Epistemologies and Scientific Reasoning Skills Among Undergraduate Science Students

Dissertation

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Abstract

Non-cognitive factors such as students’ attitudes and beliefs toward a subject and their proficiency in scientific reasoning are important aspects of learning within science disciplines. Both factors have been studied in relation to science education in various disciplines. This dissertation presents three studies that investigate student epistemologies and scientific reasoning in the domain of biology education. The first study investigated students’ epistemic viewpoints in two introductory biology courses, one for science majors and one for non-science majors. This quantitative investigation revealed that the majors exhibited a negative shift in their attitudes and beliefs about biology and learning biology during a semester of introductory instruction. However, the non-science majors did not exhibit a similar shift. If fact, the non-science majors improved in their attitudes and beliefs during a semester of instruction, though not significantly so. The second study expands epistemological research to a population that has often been left out of this work, that is, intermediate-level biology majors. Quantitative and qualitative data was collected to reveal that junior and senior ranked students for the most part were able to characterize their views about biology and learning biology, and were able to associate factors with their epistemic improvement. Finally, the third study expands epistemology
research further to determine if scientific reasoning and student attitudes and beliefs about learning science (specifically biology) are related. After a description of how various science and engineering majors compare in their scientific reasoning skills, this study indicated that among intermediate level biology majors there is no relationship between scientific reasoning skills and epistemologies, nor is there a relationship with other educational factors, including the number of courses taken during an undergraduate career, cumulative GPA, and standardized test scores (ACT). Taken together, the results of these studies can inform science education, particularly discipline-based education research in biology.
In memory of my dad, Steve Mollohan (1943-2015).
He never knew me as a doctoral student, yet he was with me the whole way.

Dedicated to my mom, Marti, who was with me every step of the way.
I couldn’t have done it without you.
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Fields of Study

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Chapter 1: Introduction

Attributes such as content learning and developing expertise in a specific field are undoubtedly of utmost importance to tertiary level education; however, efforts have emphasized a need to consider affective factors—including attitudes, beliefs, critical thinking and reasoning abilities, and values, in improving college-level learning (Bransford, Brown, & Cocking, 2000; Ding, Wei, & Mollohan, 2014; NRC, 2011; Ruiz-Primo, Li, Willis, Giamellaro, Lan, Mason, & Sands, 2012). In the last decade affective and epistemological factors (such as attitudes and beliefs about learning) have been the subject of much research in the science education field in order to better delineate what factors affect student learning at the tertiary level (Ding, 2014). Drawing on empirical research from general and discipline-specific science education research, this dissertation presents three studies investigating student epistemologies and scientific reasoning skills in college level learning.

Defining Epistemological Beliefs

Epistemological beliefs are defined as an individual’s belief(s) about the nature of knowledge and about knowing (Hofer, 2004; Schommer-Akins, 2004; Hofer & Pintrich,
Researchers in the field generally agree that epistemological beliefs consist of four dimensions, including certainty of knowledge, simplicity of knowledge, source of knowledge, and justification of knowing (Hofer & Pintrich, 1997). These four dimensions can be divided into two overarching groups: the nature of knowledge (which includes the certainty of knowledge and the simplicity of knowledge) and the nature of knowing (which includes the source of knowledge and the justification of knowing) (Chen & Pajares, 2010; Hofer & Pintrich, 1997). (For a graphical representation of this framework, please see Figure 1.)

Epistemological beliefs are thought to affect beliefs about learning and education in general as well as in specific disciplines (Schommer, 1990; Schommer-Akins, 2004). Because these beliefs are often considered context-dependent, discipline-based research in science education has been crucial to our understanding of epistemologies over the last several decades (Adams, Perkins, Podolefsky, Finkelstein, & Wieman, 2006; Barbera, Perkins, Adams, & Wieman, 2008; Hammer & Elby, 2003; Lising & Elby, 2005; Redish, Saul & Steinberg, 1998; Semsar, Knight, Birol, & Smith, 2011).
Research on Epistemologies in Scientific Disciplines

Much research in science education views epistemologies as being positioned along a continuum from novice to expert (Figure 2). These stages, in the simplest form, consist of naïve and sophisticated views of knowledge (Hammer, 1994; Hofer & Pintrich, 1997; Schommer, 1990). Naïve, or novice, epistemologies are characterized by the idea that knowledge comes from an authority and is essentially unchanging, whereas sophisticated, or expert, beliefs are characterized by the idea that knowledge is fluid and changeable, and that knowledge is interrelated (Chen & Pajares, 2010; Hofer, 2000;
Hofer & Pintrich, 1997, among others). Novice beliefs are characterized as believing knowledge in a scientific field consists of unconnected facts to be memorized whereas experts see concepts as connected and informing one another (Hammer, 1994; Redish et al., 1998).

Figure 2. Example of a continuum of beliefs common in epistemology literature (Ding & Mollohan, 2015).

It is assumed that as students progress through school that their epistemological beliefs will progress as well, and their science epistemologies are no exception (Carey & Smith 1993; Hofer & Pintrich, 1997). Though little research into changing science
epistemologies has been done across the tertiary level, one longitudinal study in biology education research supports the hypothesis that students do in fact develop more expert-like attitudes and beliefs about biology during their undergraduate careers (Hansen & Birol, 2014). These researchers found that among matched student data, a significant positive shift in epistemologies occurs in multiple categories on the instrument (Colorado Learning Attitudes about Science Survey for use in biology, or CLASS-Bio) from freshman to senior years (n=83) (Hansen & Birol, 2014; Semsar et al., 2011).

Research in introductory college science courses has found that science majors in introductory science courses tend to become more novice in their views of science during these early required courses; this has been found in physics (Adams et al., 2006; Gray, Adams, Wieman, & Perkins, 2008; Redish et al., 1998), chemistry (Barbera et al., 2008) and the life sciences (Ding & Mollohan, 2015; Semsar, et. al, 2011). Researchers have speculated as to why this regression may occur and have hypothesized that it is dependent on students’ viewing knowledge as fragmented facts (Hammer, 1994; Lising & Elby, 2005), not recognizing real world connections of often abstract material (Ding & Mollohan, 2015), and type of instruction is sometimes blamed (Buehl & Alexander, 2006; Cam & Geban, 2011; Hammer, 1994; Hammer & Elby, 2003; Hoskins, Lopatto, & Stevens, 2011; Tsai, 2002).

This line of inquiry has traditionally been domain-specific, and involves the use of discipline-specific assessments and instruments (Adams et al., 2006; Barbera et al.,
2009; Semsar et al., 2011). One such instrument, utilized in each of the studies in this dissertation, is the Colorado Learning Attitudes about Science Survey for use in Biology (CLASS-Bio) (Semsar, et al., 2011). This instrument has several advantages, including that it has been successfully used in similar research studies (Ding & Mollohan, 2015; Hansen & Birol, 2014; Semsar et al., 2011) and situates the questions specifically within the context of biology. Additionally, the questions on this instrument align with the two-dimensional framework of epistemologies in which two of the studies in this dissertation are situated (Figure 1).

Utilizing such instruments has moved the field forward in the understanding of student epistemologies in different scientific disciplines, however, limitations still exist, including the lack of research with upper-level college students and the lack of research about factors related to changes in epistemologies at the tertiary level.

