we have talked about and in this section. (**Excerpt N**)

Even activities like listing topics and sharing those would aid in creating and cements the relationships among concepts. Athena spent a great deal of time in her SI sessions helping students understand and remember those connections.

Theme E: Students Learn from Interactions

Athena strongly adhered to the idea that students learn from interactions they have with others about concepts. Because of her repeated mentions of trying to foster discussions among her students in SI sessions, she was asked if she thought that learning takes place in the talking and interactions. She asserted that learning does take place in the interactions and specifically from the discourse. She added:

> It's definitely more about the discourse happening between students as opposed to the discourse happening between the instructor & students. Umm, it seems like the students understand much better from each other. They're using, you know, like similar language, and the examples that they can pull, the students that have a better grasp on things, the examples that they can give or the analogies that they can give are much more useful to the students than the analogies that the instructor can generally provide. (**Excerpt O**)

Athena asserted that because students share a common language, they could communicate ideas to each other at a similar level. In addition, students may know or create examples and analogies that students relate to more easily and are therefore more useful to them than what an instructor could provide.

In addition, Athena explained why conversations between students were more effective than with the instructor. She explained that the dialog among students was important because

> I mean, the students are the ones doing the learning. They are, [pause] the primary participants in the learning. That's why I think that discussions between them are so important and useful. Because they're the ones doing the learning, not me. I mean, I don't wanna talk about something that I know about that I've been talking about for years. That's not necessarily

> going to help them, just hearing about it. But being a part of, like an activity or a discussion about a concept. That is where they will learn things. (**Excerpt P**)

That is, because the students needed to learn the concepts, *they* needed to do the talking, "the work." Just passively listening was not sufficient to help students learn the material and connect it to other knowledge. Active work/learning such as a discussion or some sort of activity was necessary for students to learn.

Athena's certainty that active participation is necessary for learning was so strong that her ideal science lesson included significant student interactions. She said

> I guess it would, first of all, rely heavily on the students interacting heavily with each other. Um, it totally depends on the content that you're trying to get across. Some things are really, kind of, they lend themselves more to exploratory, even like problems-based scenarios which a lot of times work out very well, um, especially for like a non-majors course, where you have extremely differing backgrounds with science previously, um, and can be experts in different areas for their specific groups. (**Excerpt Q**)

In her ideal lesson, students would interact a great deal, for instance using problems-based learning scenarios. However, the extent of interactions was at least partially dependent on the content or topics.

The next section examines another part of Athena's knowledge in relation the Model of Science Teacher Assessment Literacy—her knowledge of assessment principles.

Athena's Knowledge of Principles of Assessment

Both Professor Liberty and Athena were asked the same interview questions and basic follow-up questions. However, their responses were quite different in some areas, such as knowledge of assessment principles. Athena's discussions about and references to assessment were fewer in number and less connected to the other themes. This could be attributed to assessment not being a central focus of SI as it should be in classrooms. In this section, Athena's understandings about principles of assessment are summarized in themes F – H.

Theme F: Athena's Views of Assessment as a tool to Understand Students' Prior Knowledge

While formative assessment is a common practice in classrooms, it is rare or subtle at best in SI sessions. In Athena's SI sessions, formative assessment could be observed through Athena listening to her students actively discussing material with each other while she 'eavesdropped.' She said

> Because with SI, you have the advantage of having about 20 kids, which it really seems like the possibilities for what you can do with them as far as like, activities and eavesdropping on conversations, I mean, pretty much

> has, you can do whatever. However, whenever you're working with a much larger room, much larger groups of kids, it's a lot harder to keep an eye on things and eavesdrop for those misconceptions as I was talking about earlier. Umm, and just the physical structure of the room makes it hard to do some things.

The smaller classroom size and fewer students allowed Athena to capture her students' understandings without the use of more formal or traditional assessment methods for capturing prior knowledge and specifically misconceptions.

Theme G: Athena's Use of Assessment to Guide Learning

Athena found the results of the CINS pre-test and post-test to be interesting and informative. She wanted to know about the misconceptions her students held about natural selection. For instance, upon learning that many students held misconceptions about CINS #2, she explained that their misunderstandings came from reading the question and choosing an answer based on how humans would respond. She intended to address this with the students in SI. She was surprised by several of the results of the pre-test but was glad to know them so she could work on them with students in SI. For CINS #4, she was emphatic about helping students understand the role of mutations in evolution. To ensure that she identified and helped students to correct misconceptions, Athena commonly asked follow-up questions and for students to clarify their statements.

Theme H: How an Assessment is written affects how Students Perceive It

Athena was interested in the results of the CINS tests and found the results to be interesting and at times, surprising. For her, the CINS questions were straightforward and easy to answer, but she saw that this was not necessarily true for the students. While common misconceptions were often to blame (see the next theme), she was able to see also how and why the way some questions were written would affect their responses. For example, CINS #1 was difficult for students both before and after instruction. Athena said that not understanding a question would affect students' ability to answer it. In this case (CINS #1), students must not have understood limiting factors, specifically

> On choice 4, they're not accounting for an unlimited food supply and there are no predators. They're not taking that into account when answering. They're thinking about that limit. Working on breaking down what is a limiting factor. That's the problem, not understanding what the question is asking. Reword the question, and see if they answer it differently.

Athena further suggested that re-wording the question could potentially have resulted in different answers from the students.

Mutations seemed to be a common difficulty for students, according to Athena's analysis of the CINS results. Athena suggested that mutations were a problem with CINS #4. She asserted that many students chose choice #4 simply because of the presence of the word 'mutations,' which reminded students of alleles that can mutate. Athena perceived that the difficulty with this question was also related to a lack of understanding about mutations. With CINS #6, similar difficulties arising from understanding (or lack of understanding) about mutations was to blame for the high number of incorrect responses.

The next section explores Athena's the third construct from the Model of Assessment Literacy, specifically Athena's knowledge of assessment interpretation and action-taking.

Athena's Knowledge of Assessment Interpretation and Action-taking

Athena had much to say about how students interpreted the questions on the CINS and about how different contexts can affect students' levels of motivation. This section describes those themes and similar to the other sections, connects to the other areas of Athena's views and knowledge sets.

Athena had taken Professor Liberty's course and led SI sessions for the course twice before. She was familiar with and enjoyed the course, both as a student and more recently as the SI Leader for the course. Thus, it is reasonable that Athena's understandings about how students interpreted the questions on the CINS are numerous and compelling. She also had some ideas about how different contexts (the large lecture class versus SI sessions) could affect students' motivation levels. This section includes two themes, lettered I and J.

Theme I: Athena's Understandings about what Students Know

Athena had many ideas about how students view science and what they thought of the CINS. For instance, Athena mentioned a common view of science among non-majors, that “science seems very mystical to some students.” She understood that many students do not feel comfortable with science because they do not understand it, “because they never [had] anyone get these, you know, connections together for them. That light bulb never comes on.” For many non-majors students, this creates distance between them and the sciences. Athena explained that non-majors students need to feel as though courses outside their major field hold relevancy to their lives and future careers. She said

> You know, there has to be some, you know, I guess, intrinsic purpose for them to be doing it and learning it. Otherwise, especially for non-majors, "I'm never gonna use this." You know. It's not important to what they're going to do or seems not important to what they're going to do in their life. (**Excerpt R**)

That is, the motivation for students to learn science is dependent on how relevant they thought the content was to their interests. The next section examines motivations more closely.

Athena had many ideas about why students missed questions on the CINS tests. Her ideas about students’ understandings (and misunderstandings) are presented in Table 5 below.

Table 5. Examples of Misconceptions about Natural Selection Identified by Athena, the SI Leader.

CINS #	Supporting Quote	Type of Difficulty
1	On choice 4, they're not accounting for an unlimited food supply and there are no predators. They're not taking that into account when answering. They're thinking about that limit. Working on breaking down what is a limiting factor. That's the problem, not understanding what the question is asking.	Students do not understand limiting factors and how they affect a population
11	It seems those that answered it would just slowly grow over time are not taking into consideration the mathematical concept behind reproduction in a population with no limiting factors. Part of this misunderstanding may be due to the fact that most of the discussions about population size that occurred both in in-class examples and in SI sessions always had at least one limiting factor.	
2	I'm not surprised about choices #3 and #4. Choice #2 comes back to reading and understanding it from a human perspective. "If there's no more meat, I'll eat veggies." These creatures can't do that. They can't do what humans do.	Students apply human perspectives to non-human events
15	This also connects to some of the issues I discussed earlier about how students tend to view all animals in the same way they perceive human interactions.	
4	Pre-test: The lowest chosen one was the correct answer. It shows one of the biggest misconceptions that students have about Evolution. We need them to link evolution to evidence and genetics. Post-test: I would say that a lot chose choice #4 because the word "mutations" is there and they know that an allele is there and can mutate.	Students do not understand mutations or the link between evolution and genetics
6	They would deal with it; they want to focus on the genetics aspect, that these are controlled by alleles which relates back to genetics discussions. Genetics aren't determined by environment but by parents. If you could get those two ideas connected in their minds, a unit on evolution would go so much more smoothly.	Students do not understand the sources of genetic variation
19	Students just need to focus on the fact that the environment does not actively do anything.	
7	I know why people would say choice #2--survival of the fittest, only passing on characteristics best suited to the environment; it's not grounded in meiosis, mitosis and	Students assume the environment

	genetics. So faults come up in evolution.	determines traits based on how beneficial they are
8	The fact that many chose #3 is not surprising. It reinforces the biggest responses on the above questions that relate to the environment changing the genetic traits of the organism… It's a fundamental misunderstanding. Students aren't applying what they know or they just don't know.	
18	Most students think of fitness in terms of strength or size not in the evolutionary sense.	Students misunderstand what "fit" and "fitness" means. They equate fitness with strength and size.

Theme J: Athena's Understandings about Students' Affective and Motivational Issues

Athena had spent much time thinking about non-majors students and how to design lessons and activities for them. A major concern she had was about how concepts, lessons, and activities would be received by students and how they would affect students' motivation levels. When discussing her ideal lesson (also see Excerpt Q in Theme E), Athena talked about using problems-based learning. She later added that

> I just feel like doing a problems-based, um, it starts to kind of combat that issue of motivation. Cause now you do have a real motivation for trying to figure out what's happening, because you need to answer this overarching problem, and hopefully it's something that is relate-able to students, that they care about answering the why. Cause I feel like that' a really big hurdle, when you get like, you know, past the teacher-pleasing stage in like fifth or sixth grade students. You have to start figuring out, okay, why

> is this important to them? What can I do to make this exciting and motivating to them, as an assignment, not as "if you complete it, you'll get a gold star". You know, especially with college students, that's definitely what flies.

This excerpt relates Athena's general view that to motivate and hold students' interests, the lesson must be relevant to their lives and interests. This was especially true for non-majors college students because extrinsic motivation no longer affected their attitudes toward course work. There needed to be a bigger purpose for completing an assignment or learning the concepts.

Athena also distinguished between the work ethic and motivation of students in the large classroom versus SI sessions. She pointed out that students in smaller groups, such as SI, have higher motivations than do students in larger groups, say

> *Athena*: Um, when you're working with smaller groups, especially in SI, such motivated students, that's really like, the best learning environment, where you have the students that really, really want to do well and really, really want to tackle, you know, specific content. They have extremely high motivation, and are much more willing to engage in seemingly silly things. Um, but whenever they get in larger and larger groups and everyone is there, um, willingly [laughs because her voice indicates sarcasm on the word willingly]. They're there because they missed so many classes already; they really have to be there. Um, you know, you kinda get like the stick in the mud [laughs] problem, which becomes

harder to overcome when you have, you multiply that by, you know, a couple hundred students. They don't all buy into it. Yeah, you have some difficulties there with the ideal, you know, um, discussion-based, activity-based types of classroom.

Interviewer: So do you find that the general rule in SI is that you don't have to worry about the buy-in after the first couple of sessions?

Athena: Yeah, they're pretty much in. They won't, they generally don't come back or don't ever come at all if they don't feel that it's helpful and useful and if they don't participate. They don't come back; it's too awkward for them to keep coming back.

Athena found that students who attend SI are more willing to engage in activities and try different things, even if they seem ‘silly’ at first. In larger classrooms, levels of student motivation varied and it was more difficult to get students to participate in discussions and other activities. In larger classes, for instance, not all students even wanted to be there. SI attendees, on the other hand, chose to attend SI voluntarily with no incentives or penalties. Hence, motivation was not something Athena worried about with her SI students.

The next section compares the constructs taken from the Model of Teacher Assessment Literacy for Professor Liberty and Athena. Specifically, their actions and interpretations are examined in three dimensions: 1) understandings about what students know; 2) how each of them handled student misconceptions; and 3) what they understood about factors that affected student performance. Following these comparisons is a discussion of how the CINS informed Professor Liberty and Athena's work.

A Comparison of Interpretations and Actions of Professor and SI Leader

Professor Liberty and Athena are both experienced educators in their respective realms, the Professor in the large lecture classroom and Athena in Supplemental Instruction. They were both greatly interested in student learning and how to support it. Both were also interested in participating in this study and in learning more about assessment and how they could use it in their teaching. In a comparison of the two, the strong similarities about teaching and learning are just the start. For many of the themes, the Professor and Athena both expressed similar ideas.

Because Athena was a former student of Professor Liberty's and because they worked closely together, it is not a surprise that they shared similar ideas about the teaching and learning of science with non-majors students. Athena explained how they communicated and shared information:

> We mostly had short chats before or after class. [Professor Liberty] would let me know when a particularly difficult topic was coming up or when many students struggled with a certain in-class assignment. I could then spend extra time on these things in SI sessions. If I used an activity in SI that seemed to really help students, I would share it with her and on a few occasions, these activities became part of the in-class assignments she used. Overall, we worked fairly independently but were good at sharing

> the general successes and struggles of our students in order to best help them.