**Research on Student Scientific Reasoning**

**Defining Scientific Reasoning**

Reasoning, in general, is defined simply as the process of drawing conclusions from any given information (Kuhn, 2002; Lawson, 2004). Everyone, in his or her everyday lives, uses this process. In order to distinguish it from formal reasoning, scientific reasoning is defined in the literature as reasoning that has direct influence on or
is utilized during different types of scientific inquiries (Kuhn, 2002; Zimmerman, 2000). Some researchers stress that it is a way to infer and make conclusions about natural phenomena (Lawson 2004), while others define it more specifically, such as the ability to coordinate and reconcile evidence with theory (Kuhn & Dean, 2005; Zeineddin & Abd-El-Khalick, 2010). The view that Lawson puts forth also contains five “subsets” of skills, including control of variables, correlational reasoning, hypothetical-deductive reasoning, proportional and probabilistic reasoning (Lawson, 2004; Lawson, Clark, Cramer-Meldrum, Falconer, Sequist, & Kwon, 2000). These specific types of reasoning are often stated as necessary for exploration across and within disparate scientific disciplines (Braaten & Windschitl, 2011; Lawson, 2004; Zimmerman, 2000).

**Scientific Reasoning at the College Level**

While the existing literature is in agreement that reasoning skills can be learned, it remains unclear if content learning or affective factors can increase this aptitude (Coletta & Phillips, 2005; Kuhn, 2002; Moore & Rubbo, 2012). A cross-national study comparing American and Chinese undergraduates investigated their scientific reasoning abilities using the Lawson Classroom Test of Scientific Reasoning (LCTSR, Lawson, 1978; Lawson et al., 2000) and found that freshmen physics students in both countries exhibited similar levels of scientific reasoning despite the disparate pre-college education curricula in the two nations (Bao, Cai, Koenig, Fang, Han, Wang, Liu, Ding, Cui, Luo,
Wang, Li, & Wu, 2009). Similar findings have come from other studies, in America and China.

In a national study it was found in survey research of American colleges and universities (n=24) that by the end of their sophomore years nearly half of the students did not show significant improvement in their scientific reasoning ability (Arum & Roksa, 2010). Students took the Collegiate Learning Assessment (Benjamin & Chun, 2003), on which they are asked to “weigh evidence, analyze and synthesize data” and provide written responses to a “real world situation” (Cain, 2011). Nearly half (45%) of the sophomores in the study did not exhibit statistically significant improvement, a sign that, according to the authors, means there is “evidence of limited learning”, particularly in relation to critical thinking and reasoning (Arum & Roksa, 2010; p. 54). Similarly, a study took a snapshot of students across four years of undergraduate schooling and across two tiers (similar to research-one institutions versus vocational colleges in the US) of schools in China and found that there was no significant difference between freshman and senior students on the Lawson Classroom Test of Scientific Reasoning (LCTSR) at either tier (Ding, Wei, & Mollohan, 2014). Additionally, this study found that although there was a significant difference between the two tiers of university, neither tier showed improvement across the four years of undergraduate education (Ding, et al., 2014).

These and similar findings are often cited as evidence that we need to improve reasoning skills at the tertiary level, and further research needs to be conducted as to whether or not
there are factors—such as quantity of content learning or affective factors like attitudes and beliefs—associated with reasoning gains at the undergraduate level.

In this dissertation, the three studies that follow each relate to student epistemologies and reasoning skills and the current findings within that body of knowledge. An outline of each study is provided in this introduction.

**Study One: Comparison of Science Major and Non-Science Major Epistemologies in Introductory Biology**

As instructors, we hope students will move from novice understandings toward more expert understandings as they complete our courses. However, research with large-enrollment introductory science courses shows a very different trend, telling us that students tend to become more novice-like in their views after taking introductory-level science courses in these subject domains (Perkins, Adams, Pollok, Finkelstein, & Wieman, 2006; Adams et al., 2006; Barbera et al., 2009; Semsar et al., 2011). The research conducted in this study is based on work published in reference to introductory biology courses that shows students in large-enrollment introductory biology courses exhibited a novice-like shift in their thinking after a semester of college learning (Semsar et al., 2011). Building on previous discipline-based research, this study expands the prior findings to include a comparison between science majors and non-science majors, a
population whose epistemologies have not been extensively studied in biology. Utilizing a pre-post survey design, Study One investigates the differences between science and non-science majors’ attitudes and beliefs about biology and learning biology, and the extent to which a semester of introductory biology instruction may change student views. Results have implications for teaching all college students about the subject, not just science majors.

**Study Two: Student Epistemologies in an Intermediate Level Biology Course**

Despite the fact that students’ epistemologies have been studied for decades (Carey & Smith, 1993; Edmonson & Novak, 1993; Hofer & Pintrich, 1997; Schommer, 1990), there is, to the best of my knowledge, no research that examines intermediate and upper-level students’ epistemologies and how their attitudes and beliefs about the subject change as they progress through their undergraduate careers. The second study in this dissertation expands my previous study of students’ epistemologies of biology and learning biology to students in an intermediate level biology course. The aim is to better understand how and when their epistemologies shift. Using a mixed-method design, student attitudes and beliefs were investigated through a pre-post survey design and via repeated student interviews to uncover how their epistemologies change during intermediate level courses and what factors may be associated with the changes in their
It has long been known that student learning in science is influenced by a variety of factors, including affective factors such as epistemologies, cognitive and developmental factors, and critical thinking and reasoning skills (Hammer & Elby, 2003; Hansen & Birol, 2014; Semsar et al., 2011). Additionally, higher education has pinpointed reasoning skills as one of the important overall abilities to develop during a student’s college career (Achieve, Inc., 2013; NRC, 2011). It has been found that student scientific reasoning skills, in particular, may also be linked to conceptual gains and learning (Coletta & Phillips, 2005; Ding, 2014; Moore & Rubbo, 2012; Zeineddin & Abd-El-Khalick, 2010). However, few if any large-scale studies of student scientific reasoning have been conducted at the tertiary level, and in particular with biology students. This study sought to better understand undergraduate students’ scientific reasoning abilities, and investigated multiple years and majors in a large-scale descriptive study. The specific questions to be addressed include the association between quantity of content learning (rank/year) and context of content learning (major) in relation to student scientific reasoning abilities. Additionally, to determine if student epistemologies are related to student scientific reasoning abilities, a smaller sample of intermediate and
upper-level biology students was surveyed on both the CLASS-Bio instrument and the LCTSR questionnaire, and additional educational data (such as cumulative GPA, number of courses taken, and standardized test scores) was also used.

Together, these three studies seek to broaden the existing research regarding student epistemologies in biology to two populations that have not yet been extensively studied: non-science majors and intermediate level biology majors. Because student attitudes and beliefs and their scientific reasoning ability have been implicated as predictors of content learning and conceptual understanding, the third study seeks to better describe the state of scientific reasoning ability of American college students, as together these affective and cognitive factors may affect teaching and learning of science at the college level.
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Chapter 2: Study One
Student Epistemologies in Introductory Biology:
How Do Majors and Non-Majors Compare?