They worked to identify concepts that gave students trouble and to develop strategies to overcome those problems. The Professor and Athena shared successful strategies and occasionally even activities and lessons. Hence, some of the methods that make SI a successful program for enhancing learning were adopted into Professor Liberty's classroom, extending active learning and interactions that Athena greatly valued in SI.

Professor Liberty also discussed the nature of their relationship and communications. She said

> By the time of the study, [Athena] and I had our routine mostly worked out. Even the first time as my SI leader, she was very self sufficient. She would show me worksheets that they had done in SI sessions. I was always impressed because the worksheets she was doing as an SI leader were exactly in the spirit of the class — building understanding, connections and giving opportunities for application. They were designed to get the students to learn the material, and not just memorize concepts.
>
> [Athena] and I chatted before and after class — we would sometimes walk together to and from class and talk as we walked. We would discuss what students struggled with either that lecture or on the most recent assignment. As my grader we also met in my office to discuss common problems students had on the assessments or upcoming material. Most of our e-mail communications were strictly grading related.

> [Athena] is an educator at heart and I think she had an uncanny ability to know what students struggled with and design activities that helped them. I didn't want to give her a lot of guidance because I wanted her to approach the difficult concepts her own way. That way, if my way of explaining something didn't get to the students, maybe hers would. I didn't want to pollute her alternative source of explanation with more of my thinking if my thinking wasn't working for the students.

Professor Liberty placed a great deal of trust in Athena's abilities and ideas. She valued the role that Athena played in her course as an SI Leader and supported her by providing information but not overreaching or directing her too much. She allowed Athena to use her knowledge and skills to develop and enact lessons on her own terms because she saw the value in a student helping other students, just as Athena saw with regard to the conversations that took place in her SI sessions.

What follows is an exploration of how Professor Liberty and Athena's interpretations and actions relate and compare.

Comparing Understandings about what Students Know

In line with her primary teaching goals of knowing her students, setting goals, and tying those goals to course design and assessment, Professor Liberty thought about what goals students could master in a short time when designing lessons. She was highly aware of the general misconceptions students held about biological concepts from years of teaching introductory biology and from where those misconceptions originated (Table 4).

When she learned which specific misconceptions about natural selection that her students held from the CINS, she was thoughtful about how to address these misconceptions and help her students overcome them. She relied on a variety of strategies (Table 3 and Theme #4) that she had developed and honed over years of teaching and reflection. A great deal of experience and extensive reflection were characteristic of Professor Liberty's understandings about her students and how she approached her classes.

Athena was a science education major as an undergraduate and had been the SI Leader for Professor Liberty's non-majors biology course for two semesters before the study. She worked hard to create her SI sessions in a manner consistent with the principles of SI, with special consideration to creating activities grounded in collaborative learning. She prided herself on being able to engage students who attended SI and on their 'buy-in' of SI as an important tool for learning science. Indeed, attendance at SI was voluntary and sign-in sheets from SI sessions showed that many students that had attended SI early in the semester continued to use SI throughout the semester. Athena did not have Professor Liberty's years of experience or the insights that come with that experience, but she had an educational and theoretical foundation of knowledge about how students learn and relied on that to help guide her lesson design for SI sessions.

Both Professor Liberty and Athena contemplated reasons for various student misconceptions about concepts covered by the CINS. While some of their reasons behind student misconceptions were similar, some were actually contradictory. Table 6 compares their reasons for the various misconceptions of natural selection assessed by the CINS.

Table 6. Comparisons of Professor Liberty and Athena's Explanations for Student Misconceptions related to Questions on the Concept Inventory of Natural Selection.

CINS #: Concept Covered	**Professor Liberty's Reasoning**	**Athena's Reasoning**
CINS #1: Change in a Population	A misconception that a population will control itself and will have enough babies to match the available supplies (no understanding of limiting factors)	Students do not understand how limiting factors operate
CINS #2: Natural resources	Some students think that the individuals will adapt and change their eating habits	Students apply human perspectives to non-human events
CINS #4: Change in a population	Students do not understand the role of mutations in evolution	Students do not understand mutations or the link between evolution and genetics
CINS #6: Origin of Variation	Students think organisms change because of a "need" to do so	Students do not understand the sources of genetic variation (mutations)
CINS #7: Heritable variation	The misconception is that learned behaviors are passed on to offspring.	Students assume the environment determines traits based on how beneficial they are
CINS #8: Origin of species	A misconception that organisms change based on need.	Students assume the environment determines traits based on how beneficial they are
CINS #11: Change in a Population	Students have trouble with how time factors in with growth. It is not concrete. The idea that populations grow slowly at first, then increases faster versus steadily over time is not something they can visualize.	Students do not understand how limiting factors operate
CINS #13:	The misconception is that mutations occur to meet needs. They also think that successful behaviors are learned and passed on.	Students do not understand the role of mutations in evolution
CINS #15: Limited survival	A misunderstanding of limited resources	Students apply human perspectives to non-human events

CINS #17: Heritable variation	This deals with misconceptions that are specific to separating nurture and nature. It separates whether traits are inherited based on the genetics of the parents or created or willed because of a need. It also checks for understanding of whether learned behaviors are inherited.	The misunderstanding is that strength can be passed on to the next generation. Students are not connecting the genetics to what that looks like in the environment.
CINS #10 and #18: Differential survival	A misconception is that people who live longer are the fittest. Fitness is also usually equated with territory, strength, speed, intelligence, and longevity, so age is in there too.	Students misunderstand what “fit” and “fitness” mean. They equate fitness with strength and size.
CINS #19: Origin of Variation	A misconception that the environment somehow affects and causes these genetic changes, that the environment plays a role in forming diversity.	Students do not understand the sources of genetic variation (mutations). They think the environment plays a role.
CINS 20: Origin of species	This question examines taking that step from microevolution to macroevolution and how genetic changes can add up when two populations are isolated from each other. Choice #4 gets at that concept of need and a little at all organisms working as a unit with a grand evolutionary goal.	This is based on the misconception that the environment causes genetic changes, not that organisms survive based on how suited they are for the environment. Those that survive can reproduce and pass on their traits.

While many of the conceptual difficulties outlined in Table 6 above are self-evident and the reasoning that Professor Liberty and Athena offered were similar, a few are notable. For CINS #2 and #15, Athena suggested that students apply a “human perspective” to the lizards’ actions and this caused the misconception. For instance, Athena suggested that students “humanize the birds or lizards and think that ‘If I was in that situation, we’d all eat less and share it.’ It’s not like that in the wild. Some misconceptions about food supply and resources scarcity carry over from human views, from our emotions." While this is a realistic and *possible* reason for the misconception, Professor Liberty actually mentioned referring to human characteristics to help frame ideas (see Table 3, CINS #18). When discussing CINS #18 after the pre-test, she was not overly concerned that a large number of students had chosen incorrect responses. She was confident that the number of correct responses would increase following instruction (introduced in Theme #4 and described in the next section). She planned to frame the concept of fitness from a human perspective because it would be easier for students to understand and remember the concept.

For CINS #17, Professor Liberty ascribed student difficulties to not understanding that traits could not be willed because they were needed. Nor could they be passed on to offspring just because they were advantageous. The basis of inheritance was genetic, not need. That is, inheritance of traits occurred based on the genetic make-up of the parents, not which traits were most beneficial in a given environment and chosen to be passed on. While Athena also understood that traits could not be willed nor passed on because they were advantageous, she ascribed student difficulties to thinking that parents could choose to pass certain traits on because they did not have a strong understanding of how the genetics and environment interacted. While Professor Liberty and Athena arrived at similar explanations, Professor Liberty offered greater details and Athena described the problem in a more general manner.

For CINS #20, Professor Liberty attributed student misconceptions to a lack of understanding about how microevolutionary events compound to result in macroevolutionary changes. She pointed out that students could not make the connection that genetic changes add up over time when populations are isolated from each other and eventually result in new species. She had discussed how students had trouble relating the length of time to changes and growth when discussing biotic potential for CINS #11 (see Table 3). She related this difficulty with understanding the role of time in creating new populations. For Athena, this misconception related to environmental pressures inducing genetic changes, similar to the difficulties posed by CINS # 7, #17, and #19. While Athena was capable at dealing with student misconceptions regarding natural selection, her understandings about the sources of those misconceptions varied from those of an experienced biology professor.

For other questions, Professor Liberty and Athena used different language to describe the same reason for students' misconceptions, such as for CINS #1, 4, 13, 18, and 19. Both were able to identify the ways in which students' reasoning lacked a full understanding of the role of mutations in evolution, specifically that variation exists naturally in a population and that mutations are random. They both also identified the misconception that mutations and adaptations could be willed by individuals based on need. While their explanations may have differed slightly from each other or from the authors', there was a clear understanding of the common underlying causes of students misconceptions surrounding natural selection.

Comparison of how They handle Misconceptions

Professor Liberty and Athena both worked to identify students' misconceptions and to correct them. Their methods for acting on misconceptions were markedly different. The differences in approach could be attributed to class size and classroom layout. For Professor Liberty, identifying the misconceptions and knowing their underlying causes was simple. She had many years of teaching and a strong grasp of the material. The challenging part for her was in how to handle those misconceptions with her students. Specifically, how could several hundred students be supported in correcting their misconceptions at once? What approaches could reach the most students effectively *and* quickly? For Athena, mastering the content was a small issue, since she did not have the years of experience to fall back on. Moreover, she did not feel like her examples for conveying ideas were not always the most effective ones (see Excerpt O). She understood the concepts well enough to have a variety of appropriate activities and examples on hand for all SI sessions but sometimes lacked confidence. An example of how each of them approached the concept of biological fitness is discussed next.

For dealing with the content related to CINS #10 and #18, Professor Liberty identified that students struggle with the biological definition of "fitness" prior to instruction. She knew that this misconception was because students equated fitness with territory, strength, speed, intelligence, and longevity, rather than as the individual who produced the greatest number of viable offspring. Theme #4 gives a description of how Professor Liberty explained the concept of fitness. She presented the idea as a joke, with the punch line being that she was the fittest person in class because she had the most offspring. She had used this approach to explain fitness for years because she found that students remembered a joke better than a traditional definition. In fact, the CINS post-test showed that nearly twice as many students chose the correct answer as had on the pre-test; clearly, this joke was effective for helping students remember the biological definition of fitness.

In SI sessions, Athena had more flexibility in how to approach various concepts. To reinforce the concept of biological fitness, Athena employed a formative assessment task followed by discussion. The task is shown in Figure 3. Athena handed a copy of the task to each student and asked him or her to read it and write a response to the question at the bottom. After everyone had finished, Athena took a poll to find out how many students chose each answer listed in the task. Rather than telling the students the correct response, she encouraged them to discuss why they chose who they did and to convince their classmates that they were correct. Over the course of the discussion, students brought up definitions from their class notes and what they remembered Professor Liberty discussing about the concept of fitness. All students eventually concluded that Lance’s response was correct.

Figure 3. Formative assessment task Athena used to elicit student understandings about the concept of 'fitness' (in biological terms).

Because Athena's "class" was smaller, she was able to encourage discussion. Through discussion, students were able to explore the concept and help each other build knowledge in a meaningful way. Students who attended SI were among those who responded correctly on the post-test. Both Professor Liberty and Athena were able to help students overcome misconceptions about the concept of fitness, but their approaches had to be different to accommodate the learning contexts by which they were restricted.

Natural selection is sometimes described as "survival of the fittest." Four friends were arguing about what the phrase "survival of the fittest" means. This is what they said:

Dora: "I think 'fit' means bigger and stronger."

Lance: "I think 'fit' means more apt to reproduce."

Felix: "I think 'fit' means able to run faster."

Hap: "I think 'fit' means more intelligent."

Which person do you most agree with? Explain what you think "survival of the fittest" means.

Comparing Understandings about Factors that Influence Student Performance

When discussing how students perceive things, Professor Liberty and Athena had different points of reference and therefore different foci. Professor Liberty approached this from the viewpoint of goal setting and how it affected content choices and students' abilities. Specifically, she was concerned about what *amount* and *type* of content students could master and therefore, what would be fair to expect of them. In addition, Professor Liberty thought about outside factors that would affect student success, such as the time of day when class was held and the point in the semester that was being discussed. For instance, because she tried to know and understand her students, was aware that 8:00 a.m. classes were not ideal for supporting student learning and participation. She also recognized the effect of fatigue on student performance, such as motivation and participation at the start versus the end of the semester. She further understood that the longer an assessment was the less likely students were able to maintain a high performance. While Professor Liberty was correct to consider all of these factors as important to student success, Athena mentioned none of these factors. Athena's focus was on how to motivate students.

Athena was thoughtful about how lesson design could motivate and engage students and preferred to use activities that would compel student participation and dialogue. Throughout the interviews, Athena maintained the importance of *active* participation and discussion to support and enhance student learning and valued SI because it was designed around collaborative learning. Professor Liberty did not spend as much time much talking about active participation or discussions in the classroom during the interviews, but repeated observations of her classes, as well as examination of the in-class assignments and syllabus, all revealed that Professor Liberty also valued active learning strategies.

Athena was aware of how the large lecture hall could affect student performance and motivation. She spoke at length about how being part of a large group facilitated anonymity and decreased the motivation to participate. She compared that with the SI classroom, composed usually of no more than 20 students and self-selected for those who would actively engage with classmates and activities to learn. She compared the differences that were due to class size and asserted that the smaller environment was ideal for learning because it was easier to promote active learning. Because Athena participated in both the large lectures and in SI, she was able to gain perspective about the differences created by class and room size. For Professor Liberty though, this issue never came up because she was used to teaching large courses and spent her time in that type of learning environment.

Both Professor Liberty and Athena discussed the importance of teaching concepts in a manner that connected to students' lives. They both emphasized that if content was relevant to non-majors students' lives, majors, or interests, then students would be more likely to engage and would be more likely to learn the material. They also emphasized the importance of connecting biology topics to each other, across sub-fields such as genetics and evolution. Both felt that these were important parts of supporting student learning in a non-majors science course.

While both Professor Liberty and Athena were thoughtful of factors that influence student performance, they approached these from different perspectives. Athena, having been a student more recently, was keenly aware of the importance of engaging and motivating students because she realized how difficult that was for students. Professor Liberty, while interested in student motivation, was also aware of assessing and meeting the needs of a large group of students. Her focus was not just on motivation, but also on reducing factors that could negatively influence student learning.

How did Professor Liberty and Athena's Prior Knowledge of Students Misconceptions about Natural Selection inform Instruction?

For both Professor Liberty and Athena, the CINS was not a major source of information for students' misconceptions about natural selection. As Professor Liberty discussed in Excerpt 25, none of the students' results were surprising for her. She had expected the difficulties identified on the pre-test and felt that her lessons were organized to deal with them. From her years of experience with teaching biology and working with undergraduates, Professor Liberty had come across the misconceptions that students hold about natural selection (and biological concepts in general). She also understood the sources of these misconceptions, whether they were based on misinformation, explanations that were overly simplified, or based in misunderstandings about the content. She was also knowledgeable about how the writing of assessment questions could affect student responses (see Table 4).

She acknowledged that while the results of the CINS did not provide her with new knowledge about students' misconceptions about natural selection, the study was useful to her because it showed her that not all of her approaches were as helpful to correcting misconceptions and teaching natural selection as she had thought they were. As she discussed in Excerpt 26 and Theme #14, she planned to re-assess the pre-test and post-test results to look for areas where improvement was needed and to modify her lectures, assignments, and activities in response. For Professor Liberty, this was an exercise in helping her students to reach her goals.

As a secondary science education major, Athena had experience with researching for student misconceptions and how to address them, so she was not overly surprised either. She was aware of the general types of misconceptions students hold about natural selection and had worked to create activities for SI sessions that would support overcoming those difficulties. In addition to knowing how to look for and work with student misconceptions, Athena had resources available to her in the SI office. For example, the SI office contained a small library of biology textbooks, supplies, and information on how to develop activities to help students overcome difficulties. Athena regularly referenced books such as Keeley's *Science Formative Assessment* (2008), Koba and Tweed's *Hard-to-Teach Biology Concepts: A Framework to Deepen Student Understanding* (2009), and Donovan and Bransford's *How Students Learn Science in the Classroom* (2005). The library also included binders full of lessons and activities designed by SI Leaders past and present, and her SI training had included rigorous training in various aspects of student learning of biology. She also had ample time to talk, learn from, and collaborate with her cohort of SI Leaders. All of these resources and opportunities, coupled with Athena's educational background and deep motivation to help students learn, bolstered her work with SI and helped her create a successful learning environment for undergraduate non-majors biology students.

CHAPTER 5: DISCUSSION AND IMPLICATIONS

The study examined how an experienced biology professor and an experienced Supplemental Instruction Leader used their students' results on the Concept Inventory of Natural Selection (CINS) to design and implement lessons for a large lecture, non-majors biology course. This was accomplished by collecting a variety of data, including interviews, observations, document analysis, field notes, and collective student test results. This chapter includes: a) a discussion of the findings relative to the research literature described in chapters 1 and 2; b) implications of this study; c) recommendations for future research; and d) conclusions.

Contributions to the Literature

Although the development of CIs in biology is increasing, the literature on the *use* of CIs by faculty and academic support professionals is sparse. To the author's knowledge, this is the first study of its kind and offers insights into an emerging area of biology education research as well as contributing to the research literature on Supplemental Instruction. Very little research on Supplemental Instruction (SI) outside of effectiveness research exists (Arendale,1994; Arendale, 1993; Blanc, DeBuhr, & Martin, 1983; Congos, 2003; Hensen & Shelley, 2003; Van Lanen & Lockie, 1997). This study looked at how an experienced biology professor and an experienced SI Leader used the collective results of the Concept Inventory of Natural Selection (CINS) to guide course design and implementation. Specifically, their views of learning, knowledge of assessment principles, and knowledge of assessment interpretation and action-taking skills were examined to begin to understand the possible uses of CIs by biology educators in and outside the traditional college classroom. This study was informed by the Science Teacher Assessment Literacy model (Abell & Siegel 2011).

Core Principles of Effective Assessment

Four principles that outline effective assessment practices by teachers underscore the Science Teacher Assessment Literacy model (Abell & Siegel, 2011). These core principles state that: 1) assessment is a process through which teachers can learn; 2) assessment is a process from which students should learn; 3) assessment should help students be metacognitive about their developing knowledge and skills in order to self-regulate their learning; and 4) assessment tasks need to be equitable for all learners (Abell & Siegel, 2011; Siegel & Wissehr, 2011; Siegel, 2007; Shepard, 2000; Magnusson, Krajcik, & Borko, 1999). This section compares Professor Liberty's and Athena's understandings and actions to these core principles.

Assessment as a Process by which Teachers can Learn

Effective assessment requires that teachers reflect on student learning and use assessments to gain an understanding of the efficacy of their practices. Professor Liberty viewed assessment as an opportunity to learn about her classroom practices and how to improve them in order to better support student learning. This principle is reflected in Theme #13, where Professor Liberty's views of reflecting on her work are described. A variety of assessments and assessment types were embedded in her course design, and they occurred throughout the unit's lessons, from start to finish. This allowed Professor Liberty to know what her students thought at the start of the unit, to measure their progress during the teaching of the evolution lessons, and to assess their learning at the end of the unit, thus better supporting students' learning processes. For classroom practice, Professor Liberty's efforts to embed assessments and use them to guide teaching were effective and appropriate.

For SI sessions, use of formative assessment is essential to appropriate support student learning. While Athena spoke little of reflecting on her work, her interest in learning from the assessment of her students was evident. By encouraging discussion, 'eavesdropping' on students in small groups, and providing many formative assessment tasks (i.e. Figure 3), Athena practiced this principle regularly in her SI sessions.

Assessment is a Process from which Students should Learn and be able to Self-Regulate their Learning

Effective assessment practices also enable students to learn from the process of assessment. By regularly assessing students and using those assessments to illustrate concepts and how to master them, Professor Liberty created opportunities in her large lecture course for students to use the diagnostic, formative, and summative assessment tasks to learn and master concepts. Additionally, Professor Liberty outlined "How to Earn an A in General Biology" in her course syllabus and offered additional study tips on her course website. Some of her suggestions for students included strategies for what to do in class, how to study and prepare for exams, and general tips for course success, such as quizzing themselves on materials. By encouraging students to approach her course actively, she was supporting their learning of biological concepts and about their own learning processes.

One of the major components of the SI Model is learning how to study and succeed in college course work. For Athena, this took the form of teaching her students how to organize different types of material and how to make connections between concepts. She used a variety of strategies, such as teaching students how to create concept maps and ways to distill down a large amount of information into small, learnable units. Before exams, the SI student groups would create practice exams to help them assess their own learning. All of these activities were designed to assess current student thinking/understanding and to prepare students for larger, summative class assessments.

Assessment Tasks should be Equitable

The equitability of assessment tasks was not a focus of this study. However, it should be noted that Professor Liberty was cognizant about the importance of appropriate language and terminology use in assessment tasks, as discussed in Theme #8. She took issue with the unnecessary use of scientific jargon that could confuse some groups of students, such as those with English-as-a-Second-Language backgrounds or those with limited exposure to science course work and experiences prior to her course. In discussing the questions on the CINS, she would have preferred to change some of the language, use of terminology, and to make other modifications to make the CI fairer to all of her students.

Because she worked in small groups of students and was aware of how learning was progressing, Athena was able to alter assessment tasks or restate directions for completion of tasks in different ways to accommodate her students' abilities as necessary. While this was not a focus of the interviews, observations of SI sessions revealed multiple instances in which Athena would re-state directions for a task in new and different ways, sometimes several times, to accommodate all of her students. She would also adjust activities and tasks to support learning.

Science Teacher Assessment Literacy

This study is built on Abell and Siegel's model (2011) of Science Teacher Assessment Literacy, which outlines four forms of knowledge necessary for effective assessment. Teachers should have: 1) Knowledge of the purposes of assessment; 2) Knowledge of what to assess; 3) Knowledge of assessment strategies; and 4) Knowledge of assessment interpretation and action-taking. This section describes the correlations between the findings and the Model of Science Teacher Assessment Literacy.

Knowledge of Purposes of Assessment

This knowledge form involves teachers' understandings about the purposes for assessing students. Common purposes for assessment include assessing: to diagnose students' prior knowledge; to assess student's knowledge during instruction; to document learning at the end of a unit; and to help students diagnose their own learning. Purposes of assessment are linked to teachers' views of learning and values about assessment (Abell & Siegel, 2011).

Professor Liberty incorporated a variety of assessments into her course design (see Themes #5-6, 10). For the evolution unit alone, diagnostic, formative, and summative assessments tasks were all observed directly. For the purposes of the study, Professor Liberty agreed to use the CINS as a diagnostic instrument, rather than using an assessment of her own. During the course of the lessons, students completed in-class activities and online homework so that their ongoing learning could be assessed and used as feedback. Professor Liberty also gave an end-of-unit exam to document that students had mastered her learning goals. While she did not formally assign metacognitive assessment tasks, Professor Liberty did provide opportunities for students to assess their learning. For example, she stated the daily learning goals as questions (i.e. Figure 1), which allowed students to assess their knowledge of each learning goal, or be *metacognitive* about their learning. By building a variety of assessment types into her course, Professor Liberty was able to know if her students were learning during the instructional process and to support their learning processes more appropriately. In addition, she was able to determine if she and her students were meeting the learning goals she set for her course.

Because Athena worked in an informal environment, she relied mainly on diagnostic and formative assessment for her work with students. Theme A describes an example of a diagnostic assessment task. Students also regularly participated in formative assessment tasks, as discussed in the results section. Athena learned about areas of potential difficulty for students and about their misconceptions primarily from conversations with Professor Liberty and from looking at the research literature on various topics. Athena did not have to document students' learning gains, so summative assessment was not part of her SI sessions. She did however, help prepare students for the summative assessments given by Professor Liberty via study guides, practice exams, and other activities. Athena also encouraged students to reflect on their learning by periodically asking students to identify their levels of understanding and relate questions and concerns to her so that she could assist them with learning. While the work of SI did not require that all types of assessments be used, Athena appropriately used assessment tasks to assess student understandings and build upon them.

Knowledge of What to Assess

This knowledge form involves knowing what to assess; it is related to curricular goals for the course, as well as what is more important for students to learn (Abell & Siegel, 2011). Professor Liberty was effective at setting goals, using them to design all elements of her course, and assessed her students based on those goals. She set learning/curricular and application-based goals for the course and used those to determine which content to use, how to use it, and how to assess students--both formatively and summatively to test for mastery of those goals. Her adherence to design, implementation, and assessment based on the goals she set was strong and evident throughout the interviews and observations.

Athena relied on the goals Professor Liberty set for the course as a guide for developing activities and plans for her SI sessions. She was aware of Professor Liberty's goals throughout the semester because she sought them out from Professor Liberty, from the syllabus, the daily lectures, and the online study materials the Professor provided. Like the Professor, she would state the goals for each SI session and relate them to the lecture(s) Professor Liberty had given about those topics. Because her goals were the same as Professor Liberty's, there was more opportunity for students to practice materials to attain mastery of those goals.

Knowledge of Assessment Strategies

Knowledge of assessment strategies refers to a teacher's knowledge of strategies for assessing particular concepts (Abell & Siegel, 2011). As previously stated, Professor Liberty relied on a variety of assessment strategies to assess her students formatively, both in class and through homework. She was also of aware of a variety of summative assessment measures, but due to the large size of the class, typically relied on multiple-choice exams that students answered via scantron sheets. She augmented these exams with a page of concept mapping or short answer questions, but alternative testing measures were limited for practical reasons. However, the students did also participate in a semester-long group project, which allowed them to develop their knowledge of the scientific method and show mastery of the relevant concepts.

As previously discussed, Athena was also aware and regularly used a variety of formative assessment tasks in her SI sessions. Because SI sessions did not have a graded component, Athena perceived no need for summative assessment.

Knowledge of Assessment Interpretation and Action-Taking

This knowledge form relates to what teachers believe about how students would respond to assessment tasks and how they modify their instruction in response to this knowledge. For instance, teachers routinely use assessment data to assign grades, but more knowledgeable teachers are able to use assessment data to adjust lessons and student tasks (Abell & Siegel, 2011). This knowledge form in particular was of interest to this study because very little research has been conducted in this area of assessment. The current study is among the few conducted in this area of assessment research.

Professor Liberty's Assessment Interpretation and Action-Taking

Professor Liberty's knowledge in this area took many forms. She understood that assessment data could be used to modify her lectures and lesson plans. Hence, she customarily used a variety of assessments in her course. She used diagnostic and formative assessments to determine whether and how she should tailor her lesson plans during the instructional process. She also taught the students how to think about their own learning processes and how to self-assess by providing intermediate and overarching goals and formative assessment tasks. Finally, Professor Liberty also conducted summative assessments with her students to document mastery of learning goals and to contribute to assigning course grades.