Abstract

In this quantitative study the researcher investigated undergraduates’ epistemologies in two introductory biology courses, one for science majors (n=77) and the other for non-science majors (n=94). The study utilized the Colorado Learning Attitudes about Science Survey for use in Biology (CLASS-Bio) with the 171 participants in a pre-post survey design. Before instruction, the science majors had significantly more expert-aligned responses than did the students in the non-science course. After instruction, however, the non-majors outperformed the science majors. Using matched comparisons to determine more fine-grained details, it was found that the science majors significantly shifted toward more novice-like epistemologies over the course of the semester, where the non-science majors exhibited mostly positive, though not always statistically significant, gains.
Introduction

Comparisons of student views to those of scientists often reveal that students have very different ideas about the nature of science and learning science than experts (Edmonson & Novack, 1993; Gire & Jones, 2009; Redish, Saul, & Steinberg, 1998). When we are teaching a course, we expect learners toward more expert understandings as they progress. Nevertheless, research into undergraduate introductory science courses shows similar results across multiple scientific disciplines, namely that students in these courses become more novice-like in their thinking during these classes (Adams, Perkins, Dubson, Finkelstein, & Wieman, 2004; Perkins, Adams, Pollok, Finkelstein, & Wieman, 2006; Barbera, Perkins, Adams, & Wieman, 2009; Hammer & Elby, 2003; Semsar, Knight, Birol, & Smith, 2011).

The study described here is based on work published in reference to introductory courses in physics (Adams et al., 2004; Adams et al., 2006), chemistry (Barbera et al., 2009), and in biology (Semsar, et al., 2011). While results in all three disciplines reveal that science majors in large-enrollment courses show novice-like shifts in their thinking about science and about how they learn science during a semester of college instruction, there has been little if any work to illustrate how their non-science major counterparts in required non-major biology courses change in their epistemologies. Building on previous research, our study expands what is known from prior findings to include a comparison
between these two groups. Specifically, this study was to investigate what epistemic differences may exist between science and non-science majors and the extent to which a semester of introductory biology instruction may change student views.

Knowing what students think about science and learning science is important to teaching all students but little research has been done to investigate student epistemologies among non-science majors in introductory courses, particularly in biology. These large-enrollment general education courses are often the last opportunity to expose these students to this subject matter; therefore promoting accurate views of science and positive attitudes toward learning science is critically important in these courses. The present study attempts to provide a more thorough understanding of all students’ epistemologies about biology and learning biology.

**Research into Epistemological Beliefs**

Epistemological beliefs differ from other types of beliefs in that they are considered foundational, meaning that other beliefs and types of knowledge depend on them; they are, quite simply, fundamental to how humans think (Steup, 2012). For instance, how a student thinks knowledge is structured or justified in science is fundamental to how s/he views the scientific enterprise, and ultimately, what s/he will learn in science classes (Edmonson & Novak, 1993; Schommer, 1990; Schommer-Akins,
Epistemological beliefs are thought to influence learning in several ways, affecting beliefs about education in general (Schommer, 1990; Schommer-Akins, 2004), knowledge acquisition (Barnard, Crooks, Lan, & Paton, 2008; Schommer, 1990; Stathopoulou & Vosniadou, 2007), learning and study strategies (Edmonson & Novak, 1993), self-efficacy (Ricco, Pierce, & Medinilla, 2009), and student motivation (Buehl & Alexander, 2006).

Theoretical Framework. In this investigation epistemological beliefs are defined as an individual’s attitudes, beliefs, and views about the nature of knowledge and the nature of knowing and learning (Hofer, 2004; Hofer & Pintrich, 1997; Pajares, 1992; Schommer, 1990; Schommer-Akins, 2004). Researchers generally agree that epistemological beliefs consist of four components, including one’s certainty of knowledge, how they view the simplicity of knowledge, the source of knowledge, and their justification of knowing (Hofer & Pintrich, 1997; Schommer, 1998; Ulucinar, Akar, Demir, & Demirhan, 2012). The dimensions can be generalized as described in Figure 3.

Existing knowledge into student epistemologies has been situated in the notion that epistemologies are context-dependent (Hammer & Elby, 2003; Hofer, 2001). While broad research into this topic may help reveal student views about universal knowledge, more fine-grained details can be revealed using discipline-specific investigations. Prior discipline-specific studies of student epistemologies indicate that students’ attitudes and beliefs of science vary—sometimes widely—from those of scientists. Findings in
physics education research have reported that both majors and non-majors often view this subject matter as fragmented bits and pieces (Hammer, 1994), whereas physicists structure the knowledge hierarchically, making connections among different concepts (Gray, Adams, Wieman, & Perkins, 2008; Adams et al., 2004; Redish, et al., 1998).

![Diagram of Epistemological Beliefs](image)

Figure 3. Graphic representation of the overarching dimensions of epistemological beliefs.

Similarly, research in chemistry education at the undergraduate level has shown similar trends with traditionally taught introductory students’ beliefs about knowledge in chemistry (Barbera et al., 2009). Chemistry education research has also found that the type of instruction (traditional versus reformed) may have an impact on changing
student epistemologies (Cam & Geban, 2011). Discipline-based education research in biology has revealed similar findings. One study found a significant relationship between epistemological beliefs and students’ learning strategies, which in turn affected their assessment in a biology course (Holschuh, 1998). Another looked at a particular instructional approach that focused on teaching students to read primary literature in biology. These authors found that the approach led to a sophistication of students’ epistemological beliefs across the semester (Hoskins, Lopatto, & Stevens, 2011). Finally, research has found that students in introductory biology courses shift toward more novice-like perceptions of biology knowledge post-instruction (Semsar et al., 2011), just as they do in other disciplines. Unfortunately though, non-majors have not been a major focus in any of these studies.

The specific questions the researcher wished to answer in this study are: 1) how do science majors and non-science majors in introductory courses compare in their epistemic beliefs, and 2) how does a semester of instruction change their attitudes and beliefs about biology?

Methods

This study was conducted using a pre-post survey methodology to investigate undergraduates’ beliefs about biology and attitudes toward learning biology.
Instrument

There are a number of instruments available for measuring students’ epistemic views about science, including the Connotative Aspects of Epistemological Beliefs (Stahl & Bromme, 2007), the Epistemology Questionnaire (Schommer, 1990), Views of Nature of Science Survey (VNOSS) (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), and the Reflective Judgment Model (Kitchener & King, 1981). However, all of these instruments are domain-general and do not ask students specific questions about any one scientific discipline. The CLASS instruments, on the other hand, were exclusively designed for use in individual disciplines (Adams et al., 2006; Barbera et al., 2009; Semsar et al., 2011). The CLASS-Bio survey also aligns closely with the two overarching dimensions depicted in our theoretical framework. Specifically, the questions are designed to probe learners’ beliefs about the nature of biology (the “nature of knowledge”), and attitudes about learning biology (the “nature of knowing/learning”). Further, the CLASS-Bio was designed for use in large-enrollment, undergraduate introductory biology courses, suitable for both science and non-science majors taking introductory biology (Semsar et al., 2011).

The CLASS-Bio instrument is designed to prompt students’ agreement (or disagreement) with experts about the nature of biology and learning biology. The survey consists of 31 items on a 5-point Likert scale, each scored along a continuum from novice to expert. This type of scoring is commonly used in research into student attitudes and
beliefs (Adams et al., 2004; Adams et al., 2006; Barbera et al., 2009; Hammer, 1994) and allows researchers to determine how students differ from experts in several areas, including how knowledge is structured, problem solving tactics, and what they view as the source of knowledge (Figure 4).

**Figure 4.** Example of scoring epistemologies along a novice-expert continuum.

The 31 statements are grouped into seven categories, which address different aspects of students’ attitudes and beliefs about biology. These include: conceptual connections/memorization (if students see knowledge in biology as conceptually connected or as simple memorization), enjoyment (their interest in the subject), real world connection (if students see biology as being connected to their non-academic,
everyday lives and/or to society), and four categories characterizing student views about problem solving in biology—problem solving difficulty (the difficulty students’ have in solving problems), problem solving effort (the amount of effort students put in to solving biology problems), problem solving reasoning (the types of thinking they use in solving problems in biology), and problem solving strategies (their approaches to solving problems).

In scoring this results, the original authors collapsed the Likert scale from a 5-point scale to a 3-point scale, awarding one point for either strongly agree or agree, a score of zero for neutral, and a negative point for either strongly disagree or disagree. These scores are then used to determine a percent favorable response, or the average in which the student chose responses that agree with expert responses. By surveying practicing scientists and science education experts, the expert level was determined by Semsar and colleagues (2011) to be at or above 90%.

In the current study, the reliability of the survey (excluding a screening question used to identify if students are taking the questions seriously) was $\alpha = 0.75$, indicating a satisfactory level of reliability of the instrument. Categorical reliability was also calculated, however since each category has only a few items (ranging from 4 to 8) the $\alpha$ level for each category was low (Table 1).
Table 1. Reliability for each category on the CLASS-Bio instrument: $\alpha$ indicates raw reliability; scaled reliability using the Spearman-Brown Equation is represented by $\alpha^\prime$.

<table>
<thead>
<tr>
<th>Category</th>
<th>Conceptual Connections/Memorization</th>
<th>Enjoyment</th>
<th>Problem Solving Difficulty</th>
<th>Problem Solving Effort</th>
<th>Problem Solving Reasoning</th>
<th>Problem Solving Strategies</th>
<th>Real World Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>.76</td>
<td>.75</td>
<td>.68</td>
<td>.51</td>
<td>.65</td>
<td>.57</td>
<td>.64</td>
</tr>
<tr>
<td>$\alpha^\prime$</td>
<td>.88</td>
<td>.90</td>
<td>.86</td>
<td>.75</td>
<td>.86</td>
<td>.68</td>
<td>.87</td>
</tr>
</tbody>
</table>

Cronbach’s alpha is influenced by test length (Kline, 1986), so in order to better estimate categorical reliability, it was calculated using the Spearman-Brown formula to see what $\alpha$ values may be if the number of items in each category was increased to 20—this number is common in survey designs but still less than the total number of items in the CLASS-Bio instrument (Figure 5) (Kline, 1986).

$$r_{kk} = \frac{k(r_{11})}{[1 + (k - 1)r_{11}]}$$

$r_{kk}$ = reliability of the test $k$ times as long as the original test  
$r_{11}$ = reliability of original test  
k = factor by which the length of the test is changed

Figure 5. Spearman-Brown Equation for determining categorical reliability. Below the equation are descriptions of the variables.
Participants

Participants were students enrolled in one of two introductory biology courses at The Ohio State University during Spring Semester 2013. The CLASS-Bio was given pre- and post-instruction to students in both general education biology courses—one a required introductory course for science majors and the other course for non-science majors offered as part of the natural science requirement (see Courses, p. 28). A total of 171 students participated and consented to have their responses used for the study. Among them, 94 (66 females, 28 males) were from the science major course and 77 (44 females, 33 males) were from the non-major course, accounting for 95% and 97% participation rates in the respective courses and largely representative of the students of interest.

Administration

The surveys were administered as online assignments in both courses. Pre-instruction surveys were disseminated to students within the second week of class, and post-instruction surveys were administered during the last week of classes (just prior to final exams). Students were asked to take the surveys seriously and were encouraged to
give their own opinions. In order to create an environment in which to solicit students’ honest responses, we reminded students that they would not be graded on their responses but instead they would receive credit for completion of both surveys.

**Courses**

Both courses, traditionally taught by senior faculty members, consisted of three 50-minute lectures and one 180-minute weekly laboratory every week. Each of these is a required course, needed by science and biology majors to move on into upper level coursework, or one of the natural science choices to fulfill a general education graduation requirement for non-science majors. While both courses are aimed at promoting student understanding of basic facts, methods, and theories of modern biology, the science major course goes much deeper into the details of cellular and molecular biology. The content of this course is comprehensive and involves a detailed examination of nearly 20 topics (Appendix A). You can see by looking at the syllabus that students are immersed in the content for the duration of the semester, and the laboratory portion counts for a large fraction of the course grade. Conversely, the non-science major course is intended to provide students with a general overview of the subject of biology with a focus on broad, overarching themes such as evolution, genetics, and the natural history of life (Appendix B). While there is also a laboratory associated with this course the emphasis is less on teaching students how to excel at the lab work and more on ensuring that they are
familiar with the processes of science. In this course the non-science majors are encouraged to gain a value for how biology affects their lives through course work that highlights everyday interactions of science, technology, and society.

**Data Analysis**

To determine student performance on the CLASS-Bio survey, we followed the scoring spreadsheet and schemata produced by the original authors (Semsar et al., 2011). Individual student scores were calculated by determining their percentages of expert-like responses on the entire survey as well as in each of the seven categories. These were averaged to get the results for the class on whole. Comparisons were then made between the science major and non-major courses at the two time points of pretest and posttest.

For between-class comparisons, the researcher used two-sample *t*-tests to seek the differences in student epistemological gains between the majors and non-majors. A 2-way ANOVA could also have been calculated, however, this approach can only reveal between-class differences at the two time points (pretest and posttest) and not information on the shift in epistemologies of the two classes. The gains are better compared through 2-sample *t*-test in this scenario.

Matched gains (Gain = Post-test score – Pre-test score) were also examined via one-sample *t*-tests within each class to investigate the extent to which individual students shifted in their epistemological views over the course of a semester.
Results and Findings

Between Class Findings

Pre-instruction results showed that the science majors exhibited a higher percentage of favorable responses (those responses deemed as more expert-like) than did the non-science majors overall and in all of the categories (Table 2); there was a significant difference between the science and non-science major results ($p$’s<0.01).

Interestingly, the post-instruction results showed the reverse of this trend, with the non-science major class exhibiting a higher percentage of favorable responses than the science major class, in all categories except for “Enjoyment”. As with the pre-instruction comparison, the between-group differences for the post-instruction survey are also significant ($p$’s < 0.01) for all categories except “Problem Solving Effort” ($p = 0.75$)

Table 2. Pre- and post-instruction percent favorable responses for science major and non-science major introductory biology courses, ±SE.