Professor Liberty believed that one of her most important duties as an instructor was to get to know her students. She endeavored to understand their prior knowledge, their learning goals for the course, and their needs and expectations of the course. For instance, she was aware of the effects of fatigue and time on students' test-taking abilities (Theme #11). She understood that factors such as the language used, scientific terminology, and order of answer choices could affect student responses to questions (Theme #8). To avoid this, she worked to remove bias from her assessments and tried to 'level the playing field' for all of her students. Professor Liberty was focused especially on her students' learning needs and abilities. Part of this was assessing for misconceptions and addressing them (i.e. Theme #10 and Comparisons of how Misconceptions are Handled). For example, Professor Liberty learned that even after extensive lessons about genetics and evolution, students still held misconceptions about the role of mutations in natural selection. Thus, she intends to re-think how she will approach the relevant lessons in the future (Theme #14). Without the CI, she would have assumed that her lessons for this topic were effective for creating the connections between genetics and evolution that enabled students to master her learning goals.

In addition to focusing on her students, Professor Liberty also routinely reflected on her teaching (Theme #13). That is, she took time after teaching a lesson to think about which parts were effective and which needed revision. She took time to do studies in her class each semester, so that she could learn more about her teaching and how it affected student learning. She also developed her own pre-assessments for various biological concepts.

Collectively, Professor Liberty's interpretations and actions aligned with the expectations of an instructor who is knowledgeable about assessment and knows how to use it effectively. Notably, Professor Liberty's educational background is all in biology, not education, although she has taken part in professional development opportunities meant to help her improve her classroom instructional practices. Hence, her years of experience in the classroom play a significant role in how she designs and teaches her course.

This finding aligns with the results of McMillan's study (2003), which examined the role of teacher beliefs and values in assessment decision making. In examining more than 1000 coded responses from 27 teachers, he found that decision-making about assessment and grading was "highly individualized" (p. 38) and did not seem to be based on common principles of assessment. Furthermore, his data showed that teachers' decisions about assessment were mostly based on on-the-job experience. In the current study, while the Professor lacked the formal background in educational theories and practice, she acquired practical knowledge and experiences while working and utilized those to make decisions about lesson design and implementation. This is significant because it suggests that through practice (here, teaching practice), reflecting on her teaching, understanding her students, and applying her knowledge, Professor Liberty has gained a deep understanding of assessment. It is important to consider how such knowledge development occurs and can be properly nurtured.

Athena's Assessment Interpretation and Action-Taking

Observation and understanding of Athena's knowledge of assessment interpretation and action-taking were more difficult to ascertain than Professor Liberty's were. Because Athena was responsible for academic support sessions connected to the course being studied, her responsibilities were not the same as that of a traditional instructor. Her duties involved facilitating learning for smaller groups of students in an informal but highly collaborative environment (Theme B). There was no formal grading, no summative assessment, and no on-the-record accountability necessary. For Athena, this level of freedom with the course stimulated her creativity and prompted her to recall and use her undergraduate education in teaching and her training with SI to create dynamic and effective activities for her SI sessions. She felt supported in her work by her colleagues and by Professor Liberty and therefore was comfortable with trying new things and pushing students' ideas of what is normal in science learning (see Comparing Understandings about Factors that Influence Students' Performance). Her sessions were well-attended by groups of students loyal to the SI model; they saw improvements in their learning and so were willing to try whatever Athena suggested.

Athena relied on a wide range of human, textual, and electronic resources, but she also worked to understand her students' knowledge and what they needed from her (Theme I). This was evident in her SI sessions and from watching her interactions with students in SI and in the course lectures. She was able to speculate about the sources of student difficulties (Theme I) and to understand where and why students would struggle. She also had a strong understanding of non-cognitive factors that affected the performance of students enrolled in the course, such as motivation (Theme J). By concentrating on her students' needs and abilities and using available resources, Athena created a supportive learning environment for her students, one where they were motivated to learn and strive for success.

Concept Inventories

In recent years, many concept inventories have been developed for use in undergraduate biology education. These concept inventories are supposed to aid faculty with diagnosing student understandings of scientific concepts *prior* to instruction (D'Avanzo, 2008; Garvin-Doxas et al., 2007; Klymkowsky et al., 2003). While all of these concept inventories have been developed, meticulously researched, and soundly validated, they have not been studied in the context of the biology classroom at any grade level. Similarly, no one has examined whether such concept inventories would have teaching and learning applications in academic arenas outside the classroom. To the author's knowledge, this is the first study to examine either of the aforementioned contexts and therefore contributes to the body of literature for both areas—concept inventories and Supplemental Instruction. This section explores how the results of this study contribute to the literature on biology concept inventories.

One of the major goals of the developers of various concept inventories is to provide faculty with tools to diagnose their students' understandings prior to instruction. By understanding their students' thinking, faculty should be able to use this information to prepare lessons targeted at maximizing learning opportunities. While this seems like a logical proposition, this study showed that in the hands of an experienced professor, a concept inventory is not always necessary for diagnosing student understandings. In fact, Professor Liberty primarily used the results of the CINS pre-test to confirm the misconceptions she was already expecting. Hence, after reviewing the results of the pre-test, she did not need to make any major changes to her planned lectures, activities, and lessons. For the most part, her plans were ready to tackle the misconceptions identified by the CINS. It is important to note, however, that Professor Liberty did plan to return to the collective results of both the pre-test and post-test after the semester ended and take a closer look at the results. This was important to her because she valued student learning and wanted to maximize every opportunity to help students learn and succeed in her course.

The expectation was that Athena, the SI Leader, would find the results of the CINS pre-test to be valuable in learning about students' misconceptions prior to instruction. However, similar to Professor Liberty, Athena was prepared for the common misconceptions students held in regards to evolution and specifically natural selection. While Athena did not have as many years of experience as did Professor Liberty, she did have Professor Liberty as a primary resource, as well as a variety of books, online resources, and research literature on student misconceptions at her fingertips. Hence, she mostly was not surprised by the results of the CINS. Like Professor Liberty, she was also often able to identify the sources of various student misconceptions. Hence, for an experienced SI Leader, the use of a CI as a pre-assessment was not as useful a tool as was predicted.

For both Professor Liberty and Athena, a pre-assessment tool was not necessary in order to understand their students' prior knowledge about natural selection. Professor Liberty had a great deal of knowledge about her students' prior knowledge and about methods by which to elicit conceptual change. Her interest in her students, in biology learning, and in improving student learning all contributed to these advanced understandings and to her appropriate and well-prepared responses to student misconceptions. For a professor who did not have Professor Liberty's knowledge, background, experiences, or interests, the CINS as a pre-assessment could be a useful tool in diagnosing students' prior knowledge about natural selection. This could be examined in future studies.

Similar to Professor Liberty, Athena was aware of common student misconceptions about natural selection and of how to deal with those misconceptions. This could be attributed to Athena's preparation for science teaching as an undergraduate, from her training as an SI Leader, from her previous experiences as an SI Leader, and from her interest and dedication to students and to creating high-quality SI sessions. An SI Leader who did not have Athena's educational background, preparation, experiences, or interests may not have been able to identify common student misconceptions about natural selection or how to help students overcome them.

The choice of participants informed the data that was collected and consequently, the conclusions of this study. If participants with different backgrounds, experiences and interests had been chosen for participation, the resulting data would be different, and therefore, the results and conclusions. These results are specific to Professor Liberty and to Athena and may also be appropriate descriptions for biology professors and SI Leaders with backgrounds, experiences, and interests similar to theirs. The significance of this study lies not in generalizing the findings to all biology professors and SI Leaders, but in understanding the actions of this type of educator and perhaps learning from their work.

Potential Uses for Concept Inventories

For the purposes of this study, Professor Liberty used the questions from the CINS *only as* a pre-assessment diagnostic tool and as part of a post-test/summative assessment. She did not use the questions during instruction because she did not want to inflate artificially the post-test scores. However, normally, whenever Professor Liberty used a pre-assessment as a diagnostic tool, she referred back to those questions later (see Excerpt 8 in Theme #5 of Results). She would return regularly to pre-assessment questions during instruction to help students think about important concepts and where their understandings were in relation to the scientific view. That is, by asking students to self-evaluate their knowledge during instruction, she was helping them to be metacognitive about their learning. By doing this, Professor Liberty was helping students to evaluate the status of their knowledge in relation to the scientific views, which is cited as an effective method for helping students overcome misconceptions (Hewson, Beeth, & Thorley, 1998).

Similarly, Athena also did not refer back to the CINS during this study. She did, however, use different formative assessment tasks to engage students in evaluating their own ideas in relation to the scientific understandings (i.e. Figure 3). By supporting students in performing self-checks for understanding, she was fostering development of their metacognitive skills.

Supplemental Instruction

Supplemental Instruction is a peer-based academic support and enhancement program designed to help *all* students in a course succeed. The success students attain is based upon collaborative learning principles among participants in sessions designed and run by undergraduates (Arendale, 1994; Arendale, 1993; Blanc, DeBuhr, & Martin, 1983; Congos, 2003; Hensen & Shelley, 2003; Van Lanen & Lockie, 1997). As stated earlier, it is well-documented that SI contributes to higher achievement and increased retention rates for courses traditionally considered “high-risk” (Arendale, 1994; Congos, 2003). While many studies have examined the effectiveness of SI in improving student achievement and increasing retention rates (Blanc et al., 1983; Collins, 1982; Congos, Langsam, & Schoeps, 1997; Congos & Schoeps, 1993; Hodges & White, 2001; Ogden et al., 2003; Shaya, Petty, & Petty, 1993; Zaritsky & Toce, 2006), few studies have examined the relationship of SI with the courses to which they are attached. Furthermore, there is limited research available on the actions of SI Leaders or the interactions among students and with SI Leader during SI sessions (Jacobs et al., 2008; Grier, 2004). Similarly, no research has examined the details of the relationship between the SI Leader and course professor. Finally, no research has examined how a diagnostic assessment tool could be used in SI or other academic support programs. This study brings together all of these areas that have been largely overlooked by Supplemental Instruction research, presumably because of the difficulty of doing so.

Findings of this study suggest that an experienced SI Leader may not necessarily need a diagnostic assessment tool to understand her students' prior knowledge and misconceptions. In this study, the SI Leader was able to identify many potential misconceptions and their probable sources after reading through the CINS. She was aware of these misconceptions *before* she even "took" the CINS pre-test because of her regular communication with the course professor, her own learning about student misconceptions, and her experiences from previously taking the course, from interacting with students in the lecture hall and during SI sessions. This SI Leader was able to design and implement activities in SI based on what she already knew about student understandings and was successful in helping students re-construct some of their ideas about evolution. For her, the pre-assessment results were not crucial to success. Perhaps a less experienced SI Leader would have found the results to be surprising and useful in planning SI sessions.

The significance of these results lies in the recognition that similar to experienced professors, experienced SI Leaders may not require as much support in uncovering student misconceptions as less experienced SI Leaders might. This can be attributed to knowledge gained from practical experience, effective training in SI and related learning theories and strategies, and judiciously drawing upon the resources available to the SI Leader. It is worthwhile to think about how to enhance the ability of SI Leaders to uncover and understand misconceptions, as well as how to manage them.

These findings also shed light on the importance of the relationship between the SI Leader and the course professor. The SI Leader and the Professor in this study communicated often about topics related to the course and students (see Comparisons of Interpretations and Actions of Professor and SI Leader). While most conversations lasted only minutes (preceding or following class), they were meaningful enough to give the both the SI Leader and the course professor important information about student understandings, difficulties, and associated strategies that she could implement. This finding underscores the importance of communication between the SI Leader and course professor.

Implications for the Model of Science Teacher Assessment Literacy

These findings suggest that teachers do not always use theories and tools about teaching and learning to guide their decision making. Their decision-making is often guided by practical knowledge gained from experience and affects not only their lesson design and implementation practices but also their assessment practices. Hence, it is important to consider their decision-making processes and how those affect their assessment decisions. Theoretically, this could take the form of an additional layer to the Model of Science Teacher Assessment Literacy that accounts for decision-making skills consistent with effective assessment practices. In practical terms, this finding suggests the need for providing teachers with guidance on how to make thoughtful and measured decisions in regards to assessment.

These results also suggest a need for faculty to examine the effects of their practices using research-based assessments and to use those findings to re-structure their courses because misconceptions still exist after instruction. In addition, the results suggest that use of a variety of assessment approaches, both formative and summative, allow for multiple opportunities for students to practice working with concepts. In addition, use of multiple methods of assessment is feasible even in large lecture science courses. Biology educators need opportunities to learn about and practice these strategies in a variety of classroom settings.

Implications for Concept Inventories in Practice

The results of this study indicated that experienced professors and SI Leaders are able to analyze and interpret the collective results of concept inventories to aid them in modifying their instructional plans. However, this is the first study to examine what *anyone* does with the data gathered from biology concept inventories. The question of how less experienced faculty members and SI Leaders would use such assessment data has not been answered. It seems reasonable to assume though, that professional development may be of value to all educators interested in increasing their knowledge of assessment practices. Professional development could support faculty and SI Leaders in implementing and interpreting CIs (and other pre-tests), formative assessment, and course-re-design that is responsive to student needs and abilities.

Implications for Supplemental Instruction in Practice

The findings of this study highlight a way to help Supplemental Instruction Leaders acquire knowledge about the common misconceptions their students may hold. For SI Leaders who do not already know of these, as Athena did, such information could be vital for helping them to create SI sessions that support students' conceptual change processes (Hewson et al., 1998). Hence, if a course professor does not employ diagnostic assessment practices, it would be useful to train SI Leaders in methods for uncovering student misconceptions via a variety of assessment tasks. SI Leaders should also be informed of ways that they could support their students in overcoming misconceptions.

Future Directions for Research

Several findings were identified in this study. While significant on their own, they highlight the need for more research in some areas targeted by this study, including how educators interpret and act on assessment data, how they use concept inventories, and about Supplemental Instruction. This section describes potential avenues for future studies in related areas.

On Teacher Assessment Literacy

This case study identified the interpretations and actions of a professor and an SI Leader in relation to how they use pre-assessment data to design and implement their course. More studies of this kind are needed. There is a need to understand better how teachers make decisions about assessment practices and act on them. More research is needed to examine how other instructors and academic support specialists would interpret and act on assessment data since this is a new area of assessment research that has received little attention. Additional research could look at different contexts, such as with different class sizes or academic level (freshmen versus senior), or professors and/or SI Leaders who are less experienced. The data collection could include interviews with students to gain understanding of how their instructors' interpretations and actions influenced their learning. Finally, examining the interpretations and actions of faculty at different types of higher education institutions or different sized classes may give different insights into assessment practices.

On Concept Inventories in Biology

The findings of this study are the first of its kind in biology concept inventories research. No one has previously examined how faculty members or other educators use assessment data from concept inventories in practice. Hence, a variety of studies are needed. It is important to understand how educators at different levels of experience and knowledge about assessment practices use assessment data. Furthermore, it is of interest to extend the parameters of this study to other content areas of biology such as genetics, cell biology, or molecular biology. Other studies could examine how professors choose which pieces of assessment data to rely on and how they use it to change their instruction.

On Supplemental Instruction

Supplemental Instruction has been a part of the higher education landscape for 30+ years. A significant amount of research has been conducted on its effectiveness, but the findings of this study are among only a few that look at other aspects of the SI model. The SI Leader in this study knew common misconceptions, but it is unknown whether this is common among all SI Leaders across academic disciplines. It is also unknown how SI Leaders acquire such knowledge across disciplines and at different levels of experiences. Also, the SI Leader in this study suggested that the learning that takes place in SI sessions occurs in the interactions among students. Hence, there is a need to understand better those interactions, which of their characteristics enhance learning and how. Furthermore, the communications and relationships between SI Leaders and the course faculty need to be better understood so that SI Leaders can be supported more appropriately in the development of necessary skills.

Conclusions

At a time when assessment research is gaining momentum, Abell and Siegel (2011) saw a need to divert from the current lines of research and to "examine how science teachers interpret assessment information and make instructional decisions." This study is a first attempt at examining these practices. It is also a novel study because it is the first of its kind with respect to concept inventories in undergraduate biology education. That is, while biology concept inventories are being created with a sense of urgency, no one has examined what faculty and other educators actually *do* with those concept inventories. This study is useful as an example of what experienced instructors and SI Leaders do with assessment data gathered from concept inventories, and how they instruct, even if the professionals in this study did not adjust their instruction very much. Finally, in the area of Supplemental Instruction, this study is one of a few (Congos, Langsam, & Schoeps, 1997; Congos & Schoeps, 1993; Hodges & White, 2001; Ogden et al., 2003) that examines factors not related to efficacy or achievement of the SI Model. It examines the practices of an SI Leader as she adjusts her practices in response to student needs. Close examination of SI Leader practices could enhance training and professional development of SI Leaders and even instructors.

This research examined the interpretations and actions of an experienced biology professor and an experienced SI Leader to learn how they used their students' collective results on the Concept Inventory of Natural Selection. The findings suggest that because faculty and SI Leaders have different amounts of experience with assessment, their responses to assessment data will vary, but not necessarily based on common principles of assessment. Rather, these educators may rely more on their previous experiences and reflections of those experiences to guide their decision making about assessment. Hence, there a need to examine teachers' decision-making processes in regards to assessment and how that affects their interpretations and actions. Further results propose that professors' and/or SI Leaders' level of experience with the subject matter and course may play a role in how they use diagnostic instruments such as concept inventories. By expanding the research base in these areas, significant gains in student learning and in teaching strategies may be attained.

REFERENCES

Abell, S.K., & Siegel, M.A. (2011). Assessment literacy: What science teachers need to know and be able to do. In Corrigan, D., Dillon, J. & Gunstone, R. (Eds.). *Recognizing and Judging Quality Science Teaching.*

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy: Project 2061.* New York: Oxford University Press.

American Federation of Teachers, National Education Association, and National Council on Measurement in Education. (1990). Standards for teacher competence in the educational assessment of students. *Educational Measurement Issues and Practice, 9*(4), 30-32.

Anderson, D.L., Fisher, K.M., & Norman, G.J. (2002). Development and evaluation of the Conceptual Inventory of Natural Selection. *Journal of Research in Science Teaching, 39* (10), 952-978.

Arendale, D. (2003). *Overview of Supplemental Instruction*. Unpublished manuscript.

Arendale, D. (1994). Understanding the Supplemental Instruction model. In D. Arendale & D. C. Martin (Eds.), *Supplemental Instruction: Increasing student achievement and retention*. (pp. 11-21). New Directions in Teaching and Learning, No. 60. San Francisco: Jossey-Bass.

Banta, T.W., Lund, J.P., Black, K.E., & Oblander, F.W. (1996). *Assessment in practice: Putting principles to work on college campuses*. San Francisco: Jossey Bass.

Blanc, R.A., DeBuhr, L., & Martin, D.C. (1983). Breaking the attrition cycle: The effects of Supplemental Instruction on undergraduate performance and attrition. *Journal of Higher Education, 54*(1), 80-89.

Bogdan, R.C., & Biklen, S.K. (2003). *Qualitative research for education: An introduction to theories and methods.* Boston: Pearson Education Group.

Boyer, E.L. (1990). *Scholarship reconsidered: Priorities of the professoriate*. New York, NY: The Carnegie Foundation for the Advancement of Teaching.

Bruffee, KA (1993). *Collaborative learning: higher education, interdependence, and the authority of knowledge.* Baltimore, MD: John Hopkins University Press.

Burmeister, S.L. (1994). Supplemental Instruction sessions in college algebra and calculus. *New Directions for Teaching and Learning*, 60, 53-61.

Charmaz, K. (2005). Grounded theory in the 21st century: Applications for advancing social justice studies. In N.K. Denzin & Y.S. Lincoln (Eds.), *Handbook of qualitative research* (3rd ed.), (pp. 507-535). Thousand Oaks, CA: Sage Publications, Inc.

Collins, W. (1982). Some correlates of achievement among students in a Supplemental Instruction program. *Journal of Learning Skills, 2*(1), 19-28.

Congos, D.H. (2003). Is SI helpful? *Research and Teaching in Developmental Education, 19*(2), 79-90.

Congos, D.H., Langsam, D.M., & Schoeps, N. (1997). Supplemental Instruction: A successful approach to learning how to learn college introductory biology. *The Journal of Teaching and Learning, 2*(1), 2-17.

Congos, D.H., & Schoeps, N. (1993). Does supplemental instruction really work and what is it anyway? *Studies in Higher Education, 18*(2), 165-176.

D'Avanzo, C. (2008). Biology concept inventories: Overview, status, and next steps. *Bioscience, 58* (11), 1079-1085).

Denzin, N. K., & Lincoln, Y. S. (Eds.). (2000). *Handbook of qualitative research* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Donovan, S.M., & Bransford, J. D. (Eds.). (2005). *How students learn: Science in the classroom*. Washington: National Academy Press.

Elrod S. 2008. Genetics concept inventory (GenCI) development. Paper presented at Conceptual Assessment in Biology Conference II; Asilomar, California. *http://bioliteracy.net/CABS.html*

Gaddis, B.A. (1994). The science learning center. *Education, 115*(2), 195-201.

Garvin-Doxas, K., Klymkowsky, M.W., & Elrod, S. (2007). Building, using, and maximizing the impact of concept inventories in the biological sciences: Report on a National Science Foundation-sponsored conference on the construction of concept inventories in the biological sciences. *Life Science Education, 6*, 277-282.

Grier, T. (2004). Supplemental Instruction and non-cognitive factors: Self-efficacy, outcome expectations, and effort regulation. *The Learning Assistance Review, 9*(2), 17-28.

Grossman, T. (2004). Supplemental Instruction and non-cognitive factors: Self-efficacy, outcome expectations, and effect regulation. *The Learning Assistance Review, 9*(2), 17-28.

Hatch, J.A. (2002). *Doing qualitative research in education settings*. Albany, NY: State University of New York Press.

Hensen, K.A., &Shelley, M.C., II. (2003). Impact of Supplemental Instruction: Results from a large, public, Midwestern university. *Journal of College Student Development, 44*(2), 250-249.

Hestenes, D., Wells, M., & Swackhammer, G. (1992). Force concept inventory. Physics Teacher, *30*, 141–158.

Hewson, P.W., Beeth, M.E., & Thorley, N.R. (1998). Teaching for conceptual change. In B.J. Fraser and K.G. Tobin (Eds.), *International Handbook of Science Education*, (pp.199-218). Great Britain: Kluwer Academic Press.

Hodges, R., & White, W.G. (2001). Encouraging high-risk student participation in tutoring and Supplemental Instruction. *Journal of Developmental Education, 24*(3), 2-10.

Jacobs, G., Hurley, M., & Unite, C. (2008). How learning theory creates a foundation for SI Leader training. *Australasian Journal of Peer Learning, 1*, 6-12.

Keeley, P. (2008). *Science formative assessment.* Thousand Oaks, CA: Corwin, Press, A Sage Company.

Keimig, R (1983). Raising academic standards: A guide to learning improvement. *ASHE-ERIC Higher Education Report No.4.* Washington D.C.: Association for the Study of Higher Education.

Kenney, P., & Kallison, l. (1994). Research studies on the effectiveness of Supplemental Instruction in mathematics. *New Directions for Teaching and Learning*, 60, 75-82.

Kenney, P. (1989). *Effects of Supplemental Instruction on student performance in a college level mathematics course* (Doctoral dissertation, University of Texas-Austin, 1994). Dissertation Abstracts for Social Sciences, 50, DA 8909688.

Klymkowsky, M.W., & Garvin-Doxas, K. (2008). Recognizing students' misconceptions through Ed's Tools and the Biology Concept Inventory. *PloS Biology, 6* (1), 14-17.

Klymkowsky, M.W., Garvin-Doxas, K., & Zeilik, M. (2003). Bioliteracy and teaching efficacy: What biologists can learn from physicists. *Cell Biology Education, 2*, 155-161.

Koba, S. (2009). *Hard-to-teach biology concepts: A framework to deepen student understanding*. Arlington, VA: NSTA Press.

Lave, J., & Wenger, E. (1998). Communities of Practice: Learning, Meaning, and Identity: Cambridge University Press.

Le Compte, M., & Preissle, J. (1993): Ethnography and Qualitative Design in Educational Research. London: Academic Press Inc.

Lincoln, Y.S. & Guba, E.G. (1985). *Naturalistic Inquiry*. Newbury Park, CA: Sage Publications.

Lockie, N.M., & Van Lanen, R.l. (1994). Supplemental Instruction for college chemistry courses. *New Directions for Teaching and Learning*, 60, 63-74.

Lundeberg, M.A., & Moch, S.D. (1995). Influence of social interaction on cognition: Connected learning in science. *Journal of Higher Education*, 66(3), 312-35.

Lundeberg, M.A. (1990). Supplemental Instruction in chemistry. *Journal of Research in Science Teaching*, 27(2), 145-55.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome and N.G. Lederman (Eds.), *PCK and Science Education,* (pp.95-132). The Netherlands: Kluwer Academic Publications.

Marshall, C., & Rossman, G.B. (1989). *Designing Qualitative Research.* Newbury Park, CA: Sage Publications, Inc.

Martin, D.C., & Blanc, RA. (1994). VSI: A pathway to mastery and persistence. *New Directions for Teaching and Learning*, *60*, 83-91.

Martin, D.C., & Blanc, RA. (1994). VSI: A pathway to mastery and persistence. *New Directions for Teaching and Learning*, *60*, 83-91.

McMillan, J. H. (2003). Understanding and improving teachers' classroom assessment decision- making: Implication for theory and practice. *Educational Measurement: Issues and Practice, 22*(4).

McMillan, J. H. (2001). Classroom assessment: Principles and practice for effective instruction. (2nd Ed.). Boston: Allyn and Bacon.

National Research Council. (1996). *National Science Education Standards.* Washington, DC: National Academy Press.

Nehm, R.H., & Schonfeld, I.R. (2008). Measuring Knowledge of Natural Selection: A Comparison of the CINS, an Open-Response Instrument, and an Oral Interview. *Journal of Research in Science Teaching, 45*(10), 1131-1160.

Odom AL, Barrow LH (1995). Development and application of a two-tier diagnostic test measuring college biology students' understanding of diffusion and osmosis after a course of instruction. *Journal of Research in Science Teaching, 32*, 45–61.

Ogden, P., Thompson, D., Russell, A., & Simons, C. (2003). Supplemental Instruction: Short and long term impact. *Journal of Developmental Education, 26*(3), 2-8.

Ormod, J.E. (1998). *Educational psychology: Developing learners.* Columbus, OH: McGraw-Hill.

Park, T.J. & Braxton, J.M. (2010). Latent scholarly identities of college and university faculty members. Paper presented at the meeting of the American Educational Research Association, Denver, CO.

Parker, J.M., Anderson, C.W., Heidemann, M., Merrill, J., Merritt, B., Richmond, G., & Urban-Lurain, M. (2012). Exploring Undergraduates' Understanding of Photosynthesis Using Diagnostic Question Clusters. *Life Sciences Education, 11*, 47-57.

Patton, M.Q. (1990). Qualitative *evaluation and research methods* (2nd ed.). Newbury Park, CA: Sage Publications, Inc.

Price, M., & Rust, C. (1995). Laying firm foundations: The long-term benefits of Supplemental Instruction for students in large introductory courses. *Innovations in Education and Training International, 32*(2), 123-130.

Pryor, S.A. (1989). *The relationship of Supplemental Instruction and final grades of students enrolled in high risk courses*. Dissertation Abstracts for Social Sciences, 50, DA 8923554.