<table>
<thead>
<tr>
<th>Category</th>
<th>Majors</th>
<th>Non-Majors</th>
<th>$p$ value</th>
<th>Majors</th>
<th>Non-Majors</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td></td>
<td>Pre</td>
<td>Post</td>
<td></td>
</tr>
<tr>
<td>Conceptual Connections/Memorization</td>
<td>65.5±2.5</td>
<td>25.8±2.3</td>
<td>≤0.001</td>
<td>54.2±2.9</td>
<td>56.0±3.3</td>
<td>0.19</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>48.6±3.6</td>
<td>42.8±1.7</td>
<td>0.02</td>
<td>28.1±3.4</td>
<td>31.5±3.7</td>
<td>≤0.001</td>
</tr>
<tr>
<td>Problem Solving Difficulty</td>
<td>53±3.1</td>
<td>39.2±1.9</td>
<td>≤0.01</td>
<td>44.4±2.8</td>
<td>46.7±3.3</td>
<td>0.45</td>
</tr>
<tr>
<td>Problem Solving Effort</td>
<td>56.9±3.0</td>
<td>42.6±1.8</td>
<td>≤0.01</td>
<td>42.7±2.7</td>
<td>44.5±3.5</td>
<td>0.88</td>
</tr>
<tr>
<td>Problem Solving Reasoning</td>
<td>69.1±2.8</td>
<td>36.4±2.3</td>
<td>≤0.01</td>
<td>60.2±3.2</td>
<td>53.2±3.4</td>
<td>≤0.001</td>
</tr>
<tr>
<td>Problem Solving Strategies</td>
<td>60.3±3.5</td>
<td>36.7±2.2</td>
<td>≤0.01</td>
<td>46.9±3.8</td>
<td>51.0±4.2</td>
<td>≤0.01</td>
</tr>
<tr>
<td>Real World Connection</td>
<td>65.3±2.9</td>
<td>35.9±2.0</td>
<td>≤0.01</td>
<td>53.2±3.2</td>
<td>52.9±3.5</td>
<td>0.84</td>
</tr>
<tr>
<td>Overall</td>
<td>57.8±2.3</td>
<td>34.3±1.1</td>
<td>≤0.01</td>
<td>45.5±1.7</td>
<td>46.8±2.6</td>
<td>0.59</td>
</tr>
</tbody>
</table>
Of interest in the post-instruction results is the positive gain in the category of “Problem Solving Strategies”, which was statistically significant ($p \leq 0.01$). However, the non-science students also showed a decrease in the two categories of “Problem Solving Reasoning” and “Real World Connection” post-instruction. Despite the shift, the decrease for “Real World Connection” showed no significant difference ($p = 0.84$), whereas the loss for the “Problem Solving Reasoning” category was significant ($p < 0.001$). In sum, unlike the science majors, those in the non-science major course did not deteriorate in their attitudes and beliefs about biology; generally speaking they actually showed a positive gain over the course of a semester of instruction.

**Shifts in Epistemologies**

Matched gains (positive or negative shifts) within each course were also analyzed (Table 3). For the science majors’ course, a negative shift was detected in the overall result as well as in all of the categories—a result see in the existing previous research. The negative shifts were all significant ($p$’s<0.001), suggesting that the science students deteriorated toward more novice-like conceptions in their views about biology and learning biology after a semester of instruction. Alternatively, students in the non-science major course exhibited a positive gain—both on the overall survey and in the majority of the individual categories. This outcome was largely unexpected, and has not been previously reported.
Table 3. *Overall and categorical shifts (±SE) in each course over the course of a semester of instruction. Bold values indicate significant shifts.*

<table>
<thead>
<tr>
<th>Categories</th>
<th>Majors</th>
<th>( p )</th>
<th>Non-Majors</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual Connections/Memorization</td>
<td>-39.7 ± 3.0</td>
<td>≤0.001</td>
<td>1.8 ± 2.9</td>
<td>0.90</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>-5.8 ± 4.0</td>
<td>≤0.001</td>
<td>3.4 ± 3.4</td>
<td>0.12</td>
</tr>
<tr>
<td>Problem Solving Difficulty</td>
<td>-13.8 ± 3.0</td>
<td>≤0.001</td>
<td>2.3 ± 2.8</td>
<td>0.29</td>
</tr>
<tr>
<td>Problem Solving Effort</td>
<td>-14.3 ± 3.2</td>
<td>≤0.001</td>
<td>1.8 ± 2.7</td>
<td>0.90</td>
</tr>
<tr>
<td>Problem Solving Strategies</td>
<td>-23.6 ± 3.5</td>
<td>≤0.001</td>
<td>4.1 ± 3.8</td>
<td>≤0.01</td>
</tr>
<tr>
<td>Problem Solving Reasoning</td>
<td>32.7±3.0</td>
<td>≤0.001</td>
<td>-7.9±3.2</td>
<td>≤0.001</td>
</tr>
<tr>
<td>Real World Connection</td>
<td>-29.4 ± 3.0</td>
<td>≤0.001</td>
<td>-0.4 ± 3.2</td>
<td>0.20</td>
</tr>
<tr>
<td>Overall</td>
<td>-23.5 ± 2.3</td>
<td>≤0.001</td>
<td>1.3 ± 1.7</td>
<td>0.65</td>
</tr>
</tbody>
</table>

**Discussion**

The primary goal of this study was to better understand students’ epistemologies toward the discipline of biology and learning biology. This type of research has been broadly carried out in introductory physics and chemistry education, but to a lesser extent in biology education. What distinguishes this study from others of its kind is that it involves non-majors; no studies within biology education have been reported to
specifically compare epistemologies between science and non-science majors. That said, the results of this study in part confirmed those found with other introductory science students, that the science majors decreased in the views about their disciplines over the course of a semester of traditional introductory instruction (Adams et al., 2004; Perkins et al., 2006; Barbera et al., 2008). However, this study also revealed that students in the non-science majors’ biology course did not exhibit this trend—a somewhat unexpected finding that has not been reported in the prior literature. The results here bring up the question: what are we doing in our instruction for non-science majors that we are not doing for the science majors?

Possible Factors Associated with Results

There could be several reasons for the results we obtained. The major hypothesis here is that in general, science majors receive more concentrated instruction in cellular and molecular aspects of the subject. In fact, a quick glance at the two syllabi reveals that the science majors receive detailed and exhaustive instruction in such topics, versus the relatively general overview of the subject received in the non-science major course. There are differences in the approaches that students in each course take the material, crucial differences in the content covered in the courses, and the level of real-world relevance. These three factors may play a role in students’ epistemological change.

*Coverage and depth of course materials.* Although the coverage of the number
of biology topics in the two courses is comparable, the depth of material (or the level of
detail) varies considerably. Science majors frequently get presented with elaborate details
about a host of biological concepts that are characteristically abstract, such as features of
cellular functions and structures and in-depth genetic processes. Traditionally in these
majors’ courses there has been an emphasis on fine-grained details of often abstract
phenomena as well as their theoretical underpinnings. It is assumed that science students,
particularly biology majors, are able to spontaneously make connections of the
microscopic details with macroscopic phenomena, so these relationships are not always
explicitly addressed during instruction. With non-science majors however, complex
details and theoretical processes are less stressed. Instead, after overviews of key
fundamentals, the instruction quickly moves on to macro-level phenomena with a focus
on guiding students through making links between microscopic systems and macroscopic
human endeavors. To this end, what is being presented to the science majors is often
seen as more theoretical and abstract than the material in the non-majors course.

Learners’ approaches to course material. The differing levels of detail and the
differences in the sheer amount of information required of learners in the two courses
suggest that students in each class may approach the material differently. Science majors
might feel inundated with the overwhelming amount of content (and details about that
content), and consequently resort to memorization as a way to simply survive the course
and achieve high grades. Conversely, non-science majors are often presented with broad,
overarching content and less detail is required from them. This may reduce the reliance of
non-majors on memorizing biological concepts and it may also reduce the feeling of
being overwhelmed that the majors experience. In fact, this hypothesis is supported by
the comments collected from the same student groups in end of semester surveys of
instruction collected by the department. In regards to how they studied for the course,
over half (51%) of the majors indicated that they felt overwhelmed by all of the content
and details that they were responsible for; as a result they felt they had to memorize
information by rote. Alternatively, only 35% of the non-majors reported similar
approaches to the material.

Perceived relevance of course material. Since the majors’ course dwells on
theoretically abstract details, intentional and explicit instruction on the real-world
relevance of the course material is less of a focus. As a consequence science majors may
have difficulty perceiving the course content as pertinent to their everyday lives, viewing
that material instead as only necessary to passing the course. Certainly, this will
negatively affect their epistemic views about biology (Bromme, Kienhues, & Stahl,
2008). In contrast, non-science majors are frequently introduced to materials and
problems that are closely related to humanities and directly related to the everyday
human experience. As such, the non-majors may tend to view the subject matter from a
more holistic and possibly positive perspective. The applicability of the material to which
the non-science students are exposed may have facilitated their shift toward more expert-
Instructor effect. Instructor epistemologies and characteristics have long been recognized to play a significant role in student achievement (Sundberg, Dini, & Li, 1994; Wayne & Youngs, 2003). It is the case here that there are a number of similarities between the two instructors, including their gender (male), teaching experience (experienced instructors having taught both majors and non-majors introductory courses multiple times), and interest in teaching undergraduates, and both also share a history of satisfactory student evaluations. As similar as they might be, it is still important to acknowledge some potential differences that could have affected the outcomes of this study. For instance, the instructors might differ in their personalities, teaching styles, and even their own epistemological stances that could impact their teaching foci and selection of class activities or exam questions (Ding, 2013). These differences, albeit beyond the scope of the current study, could have important implications for student epistemological growth, thus the instructor effect is a potential confounding factor in this study.

Implications for Teaching and Learning

It is of note that this study was conducted with students in courses that were traditionally taught in large lecture halls with minimal student-instructor interaction. While it is unknown what the results would have been if had the study was conducted within classes utilizing unconventional instructional techniques, there are some promising
ideas for encouraging epistemic gain in science courses. For instance, prior literature suggests that active learning and reflection can be a possible alternative to traditional course assignments, and might lead to more expert-like thoughtful and meaningful learning (Prince, 2004; Ebert-May, Brewer, & Allred, 1997). Techniques such as the utilization of audience response systems (Gauci, Dantas, Williams, & Kemm 2009; Wood, 2004), case study teaching (NCCSTS, 2005; Allen & Tanner, 2005), focusing on primary literature (Hoskins et al., 2011), engaging students in peer discussions (Allen & Tanner, 2005), and even conducting ‘think-pair-share’ activities (Allen & Tanner, 2005; Goodwin, Miller, & Cheetham, 1991), are all a step in the right direction. There is promising research on student reflection, with studies showing that reflection may foster epistemological growth and even increase content learning (May & Etkina, 2002), and the current trend of engaging students in authentic research may ascertain that such experiences have a positive effect on student epistemologies (Brownell, Kloser, & Shavelson, 2012; Lopatto, 2007), though research into that matter will need to be conducted.

Conclusions

This study extends research with introductory science students to include an important student population: the non-majors. This is a valuable effort toward developing a better understanding of science majors’ and non-science majors’
epistemological views about science. Understanding students’ prior beliefs and attitudes toward a subject is crucial for developing courses and curricula that can move them toward more expert-like thinking.

The results in this study regarding science majors are familiar, as science majors significantly decreased in their epistemic understanding during the semester. However, the results regarding non-science majors were unanticipated, as they actually improved in their epistemologies during the semester of introductory instruction. While both courses are taught with an accent on scientific literacy and are designed to provide insight into the processes of biology, the non-science major course is less content-driven and places more emphasis on the relevance of biology to students’ everyday lives. Emphasis on applicability of biology to student lives is just as important to the science majors as it is to the non-science majors, and as instructors we should not assume that because they are majoring in biology that they have already made such connections to their lives. Past research has shown that because students do not always possess productive epistemological resources, instruction must explicitly address student attitudes and beliefs toward learning science (Bromme et al., 2008; Hammer & Elby, 2003).

While more research needs to be conducted, these findings, along with those previously reported, could have broad implications not just for introductory major and non-major STEM courses, but also for developing and improving all required general education courses.
References


connotative aspects of epistemological beliefs. *Learning and Instruction*, 17, 773-785.


Chapter 3:
Student Epistemologies in an Intermediate Level Biology Course

Abstract

Student attitudes and beliefs have been extensively studied in many scientific disciplines, however, at the tertiary level these studies have generally been conducted in introductory science courses. This investigation reports a mixed-method study of students’ attitudes and beliefs about biology and learning biology in an intermediate level biology course. The study included a survey component to gauge student epistemologies in an intermediate level biology course (n=102), and individual interviews with a subset of students (n=15) throughout an entire semester to determine the reasoning behind their answers to uncover factors that students themselves see as important to changing their attitudes and beliefs about biology. By explicating the reasons behind how they answered, this study reveals fine-grained details about how epistemologies change during a semester of mid-level instruction. Survey results indicated that students improved slightly in their epistemologies during the course of the semester and did not display the same novice-like shifts as seen in science majors within introductory courses. However, these shifts were not statistically significant. Interview data showed several factors, including experience in college and “learning how to learn”, that may be associated with
expert-like changes in epistemologies over the course of a semester of intermediate level instruction.

**Introduction**

Students’ epistemologies about science have been studied for decades but at the college level most work has been done with students in large, introductory courses for science majors (Adams, Perkins, Podolefsky, Finkelstein, & Weiman, 2006; Barbera, Perkins, Adams & Wieman 2008; Semsar, Knight, Birol & Smith, 2011). Scant research has investigated student epistemologies past the introductory level, though what has been done appears to support epistemological gain over undergraduate careers. The one existing longitudinal study looking at students’ epistemologies across the course of their undergraduate careers found that the negative shifts seen with introductory students do not persist into upper level course work (Hansen & Birol, 2014). While upper level students did not necessarily score as high as experts, there were significantly more favorable responses among students at the end of their fourth year versus those in their first year of college. However, more detailed understanding needs to be acquired about students at the intermediate and upper levels of undergraduate course work in order to ensure that we are moving students toward more expert-like conceptions about biology before they graduate from college. A better understanding of students’ attitudes and
beliefs about biology across all four years of undergraduate education can in the short term provide insight into better instruction and improved learning, and in the long run help ensure retention of STEM majors.