Sadler, P.M. (1998). Psychometric models of student conceptions in science: Reconciling qualitative studies and distracter-driven assessment instruments. *Journal of Research in Science Teaching, 35*(3), 265-296.

Schmidt, P. (2010). Professors who focus on honing their teaching are a distinct breed. *The Chronicle of Higher Education,* http://chronicle.com/article/Professors-Who-Focus-on-Honing/65262/.

Shavelson, R.J. (1973). The basic teaching skill: Decision-making. Stanford, CA: Stanford University School of Education, Center for Research and Development in Teaching.

Shaya, S.B., Petty, H.R., & Petty, L.I. (1993). A case study of Supplemental Instruction in biology focuses on at-risk students. *BioScience, 43*(10), 709-711.

Shepard, L.A. (2000). The role of assessment in a learning culture. *Educational Researcher, 29*(7), 4-14.

Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-13.

Siegel, M.A. (2007). Striving for equitable classroom assessments for linguistic minorities: Strategies for and effects of revising life science items. *Journal of Research in Science Teaching*, 44 (6), 864-881.

Siegel, M.A., & Wissehr, C. (2011). Preparing for the plunge: Preservice teachers' assessment literacy. *Journal of Science Teacher Education.*

Silverman, D. (2000). *Doing Qualitative Research: A practical handbook.* Thousand Oaks, CA: Sage Publications, Inc.

Van Lanen, R.J., & Lockie, N.M. (1997). Using Supplemental Instruction to assign nursing students in chemistry. *Journal of College Science Teaching, 26*(6), 419-423.

Warner, J.M. (2008). *Supplemental Instruction for Non-Science Majors Biology Students: Meanings and Influences on Science Identities for Women.* Unpublished doctoral dissertation, University of North Carolina, Greensboro.

Williams, K., Fisher, K., & Anderson, D. (2008). Using diagnostic test items to assess conceptual understanding of basic biology ideas: A plan for programmatic assessment. Paper presented at the Conceptual Assessment in Biology Conference II; Asilomar, CA. *http://bioliteracy.net/CABS.html*

Wilson, C.D., Anderson, C.W., Heidemann, M., Merrill, J.E., Merritt, B.W., Richmond, G., Silbey, D.F., & Parker J.M. (2008). Assessing students' ability to trace matter in dynamic systems in cell biology. *Life Sciences Education*, *5*, 323–331.

Zaritsky, J.S., & Toce, A. (2006). Supplemental Instruction at a community college: The four pillars. *New Directions in Teaching and Learning, 106*, 23-31.

APPENDICES

APPENDIX A

Data Collection Matrix

Research Question: How do professors & SI Leaders respond to results of concept inventories?

Data Sources / **Sub-Questions**	Concept Inventory of Natural Selection Pre & Post-test	Video (back-up for Observations of Relevant Lectures and SI Sessions)	Three Interviews with Professor	Three Interviews with SI Leader	Professors', SI Leaders', & Students' Artifacts & Documents	Field Notes	Lessons of same concepts from previous semesters
In what ways do the professor's views of learning, understandings of principles of assessment, and knowledge of assessment interpretation and action taking interact?			Primary		Secondary	Primary	Secondary
In what ways do the SI Leader's views of learning, understandings of principles of assessment, and knowledge of assessment interpretation and action taking interact?				Primary	Secondary	Primary	Secondary
What are the similarities and differences between the interpretations and actions of the professor and SI Leader?	Secondary	Secondary	Primary	Primary	Secondary	Primary	
In what ways does the CI inform the professor's efforts to support student learning?	Secondary	Secondary	Primary			Primary	Secondary
In what ways does the CI inform the SI Leader's efforts to support student learning?	Secondary	Secondary		Primary	Secondary	Primary	Secondary

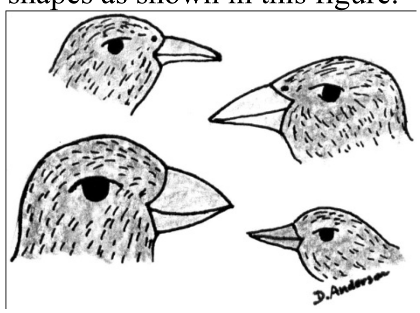
APPENDIX B

Conceptual Inventory of Natural Selection

Your answers to these questions will assess your understanding of the Theory of Natural Selection. Please choose the answer that best reflects how a biologist would think about each question.

Galapagos finches

Scientists have long believed that the 14 species of finches on the Galapagos Islands evolved from a single species of finch that migrated to the islands one to five million years ago (Lack, 1940). Recent DNA analyses support the conclusion that all of the Galapagos finches evolved from the warbler finch (Grant, Grant & Petren, 2001; Petren, Grant & Grant, 1999). Different species live on different islands. For example, the medium ground finch and the cactus finch live on one island. The large cactus finch occupies another island. One of the major changes in the finches is in their beak sizes and shapes as shown in this figure.



Choose the one answer that best reflects how an evolutionary biologist would answer.

1. What would happen if a breeding pair of finches was placed on an island under ideal conditions with no predators and unlimited food so that all individuals survived? Given enough time,
   a. the finch population would stay small because birds only have enough babies to replace themselves.
   b. the finch population would double and then stay relatively stable.
   c. the finch population would increase dramatically.
   d. the finch population would grow slowly and then level off.

2. Finches on the Galapagos Islands require food to eat and water to drink.
   a. When food and water are scarce, some birds may be unable to obtain what they need to survive.
   b. When food and water are limited, the finches will find other food sources, so there is always enough.
   c. When food and water are scarce, the finches all eat and drink less so that all birds survive.
   d. There is always plenty of food and water on the Galapagos Islands to meet the finches' needs.

3. Once a population of finches has lived on a particular island with an unvarying environment for many years,
   a. the population continues to grow rapidly.
   b. the population remains relatively stable, with some fluctuations.
   c. the population dramatically increases and decreases each year.
   d. the population will decrease steadily.

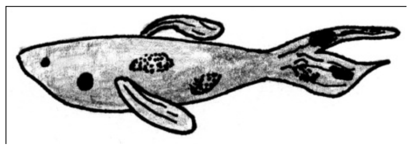
4. In the finch population, what are the primary changes that occur gradually over time?
   a. The traits of each finch within a population gradually change.
   b. The proportions of finches having different traits within a population change.
   c. Successful behaviors learned by finches are passed on to offspring.
   d. Mutations occur to meet the needs of the finches as the environment changes.

5. Depending on their beak size and shape, some finches get nectar from flowers, some eat grubs from bark, some eat small seeds, and some eat large nuts. Which statement best describes the interactions among the finches and the food supply?
   a. Most of the finches on an island cooperate to find food and share what they find.
   b. Many of the finches on an island fight with one another and the physically strongest ones win.
   c. There is more than enough food to meet all the finches' needs so they don't need to compete for food.
   d. Finches compete primarily with closely related finches that eat the same kinds of food, and some may die from lack of food.

6. How did the different beak types first arise in the Galapagos finches?
   a. The changes in the finches' beak size and shape occurred because of their need to be able to eat different kinds of food to survive.
   b. Changes in the finches' beaks occurred by chance, and when there was a good match between beak structure and available food, those birds had more offspring.
   c. The changes in the finches' beaks occurred because the environment induced the desired genetic changes.
   d. The finches' beaks changed a little bit in size and shape with each successive generation, some getting larger and some getting smaller.

7. What type of variation in finches is passed to the offspring?
   a. Any behaviors that were learned during a finch's lifetime.
   b. Only characteristics that were beneficial during a finch's lifetime.
   c. All characteristics that were genetically determined.
   d. Any characteristics that were positively influenced by the environment during a finch's lifetime.

8. What caused populations of birds having different beak shapes and sizes to become distinct species distributed on the various islands?
    a. The finches were quite variable, and those whose features were best suited to the available food supply on each island reproduced most successfully.
    b. All finches are essentially alike and there are not really fourteen different species.
    c. Different foods are available on different islands and for that reason, individual finches on each island gradually developed the beaks they needed.
    d. Different lines of finches developed different beak types because they needed them in order to obtain the available food.

Venezuelan guppies 

Guppies are small fish found in streams in Venezuela. Male guppies are brightly colored, with black, red, blue and iridescent (reflective) spots. Males cannot be too brightly colored or they will be seen and consumed by predators, but if they are too plain, females will choose other males. Natural selection and sexual selection push in opposite directions. When a guppy population lives in a stream in the absence of predators, the proportion of males that are bright and flashy increases in the population. If a few aggressive predators are added to the same stream, the proportion of bright-colored males decreases within about five months (3-4 generations). The effects of predators on guppy coloration have been studied in artificial ponds with mild, aggressive, and no predators, and by similar manipulations of natural stream environments (Endler, 1980).

Choose the one answer that best reflects how an evolutionary biologist would answer.

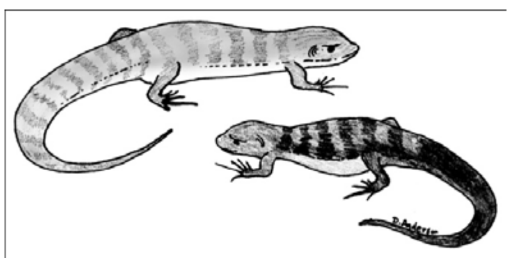
9. A typical natural population of guppies consists of hundreds of guppies. Which statement best describes the guppies of a single species in an isolated population?
    a. The guppies share all of the same characteristics and are identical to each other.
    b. The guppies share all of the essential characteristics of the species; the minor variations they display don't affect survival.
    c. The guppies are all identical on the inside, but have many differences in appearance.
    d. The guppies share many essential characteristics, but also vary in many features.

10. Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Which feature would a biologist consider to be most important in determining which guppies were the "most fit"?
    a. large body size and ability to swim quickly away from predators
    b. excellent ability to compete for food
    c. high number of offspring that survived to reproductive age
    d. high number of matings with many different females.

11. Assuming ideal conditions with abundant food and space and no predators, what would happen if a mating pair of guppies were placed in a large pond?
    a. The guppy population would grow slowly, as guppies would have only the number of babies that are needed to replenish the population.
    b. The guppy population would grow slowly at first, then would grow rapidly, and thousands of guppies would fill the pond.
    c. The guppy population would never become very large, because only organisms such as insects and bacteria reproduce in that manner.
    d. The guppy population would continue to grow slowly over time.

12. Once a population of guppies has been established for a number of years in a real (not ideal) pond with other organisms including predators, what will likely happen to the population?
    a. The guppy population will stay about the same size.
    b. The guppy population will continue to rapidly grow in size.
    c. The guppy population will gradually decrease until no more guppies are left.
    d. It is impossible to tell because populations do not follow patterns.

13. In guppy populations, what are the primary changes that occur gradually over time?
    a. The traits of each individual guppy within a population gradually change.
    b. The proportions of guppies having different traits within a population change.
    c. Successful behaviors learned by certain guppies are passed on to offspring.
    d. Mutations occur to meet the needs of the guppies as the environment changes.



Canary Island Lizards

The Canary Islands are seven islands just west of the African continent. The islands gradually became colonized with life: plants, lizards, birds, etc. Three different species of lizards found on the islands are similar to one species found on the African continent (Thorpe & Brown, 1989). Because of this, scientists assume that the lizards traveled from Africa to the Canary Islands by floating on tree trunks washed out to sea.

Choose the one answer that best reflects how an evolutionary biologist would answer.

3. Lizards eat a variety of insects and plants. Which statement describes the availability of food for lizards on the Canary Islands?
    a. Finding food is not a problem since food is always in abundant supply.
    b. Since lizards can eat a variety of foods, there is likely to be enough food for all of the lizards at all times.
    c. Lizards can get by on very little food, so the food supply does not matter.
    d. It is likely that sometimes there is enough food, but at other times there is not enough food for all of the lizards.

4. What do you think happens among the lizards of a certain species when the food supply is limited?
   a. The lizards cooperate to find food and share what they find.
   b. The lizards fight for the available food and the strongest lizards kill the weaker ones.
   c. Genetic changes that would allow lizards to eat new food sources are likely to be induced.
   d. The lizards least successful in the competition for food are likely to die of starvation and malnutrition.

16. A well-established population of lizards is made up of hundreds of individual lizards. On an island, all lizards in a lizard population are likely to . . .
   a. be indistinguishable, since there is a lot of interbreeding in isolated populations.
   b. be the same on the inside but display differences in their external features.
   c. be similar, yet have some significant differences in their internal and external features.
   d. be the same on the outside but display differences in their internal features.

17. Which statement best describes how traits in lizards will be inherited by offspring?
   a. When parent lizards learn to catch particular insects, their offspring can inherit their specific insect-catching-skills.
   b. When parent lizards develop stronger claws through repeated use in catching prey, their offspring can inherit their stronger-claw trait.
   c. When parent lizards' claws are underdeveloped because easy food sources are available, their offspring can inherit their weakened claws.
   d. When a parent lizard is born with an extra finger on its claws, its offspring can inherit six-fingered claws.

18. Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Below are descriptions of four fictional female lizards. Which lizard might a biologist consider to be the "most fit"?

	Lizard A	Lizard B	Lizard C	Lizard D
Body length	20 cm	12 cm	10 cm	15 cm
Offspring surviving to adulthood	19	28	22	26
Age at death	4 years	5 years	4 years	6 years
Comments	Lizard A is very healthy, strong, and clever	Lizard B has mated with many lizards	Lizard C is dark-colored and very quick	Lizard D has the largest territory of all the lizards

   a. Lizard A
   b. Lizard B
   c. Lizard C
   d. Lizard D

19. According to the theory of natural selection, where did the variations in body size in the three species of lizards most likely come from?

a. The lizards needed to change in order to survive, so beneficial new traits developed.
b. The lizards wanted to become different in size, so beneficial new traits gradually appeared in the population.
c. Random genetic changes and sexual recombination both created new variations.
d. The island environment caused genetic changes in the lizards.