**Theoretical Framework**

Epistemological beliefs can be defined as an individual’s attitudes and views about the nature of knowledge and the nature of knowing (Hofer, 2004; Hofer & Pintrich, 1997; Pajares, 1992; Schommer-Akins, 2004). There is general agreement in foundational literature that epistemologies consist of two overarching parts: the nature of knowledge and the nature of knowing (Hofer & Pintrich, 1997; Schommer, 1998; Ulucinar, Akar, Demir, & Demirhan, 2012). Considered as a part of these larger aspects are the certainty and simplicity of knowledge (nested within the nature of knowledge aspect) and justification for knowing and the source of knowledge (nested within the nature of knowing aspect). For example, do students view knowledge as changing or static (certainty of knowledge), do they see knowledge in the field as simple facts to memorize or as interconnected concepts (simplicity of knowledge), and do they look to authority (such as texts, instructors, etc.) as a source of knowledge rather than seeing knowledge as being built within a field (justification and/or source of knowledge). In concert, these characteristics of one’s attitudes and beliefs about learning and about knowledge affect learning and understanding in general as well as in specific disciplines.
Research on student beliefs has been controversial in regards to the domain generality or specificity of epistemological beliefs, and it is not yet decided as to whether or not epistemological beliefs are context-specific or can be generalized across many subjects (Buehl & Alexander, 2006; Muis, Bendixen, & Haerle, 2006). Many studies have commonly conceived of epistemologies as context-dependent, meaning that what a student believes about knowledge in biology may not be the same as what they believe about knowledge in general (Buehl & Alexander, 2006; Hammer, 1994; Hofer & Pintrich, 1997). For that reason this study follows the literature pertaining to discipline specific research, with the assumption that studies of this type can offer more complete analysis to explain student attitudes and beliefs in a certain area of science as well as better inform the literature of discipline-based science education research (Adams et al., 2006; Hammer & Elby, 2003; Hofer & Pintrich, 1997; Schommer, 1998; Semsar et al., 2011). For instance, investigations into student beliefs about chemistry and physics have revealed that many undergraduates see knowledge in these fields as fragmented, though scientists themselves see concepts and topics within the disciplines as highly connected (Barbera, et al., 2008; Cam & Geban, 2011; Hammer, 1994). The research with introductory biology courses has shown much of the same, that is, science majors in large-enrollment introductory courses exhibit novice-like shifts in their epistemologies during introductory courses (Ding & Mollohan, 2015; Semsar et al., 2011). While research on students’ attitudes and beliefs about biology above the introductory level is
sparse, there is one longitudinal study within the field which revealed that students do, given time and further instruction, eventually shift back toward more expert-like conceptions after introductory courses and before graduation (Hansen & Birol, 2014).

This research is also based on the notion that science epistemologies are made up of multiple components, including if students see knowledge as conceptually connected or as discrete facts to memorize, enjoyment of the subject, problem solving capabilities, the connection of the material to their everyday lives, and problem solving and reasoning abilities (Figure 6) (Adams et al., 2006; Barbera et al., 2008; Semsar, et al. 2011). By gaining a better understanding of students’ beliefs in each of these four categories, we may better understand their learning in biology, and may develop improved instruction based on students’ beliefs about the discipline.
Figure 6. Representation of the make up of student epistemologies about biology and learning biology, consisting of (from top to bottom): two overarching dimensions of epistemologies, and four categories of epistemologies. Problem Solving Skills includes four subcategories.

These four themes, which with the four sub-themes nested within Problem Solving Skills, can be aligned with the instrument used in this study, the Colorado Learning Attitudes about Science Survey (CLASS-Bio) (see Instrument, p. 49). The CLASS-Bio survey was designed to separate epistemologies into seven categories, including conceptual connections within the material, enjoyment of the subject, four problem solving categories (including problem solving difficulty, effort, reasoning, and strategies), and
relevance of the material (“real world connection”) (Semsar et al., 2011). Table 6 (p. 56) illustrates this alignment. The themes listed in Figure 6 are equivalent to the categories, specifically conceptual connectedness of the topics in biology, students’ enjoyment of the subject, and the real world connections categories. The theme of “problem solving” can be conceived to include the subdivisions of difficulty, effort, reasoning, and strategies in order to fully align with the instrument; this means that essentially there are seven aspects within epistemic beliefs.

This investigation uses a mixed method design including a written survey, student interviews, and classroom observations, in order to characterize intermediate-level student epistemologies and how they may change during the course of a semester. The survey portion of the study provides quantitative data to show the extent to which student epistemologies change after the course of a semester of intermediate level instruction, while the interview portion of the study elaborates on their responses to the survey questions. Classroom observations were made on four occasions in order for researchers to obtain an idea of the instructors’ styles and pedagogy as well as an understanding of the topics covered in the course. Qualitative and mixed methods research in science education has been used to develop a fine-grained understanding of affective factors associated with student gains in epistemologies in the past, and case studies, interviews, and observations can be used to triangulate the data to ensure legitimate conclusions (Denzin & Lincoln, 1998; Devetak, Glazar, & Vogrinc, 2010; Merriam, 1998; Saldana,
In addition, both the qualitative and quantitative components of this study are grounded in the idea that student epistemologies about biology are multifaceted (as shown in Figure 6).

**Research Questions**

This study extends previous investigations of student epistemological beliefs about learning biology and the nature of biology to a middle-level biology majors course, to determine if continued instruction in the discipline changes student attitudes about the subject and, if so, how. Two research questions drove this study, including:

1) Are there changes in student epistemologies during the course of a semester of intermediate level biology instruction?

2) What factors do students associate with epistemic changes?

**Design and Methods**

To investigate students’ epistemologies about biology and learning biology in an intermediate level course for biology majors, a mixed methods study was conducted. Utilizing both qualitative and quantitative methods of data collection enabled us to collect data from multiple sources, including pre-post written surveys, individual interviews, and classroom observations (Merriam, 1998; Yin, 2009). In total, there were over 41 hours
of interviews transcribed and coded and approximately 3.6 hours of classroom observations.

Background and Participants

Course. The research was conducted at The Ohio State University during the spring semester of 2014. This course, Biology 3401: Integrated Biology is required of all life sciences majors at this school and was designed to be taken immediately following the introductory courses. It was designed to focus on integrating biology concepts first introduced in the introductory classes with one another and with other science disciplines such as chemistry and physics. Instruction on integrating topics and scientific disciplines was explicit, first showing students how to find commonalities among scientific disciplines and/or concepts, and then students were expected to draw from other disciplines in explaining natural phenomena on exams and during class assignments. This course was team-taught, allowing instructors who are “experts” in their fields of study to teach related subjects. The expectation that there would be interaction between students and instructors was spelled out in the syllabus (which can be found in Appendix 3). This was seen in lecture via the emphasis on large group (lecture) and small group activities, and through an emphasis on peer group work in the small group sessions, which met once a week separately from the larger lecture.

Participants. Participants were students enrolled in the integrated biology course
(n=102) during the spring 2014 semester. Students were recruited in person during a portion of the first class session and through flyers posted on the course homepage during the first week of the semester. A total of 102 students (female=51, male=51) took both surveys.