20. What could cause one species to change into three species over time?

a. Groups of lizards encountered different island environments so the lizards needed to become new species with different traits in order to survive.
b. Groups of lizards must have been geographically isolated from other groups and random genetic changes must have accumulated in these lizard populations over time.
c. There may be minor variations, but all lizards are essentially alike and all are members of a single species.
d. In order to survive, different groups of lizards needed to adapt to the different islands, and so all organisms in each group gradually evolved to become a new lizard species.

APPENDIX C

Make sure your name and student number are bubbled in correctly on the scan sheet using a #2 pencil. Please bubble in your answers to the following questions on the provided scan sheet. Do not mark on this form. Please return these sheets when you are done.

5. Bina Vanmali at the University of Missouri, Columbia is conducting a study on students' knowledge in biology. She is asking General Biology students to help by participating in this study. The information you provide will help create a better course for you this semester. This research may also be shared in scholarly publications or presentations to help other biology instructors. Is this clear to you?

1. Yes
2. No

2) You must be 18 years of age or older to participate in the research project. Responses to the questions will be kept strictly confidential. No response will be reported in a manner that the reader can associate any responses with the individual respondents. Participating in this study will subject you to no risks greater than you encounter in everyday life. **Dr. Stone will not know if you participated in the study or not.** Is this clear to you?

1. Yes
2. No

3) This project has been reviewed and approved by the University of Missouri-Columbia Institutional Review Board. The Board believes the research procedures adequately safeguard your privacy, welfare, civil liberties, and rights. For additional information regarding human subject participation in this research, please contact the University of Missouri-Columbia IRB officer at (573) 882-9585. Is this clear to you?

1. Yes
2. No

4) Dr. Stone will receive the collective results of this inventory and use this information to shape her teaching around student needs. Since the data will be reported to her as group results, she will not know who participated and how they answered any questions. **Make sure you complete it even if you are not participating in the research project!** May Ms. Vanmali use your results in this research project?

1. Yes
2. No

APPENDIX D

SYLLABUS FOR GENERAL PRINCIPLES AND CONCEPTS OF BIOLOGY, SPRING, 2011
BIO SC 1010, SECTION 1, REFERENCE # 12822

INSTRUCTOR INFORMATION

Lecture Instructor:

[NAME RETRACTED] E-mail: **XXX**@missouri.edu

Office Phone: **XXX -XXXX** Office: **XXX**

Office Hours: Monday & Friday, 9-10 AM Facebook ID: **XXX**

Wednesday, 10-11 AM

Office hours are open – no appointment needed. If those times don't work for you, please e-mail me with suggested times to schedule an appointment.

Instructional Staff:

XXX Grader & Supplemental Instruction ams44b@mail.mizzou.edu

MEETING TIMES AND LOCATIONS

Lecture: MWF from 8-8:50 AM in **Middlebush (Johnson) Auditorium**

Tutoring: See "Course Information" on Blackboard

COURSE WEB PAGE: http://bblearn.missouri.edu (Log in using PawPrint and click on Bio Sci 1010)

REQUIRED MATERIALS

There is no required textbook for this class. If you want a textbook, Belk & Borden's *Biology Science for Life* is suggested.

COURSE DESCRIPTION

A discussion of general principles and fundamental concepts of living things that emphasizes connections and applications to society and the human condition, science literacy, and critical thinking skills.

COURSE OBJECTIVES

- Provide understanding of biological concepts to aid you in becoming a knowledgeable member of society.
- Develop inquiry and critical thinking skills that allow you to assess the validity and importance of scientific findings.
- Educate you on the human condition to provide you with health-related, decision-making skills.
- Help you understand how living things interact with each other and their environment and demonstrate how this interaction drives biological change.
- Develop life skills such as working in groups, following instructions, using online resources and seeking help.

Evaluation of Achievement

Grades are not "given" – they are earned. **But your success is of great concern to me, and I would like to see every student succeed in this class. To me, this means you earn the grade you would like to earn AND that you learn information and life skills that serve you for years to come.** I view this syllabus and other materials, such as assignment descriptions and study tools, as a "game plan" for your success. **If my expectations are unclear at any point, please ask!**

Grading Scale		Scoring Opportunities	
96.95-100%	A+	4 Exams @ 100 points each	400 points
92.95-96.94%	A	Assignments*	200 points
89.95-92.94%	A-	In-class Assignments*	80 points
86.95-89.94%	B+	Semester-long Group Project*	100 points
82.95-86.94%	B	**Total:**	**780 points**
79.95-82.94%	B-		
76.95-79.94%	C+	The final is the fourth exam (worth 100 pts.)	
72.95-76.94%	C		
69.95-72.94%	C-		
66.95-69.94%	D+		
62.95-66.94%	D		
59.95-62.94%	D-	*I reserve the right to change the ratio of points in these categories. The total will remain the same.	
0-59.94%	F		

Your scores will be posted in Blackboard. You can access these scores at any time by clicking on "Your Grade". I recommend you check your grades at least once a week. I do not post grades on Blackboard until everyone has a grade. If you see a 0 or dash when you think you should have a score for an assessment, please let me know within a week of the grade being posted. Failure to do so may result in a 0.

There are no individual extra credit opportunities and the grading scale will not change (no curve). What you earn is what you earn.

Evaluation:

Student evaluation is based upon performance:

- Out-of-class assignments (10 @ 20 pts. each. 200 pts. total).
- Semester Group Research Project (100 pts.).
- In-class Practice (14 @ 5 pts. each on Mondays; best 12 kept. 60 pts. total). No make-ups available.
- In-class Assignments (10 @ 2.5 pts. each on Wednesdays and Fridays; best 8 kept. 20 pts. total). No make-ups available
- Lecture Exams (4 @ 100 pts. Each; 400 pts. total). Make-ups provided for documented, excused absences.

HOW TO EARN AN "A" IN GENERAL BIOLOGY!

These ideas don't guarantee an "A", but they can help you do your best…

- **Come to class**. Do not rely on notes from friends! Hearing and writing the information down is part of the learning process.
- **Do assigned readings and watch assigned Tegrity videos before coming to class**. These tools are designed to increase your understanding and making learning the information easier. Some in-class exercises will assume you have completed them before coming to class.
- **Ask questions**! Ask me during class (feel free to interrupt me!), ask me or your classmates before or after class, or stop by and talk to me during office hours.
- **Actively participate** during lectures and in-class assignments.
- **Complete assigned work on time**.
- Sit towards the front where you can see, hear, and participate fully.
- Sit in the same place for all lectures and exams. Your brain recalls information better if it is in the same "state" it was in when you learned it – and that includes location!
- Re-write your notes soon after class. You will be surprised by how many details you remember hearing, but didn't write down. Those details will be forgotten before your next exam unless you "set" them in your head by writing them down.
- Review past notes regularly (a good time is the spare time you have between classes!).
- Make flash cards. Although it is not a major component, there is no way of getting away from some cold memorization in biology, and the same trick you used to learn your multiplication tables in second grade will serve you well now. Most likely, just by making your flash cards you will internalize a lot of information, making studying easier.
- Study with a group! In-class work provides a great place to meet study partners. Don't be shy!
- Test yourself while you study! Studying is an active process – just "reading over the notes" won't hack it. More Exam Study suggestions are available on Blackboard under "FAQs"
- **Come talk to me**. Stop by during office hours with any questions on the materials, grading or other concerns. I also **love** comments – what don't you like about the course and what do you like. Or stop by just to say "hi!"

GROUP DISCUSSION PARTICIPATION GUIDE

I believe that students learn better through group-based inquiry than through non-interactive lectures. However, to get the most out of group work, you have certain responsibilities*:

1) Be hospitable - Encourage everyone to participate. Ask other people for their opinion.
2) Participate - Voice your opinion. Feel free to offer suggestions others have not considered.
3) Be mindful - Carefully listen and consider what other people are saying.
4) Be humble - Admit that your knowledge and experience are limited and incomplete.
5) Show concern for others - Make sure everyone in your group is comprehending. This may require that you temporarily step into the teacher role and will help you learn even more.
6) Be deliberate - Consider the discussion from every angle and every option.
7) Appreciate - Express appreciation for other's good ideas or comments.
8) Be efficient - We have limited time for group work, so stay on task.

*Part of this guide is a summary of ideas from Brookfield, S. D. & Preskill, S. (1999). *Discussion as a way of teaching: Tools and techniques for democratic classrooms*. San Fran: Jossey-Bass.

BLENDED INSTRUCTION

This course uses blended instruction. This means on a regular basis you will be asked to do special preparation before class. Class time will be used to conduct in-depth activities, answer questions, and troubleshoot difficult concepts (see In-class Practice below under Details on Scoring Opportunities). Currently, I plan for these practice sessions to be every Monday. You will do online reading, do an online activity and/or watch a Tegrity lecture before coming to class. You will need to take notes and use those notes in class to help you complete an in-class practice exercise.

Why? Why do we do blended instruction? Here are a few reasons:

- **Increased learning**. Research has found that students master the information better with blended instruction.
- **Less time and stress studying the days before exams**. Since students learn more as they go, this reduces the amount of time required to prepare for exams.
- **Increased interaction**. It gives students more time to ask questions and have confusing material explained. It gives students a chance to discuss the material with instructors and classmates. Explaining material to others helps you learn it better.
- **Increased critical thinking**. Blended instruction allows us to develop cognitive skills that would not be used in a normal lecture.
- **Preparing for future jobs.** In the workforce, learning new skills or content is increasingly happening online. Employers are looking for previous experience with online learning in their employees. Blended instruction is one type of online learning.

Please note: You are responsible for completing the preparation before coming to class. These will be required in order to fully participate and get all of the points from the in-class practice exercise.

DETAILS ON SCORING OPPORTUNITIES

Exams - There will be four 100-point exams during the semester, including the final. They will cover the lectures, reading materials and assignments. Please bring your student ID and a #2 pencil for the exams. Any exam material that leaves the room without being turned in cannot be turned in at a later time. No electronic devices (iPods, cell phones, etc.) can be on your person or in your pockets during exams. If they are found, you will receive a “0” on the exam. See Academic Responsibilities document for more on unacceptable behavior during exams.

Out-of-class Assignments - Assignments will be done outside of class. Some will be turned in at the start of class and others will be online “quizzes” posted on Blackboard. They are called quizzes, but you are free to use your notes, textbook and discuss the questions with other students in our class or me. Many of the questions are old exam questions, so they should give you a feel for your understanding of exam material and how I write exam questions. **Unless otherwise stated, I do not accept assignments sent in via e-mail. Online "quizzes" cannot be turned in late.**

In-class Assignments – The most learning happens when you have the opportunity to interact with the information: to discuss and explain. For this reason, we will complete in-class assignments that will serve multiple purposes: engage you in the topic, give you feedback on your understanding, and take you through the critical thinking process required to form key connections.

These in-class assignments will be done individually, in pairs or in small groups. Although group work can be intimidating to some, it is a good way to break up the lectures and give you a chance to talk and work through problems with other students. It is also a good chance for you to get to know people who might be good study partners.

Some of these in-class assignments will be graded and some you will get points for simply completing. These in-class opportunities will not always be announced and cannot be made up, even for excused reasons. **However, the two lowest in-class assignment scores during the semester will be dropped in case you should be absent when an in-class assignment is turned in.**

In-class Practice – One of my favorite quotes comes from Confucius:

"I hear and I forget, I see and I remember, I do and I understand."

So where does lecturing fall in that summary? If you forget the information immediately after the lecture or, if you are lucky, immediately after the exam, then we have been wasting our time. My exams test understanding. I need to provide some exercises that help you *do* the biology so you can understand the material. This will set you up for success on the exams, but also in life.

Toward that goal, we will spend Mondays doing In-class Practice exercises. They are similar to the In-class Assignments, but generally longer. They are your opportunity to troubleshoot difficult concepts, ask questions and develop deeper understanding. They are designed to help you increase your performance on the Out-of-class Assignments and Exams. For more benefits, read the details on "Blended Instruction" above.

Before class you will need to prepare for these In-class Practice exercises. You will watch a Tegrity recording or do assigned reading, or both. You will take notes and bring those notes with you to class. You will be able to use your notes during the In-class Practice sessions. Some of these exercises will be done individually, in pairs or in small groups. Some will be graded and some you will get points for simply completing. They cannot be made up, even for excused reasons. **However, the two lowest in-class practice scores during the semester will be dropped in case you should be absent when an in-class practice is turned in.**

Semester-long Project (SLP) – This semester we will be conducting a semester-long project worth 100 points, total. This assignment fulfills two primary goals. First, much work in life is done with others. According to *What Do Employers Really Want? Top Skills and Values Employers Seek from Job-Seekers* (www.quintcareers.com/job_skills_values.html), being able to work as a "team" is a priority skill requested by employers. To develop this skill, you will be working in groups for part of the SLP. Second, the best way to learn about the scientific process is to ***do*** science. This assignment is designed to give you the chance to conduct a scientific experiment – ***real*** science with no known outcome. On the group portions of the project, your group will have a chance to evaluate each member at the end of the project. Your final score on this project will be reflected in your effort as determined by your group. This means your grade may be higher or lower than the points earned by the rest of the group.

Grading - I will make every effort to make my expectations of you clear and grade you according to those expectations. If you have a question about my expectations, please feel free to ask! In return, I ask that you please follow directions, and I may deduct points if you do not. Many of you are a few months away from "the real world", and the penalties for not following directions there are much worse! Furthermore, I will make the scores available for a test or assignment when I have logged in all the scores. If you have a blank or a "0" and think you should have earned points, you need to let me know within a week of grades being posted or risk making that score permanent.

STUDENT APPEAL PROCESS

I understand that some questions will be open to interpretation, and the answer you give may not be what I was "looking for." If you disagree with the grading on an assignment or exam, please give me a typed sheet containing the following information:

1) Your name and student number
2) Assignment number and question number under contention
3) The problem, clearly stated
4) The original document stapled to the appeal

Appeals or questions about grades in general must be filed no later than one week after the grades were posted. If you don't notify me within a week and the error was yours, I reserve the right to deny you any or all points on that assignment.

ATTENDANCE/ABSENCES

It is assumed that students will be in class every class period. Situations do happen, however. If you miss class you should:

- Contact another student to get the missing notes and handouts and/or check Blackboard for Tegrity recordings of the lecture. I cannot provide my lecture slides.
- Check Blackboard for any missed announcements.
- Contact me **within three days** if you missed an exam or the submission of an out-of-class assignment for an excused reason. **Otherwise, there is no need to contact me.** Remember, in-class assignments and practices cannot be made up.

Considerations may be made for in-class assignments if you miss class repeatedly (more than the number dropped) for an excused, documented reason (decided on a case-by-case basis) and if you have not missed class for unexcused reasons. You must notify me in writing within three days of the absence if you are requesting consideration.

"Excused absence" includes a University-sponsored function (documentation required), death in the immediate family, illness (with a doctor's note), or other emergency situations (decided on a case-by-case basis with sufficient documentation). If you are an athlete at UMC or participate in University-sponsored functions and need to be gone, please notify me via a departmental letter of such dates at least one class period in advance in order for alternative arrangements to be made.

Late Assignments and Make-up Exams

In-class assignments and practice exercises cannot be made up, however other late assignments without an excused reason are accepted for up to half credit at the start of the next class period. After the start of the next class period, late assignments will not be accepted. Late assignments from an excused absence will be accepted for full credit for up to one week.

Make-up exams will be provided for excused absences. You must notify me within three days of the absence that you need a make-up, or risk not being able to make-up the exam. If you are going to miss an exam due to a University-sponsored function, you must discuss it with me before the absence and provide documentation. We will arrange a make-up time for any missed exams. Make-up exams will be a different format than the original. They will have 10-15 mixed-style questions (mostly short essay).

Academic Responsibilities and Behavior Expectations

Academic honesty and professional behavior are fundamental to the activities and principles of the University of Missouri. You are a professional student and, as such, are responsible for your education and actions while attending the University of Missouri.

As with all classes at the University, academic dishonestly (cheating) will not be tolerated in this course. This class has a very strict cheating policy. If you cheat on an in-class assignment or in-class practice exercise, you will receive 0 points for ALL in-class work for the semester. If you cheat on an out-of-class assignment you may receive 0 points for ALL out-of-class assignments. If you cheat on an exam, you may receive a 0 for ALL exams. In addition, any suspected cases of academic dishonesty will be referred to the Office of the Provost for Academic Affairs for further disciplinary action, which can range from probation to expulsion from the University of Missouri. **I may ask you to sign class work, and when you sign you are confirming the work is yours.**

I have discovered many students do not know what "cheating" is. Behavior that seemed acceptable in high school (copying answers outside the classroom before math, for example, or writing a sentence directly from an online source) can get you in big trouble in college and in life in general. To make sure you have a clear understanding of your academic responsibilities, read the Academic Integrity and Behavior Agreement (available under "Class Information" on Blackboard) for this class. You can get more information at: http://academicintegrity.missouri.edu/.

Please note: this does not mean you cannot work with other students when completing assignments! I encourage you to work together and discuss the questions together. However, your answers should be unique from each other and express your own thoughts. If they do not, penalties can range from sharing the credit with the person or people involved to losing all the points for the semester.

If you are **talking during class**, you are not only prohibiting your own involvement in the discussion, but the involvement of those around you. If you must talk to your neighbor, please take it outside. If I notice you talking when you should not be, I may ask you to leave the lecture hall.

I welcome the use of **laptop computers** as a tool for taking notes. However, use this tool appropriately. Checking e-mail, surfing the net, playing games and watching movies (yes, it has happened) will distract you from the course and may distract those around you as well. If I see laptops being abused, I reserve the right to ban any or all laptops from the classroom.

Sharing class materials with individuals outside the class (Ex: posting on web pages like Grade Genie) is strictly prohibited and may result in receiving an "F" for the semester and possible legal action. The class notes, assignments, exams and study guides are the intellectual property of Dr. Stone and protected under Copyright. You may share notes with other students enrolled in the course personally, via Blackboard or by direct e-mail.

An Academic Responsibilities and Behavior Expectations Agreement is available on Blackboard under "Course Information". You must read, sign and agree to adhere to the policies outlined in this syllabus and on the Agreement in order to remain enrolled in the class. If you do not wish to sign this Agreement, you must drop the course during the first week of classes. If you do not drop the class and do not sign the agreement, I reserve the right to drop your grade. **Details on how and when to turn in your signed agreement will be provided in class.**

AMERICANS WITH DISABILITIES ACT (ADA)

If you need accommodations because of a disability, if you have emergency medical information to share with me, or if you need special arrangements in case the building must be evacuated, please inform me immediately so we may make reasonable efforts to accommodate your needs.

To request academic accommodations (for example, a note taker or extended time on exams), students must also register with the Office of Disability Services (http://disabilityservices.missouri.edu <http://disabilityservices.missouri.edu>), S5 Memorial Union, 882-4696. It is the campus office responsible for reviewing documentation provided by students requesting academic accommodations, and for accommodations planning in cooperation with students and instructors, as needed and consistent with course requirements. For other MU resources for students with disabilities, click on "Disability Resources" on the MU homepage.

Intellectual Pluralism

The University community and I welcome intellectual diversity and respect student rights. Students who have questions concerning the quality of instruction in this class or course content are asked to discuss their concerns with me first. If you do not feel comfortable talking to me or feel unsatisfied with our discussion, you may address your concerns to either the Biological Sciences Divisional Director (Dr. John David - davidj@missouri.edu) or the Director of the Office of Students Rights and Responsibilities (http://osrr.missouri.edu/). All students will have the opportunity to submit an anonymous evaluation of the instructor at the end of the course.

Examples of questions we will ask in class

What's up with the "swine" flu? **Which is healthier: butter, margarine or olive oil?** Will artificial sweeteners give humans cancer? **Is using anti-bacterial products a "good thing"?** Is it illegal to clone humans in Missouri? **Can I get smallpox from the smallpox vaccine?** What will happen if they clone Hitler? **Do all-protein or all-carbohydrate diets work?** Should I go to the doctor for antibiotics when I have the flu? **What's the fuss about genetically modified organisms (and what are they?!)?** Can we live forever? **Should we take aspirin to lower a low-grade fever?** How can I save money on my electricity and water bills while doing my part to save the world? **Are all dogs the same species?** Should we be worried about Bird Flu? **Does Al Gore have a reason to be concerned about Global Warming?** Can one drink more alcohol if it is mixed with Red Bull? **What are three reasons I should take the stairs instead of the elevator?** How can I be a better journalist, businessperson and/or consumer?

IMPORTANT DATES

Date	Event
Wednesday, Jan. 19	First day of class – Welcome!
	Unit 1 - Scientific Process, Chemistry of Life, Cell Structure & Metabolism*
Tuesday, Jan. 25	Last day to add or change sections or drop a class and get $$ back
Wednesday, Jan. 26	Assignment 1 due
Wednesday, Feb. 2	Assignment 2 due
Monday, Feb. 7	SLP – Group Experimental Design (first submission) due
Wednesday, Feb. 9	Assignment 3 due
Wednesday, Feb. 16	Exam 1 (in class)
	Unit 2 - DNA Expression; DNA fingerprinting; Genetically Modified Organisms; Mutations, Mitosis & Cancer*
Monday, Feb. 21	SLP – Group Experimental Design (second submission) due
Monday, Feb. 21	Last day to drop classes without assigned grade
Wednesday, Feb. 23	Assignment 4 due
Wednesday, Mar. 2	Assignment 5 due
Wednesday, Mar. 9	Exam 2 (in class)
	Unit 3 – Aging, Reproduction, Human development, Stem cells & Cloning; Genetics & Genetic diseases*
Wednesday, Mar. 16	Assignment 6 due
Monday, Mar. 21	SLP – Group Experimental Data due
Wednesday, Mar. 23	Assignment 7 due
Mar. 28 – Apr. 1	No classes – Spring Break
Monday, Apr. 4	Last day to withdraw from a course.
Wednesday, Apr. 6	Assignment 8 due
Wednesday, Apr. 13	Exam 3 (in class)
	Unit 4 –The immune system & infectious diseases, Evolution and Ecology*
Wednesday, Apr. 20	Assignment 9 due
Wednesday, Apr. 20	SLP – Poster session for Odd-numbered Groups
Friday, Apr. 22	SLP – Poster session for Even-numbered Groups
Wednesday, Apr. 27	Assignment 10 due
Tuesday, May 10 @ 8 AM	Exam 4 – Final (same place as normal class sessions)

* The order of the topics covered in test units may change based on current events and student interest.

** SLP stands for Semester Long Project. The due dates may be adjusted based on class needs.

APPENDIX E

Interview #1 Protocol for Professor and SI Leader

Purpose
To understand the professor and SI Leader's views of learning, teaching, science, and students.

Guiding questions include:

1. What is the role of the teacher in science teaching?
2. What do you think is the role of the students/learners in learning science?
3. What do you think are the three most important goals in teaching science?
4. What do you do in order to help students meet your science learning goals?
5. In summary, what would good science teaching look like?
6. If you could design the ideal science lesson, what would it look like?

APPENDIX F

Interview #2 Protocol for Professor and SI Leader

Purpose

To understand instructor's perceptions about student understandings of natural selection.

Initial Ideas about CINS questions & Student Understandings

First, go through each question on the CINS with the instructor/SI Leader. (20 Questions on CINS). The concepts under study are important to biology. Use the following questions as a guideline for eliciting information.

1. Which is the correct answer choice?
2. How do you think students understand it?
3. What parts do you think they have a scientific understanding of?
4. What parts are they lacking?
5. What are their misconceptions? Where do these originate?
6. Have you taught these concepts in the past? (We can go through the old versus current lesson plans in a future interview, with your permission.)
7. How have you dealt with students alternative ideas about this in the past?
8. Do you think this is effective in helping students arrive at a scientific understanding? How? Why/why not?

Interview #2 continued

Participants' Thoughts after getting student results about CINS

Go through each question on the CINS to gain instructor's impressions. Use these questions as a guideline to elicit information.

1. What do you think of these results?
2. What are you surprised about?
3. Were these results expected? Why or why not?
4. How will you deal this misconception? (i.e. help students learn the scientific understanding of it)
5. What activities/lessons are you planning for this concept?
6. What activities will you do?

Overall results

7. Which of these concepts are most important? Why?

APPENDIX G

Interview #3 Protocol for Professor and SI Leader

Background

After studying the relevant topics, which may include questions from the CINS, the students take the CINS for a second time. Get results and tabulate them. Provide the professor and SI Leader with the collective results of the pre-test and post-test.

Results of the Post-test

Ask them about their impressions of the students' learning experiences. General themes of questions to ask include:

1. What are the pros and cons of their learning experiences?
2. What do you think of these results? Expected? Surprised about?
3. What do you think are the students' experiences of your teaching with this knowledge? How do you think the pedagogical choices you made helped/hindered learning? Content choices?
4. What would you do differently next time?
5. Did the information provided by the CIs help you? How?

Overall results

1. Which of these concepts are most important? Why? Please respond.
2. How did you and the instructor for the course share information about this and other topics for the course? (i.e. In what ways did you communicate—in-person during meetings, between classes, etc., via email, other? How did you help each other with developing plans for teaching natural selection? Things like that.)

VITA

Binaben (Bina) Vanmali was born in Harare, Zimbabwe. With her family, she moved to the United States at the age of three. She lived in and attended primary school in several different states but completed her secondary education in Dexter, Missouri. Bina earned a Bachelors of Arts degree in 1999 from Westminster College in Fulton, Missouri. She majored in biology and completed three minors, including chemistry, environmental science, and political science. She continued her education in the Division of Biological Sciences at the University of Missouri, where she earned a Masters of Arts degree in 2002. During her time in the Division, she earned two awards and published an article in a top-tier journal on her research.

Bina entered the doctoral program at the University of Missouri (MU) Science Education Center in 2005 as a part-time graduate student. During her years as a science education graduate student, she worked full-time, first at the Learning Center on campus and later in the Division of Biological Sciences. Her position in the Learning Center involved supervising the science-tutoring unit of the Center, including hiring, training, and supervising a staff of 50+ tutors. In the Division of Biological Sciences, Bina taught General Principles and Concepts of Biology four times and implemented a Supplemental Instruction program within the Division. During the final year of her degree program, she worked as a Visiting Instructor in the biology departments at Westminster College, William Woods University, and Moberly Area Community College. She taught courses in non-majors biology lecture, mixed majors biology lecture, non-majors biology lecture plus lab, and conservation biology.

Because her work was the inspiration for starting the doctoral program, her research interests remained close to the departments in which she worked. She published one invited column and one peer-reviewed article, in addition to giving many presentations at peer-reviewed conferences for academic support, for science education research, and for practitioners.

Bina has accepted a faculty position at in the School of Life Sciences at Arizona State University in Tempe, Arizona, beginning in September 2012. In addition to her teaching and research responsibilities, she will be working with a team to re-design the undergraduate courses for biology majors to incorporate active learning into large lecture courses, beginning with the first year courses. In addition, she will create and facilitate professional development in teaching and learning for life sciences faculty, graduate students, and post-doctoral students. Bina's research will continue to focus on undergraduate biology education and teaching and learning outside the classroom.