**Survey Design and Procedure**

*Instrument.* The CLASS-Bio instrument is a 31-item survey, which asks the students to answer questions on a five-point Likert scale and scores student responses on an expert-novice continuum (Semsar et al., 2011). The 31 statements were grouped into seven categories by the original authors of the instrument. These categories address students’ perception knowledge in biology (Conceptual Connections/Memorization), their enjoyment of the subject (Enjoyment), if they recognize relevance of the material to their non-academic lives (Real World Connections), and four questions that address students’ views of problem-solving in biology— their perceived difficulty in solving problems (Problem Solving Difficulty), the amount of effort they put in to solving problems (Problem Solving Effort), the types of thinking they use to solve biology problems (Problem Solving Reasoning), and their approaches to solving biology problems (Problem Solving Strategies).

The CLASS-Bio instrument was designed for use in large introductory courses and has been validated by the original authors for use in upper-level traditionally taught courses as well (Semsar et al., 2011). The alpha for this study was $\alpha=.96$, indicating an
acceptable level of reliability with this sample. This alpha level is higher than some previous studies (see, for example, Ding & Mollohan, 2015) and is comparable to what the authors of the original instrument found in their study (Semsar et al., 2011).

**Procedure.** The Colorado Learning Attitudes about Science Survey (CLASS-Bio) was made available to all students in the course via the course home page at the beginning of the semester (within the first week of classes) and at the end of the semester (during the last week of class, just before final exams). The instructors offered a small amount of course credit as incentive for students to complete both surveys.

**Interview Design and Procedure**

**Participants.** Students enrolled in the course were invited to participate in a series of interviews with the researcher. A total of fifteen students volunteered to participate in the individual interviews. Students both sexes, and several pre-professional tracts (including pre-medicine, pre-physical therapy, and those interested in going on to graduate school in biology or a related field), and a majority of the participants were in their junior or senior years (Table ). Over half of the interviewees were seniors (53%; n=8), there were six juniors (40%), and one sophomore (7%). This is reflective of the class as a whole, as the class is mostly seniors (n=133; 87%), juniors (n=19; 12%) and 1 sophomore (<1%). The average grade for the entire class was 85.3%, and the average grade for the fifteen interview participants was 89.3%, indicating that these fifteen
students are a representative sample of the class as a whole.

*Interview Procedure.* Each interview participant met with the researcher four to five times throughout the semester. Interviews lasted an average of 26.2 minutes (Table 4). Participants received a gift card as compensation for their time.

Table 4. *Interviewee demographics.*

<table>
<thead>
<tr>
<th>Student (Pseudonym)</th>
<th>Gender</th>
<th>Rank</th>
<th>Average Interview Length (in minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alice</td>
<td>Female</td>
<td>Senior</td>
<td>24.4</td>
</tr>
<tr>
<td>Jackson</td>
<td>Male</td>
<td>Senior</td>
<td>37</td>
</tr>
<tr>
<td>Jason</td>
<td>Male</td>
<td>Junior</td>
<td>25.6</td>
</tr>
<tr>
<td>Jennifer</td>
<td>Female</td>
<td>Senior*</td>
<td>16.2</td>
</tr>
<tr>
<td>Jim</td>
<td>Male</td>
<td>Junior</td>
<td>25</td>
</tr>
<tr>
<td>Joey</td>
<td>Male</td>
<td>Sophomore</td>
<td>28.1</td>
</tr>
<tr>
<td>Julie</td>
<td>Female</td>
<td>Senior</td>
<td>31.3</td>
</tr>
<tr>
<td>Keith</td>
<td>Male</td>
<td>Junior</td>
<td>23.8</td>
</tr>
<tr>
<td>Michael</td>
<td>Male</td>
<td>Senior</td>
<td>33.4</td>
</tr>
<tr>
<td>Nick</td>
<td>Female</td>
<td>Junior</td>
<td>22.3</td>
</tr>
<tr>
<td>Rhonda</td>
<td>Female</td>
<td>Senior*</td>
<td>21.5</td>
</tr>
<tr>
<td>Rick</td>
<td>Male</td>
<td>Senior*</td>
<td>15.3</td>
</tr>
<tr>
<td>Sasha</td>
<td>Female</td>
<td>Senior</td>
<td>23.5</td>
</tr>
<tr>
<td>Stephanie</td>
<td>Female</td>
<td>Junior</td>
<td>22.2</td>
</tr>
<tr>
<td>Xhin</td>
<td>Female</td>
<td>Junior</td>
<td>22.5</td>
</tr>
</tbody>
</table>
During each interview, the researcher asked the students to respond verbally to statements included on the CLASS-Bio survey (see *Survey Design and Procedure*) and asked them to explain their answers (see Appendix 3 for sample interview questions from each interview) during concurrent think-aloud interviews. This was done to get the reasoning behind their answers to see if there is any relationship between their thinking and any changes in their attitudes and beliefs about biology and learning biology during the semester. For instance, simply knowing that a student agrees with a statement about the real world connectedness of biology does not tell researchers anything about their attitudes and views or how they conceptualize this relevance. However, by asking them to expound on their response (i.e., *why* they strongly agree/agree/disagree/strongly disagree with a statement) can provide more information to see how these views connect to their attitudes toward the subject and toward learning. All interviews were audio and/or videotaped and later transcribed.

*Classroom Observation Procedure*. To gain a better understanding of the course (including the topics and the sequence in which they were taught, as well as the type of instruction and pedagogical techniques used) classroom observations were conducted. There were four observations in total including two for each of the instructors. The instructors did not know when the observations would occur, and the researcher sat in the back of the classroom and did not participate, letting the instructors manage the class as usual. Observations focused on instructors’ time spent lecturing, their interaction with
students, how much time they spent speaking on topics, how much time they spent answering student questions, and their pedagogical techniques. The complete observation protocol can be found in Figure 7.

Date:

Instructor:

Before Class:

--Any interaction with students (location, type of interaction, etc.)

--Location in classroom prior to beginning class session

During Class Period:

--Administrative Information?

--Time spent per topic/ # of topics presented

--Answer student questions? (time spent or number answered)

--Ask questions of students? (time spent asking questions or number asked)

--Level of interaction between peers

  --Any time for students to work together in class? (include activity and time spent)

--Location during instruction (podium in front of class, walk around room, etc.).

--Level of interaction with students (how much student/instructor interaction)

Figure 7. Observation protocol.
Data Analysis

Survey Data
To determine student performance on the CLASS-Bio survey we followed the scoring schemes created by the instrument authors (Semsar et al., 2011). Individual scores were calculated by determining students’ percentages of expert-like responses (termed favorable responses) on the entire survey, as well as in each category. These favorable responses were then averaged for the class as a whole. One-sample t-tests were used to determine if there were significant differences between the pre and post-instruction surveys. Student gains (Gain = Posttest Score – Pretest Score) were also examined using one-sample t-tests within the class to investigate the extent to which individual students demonstrated improvement in their epistemological views over the course of a semester.

Interview Data
During the semester, each of the fifteen students met with the researcher three to five times to elaborate on their answers given in the CLASS-Bio survey. The goal for the interviews was to get, in the students’ words, what factors they perceive as important to their attitudes and beliefs about biology and learning biology and to better understand their reasoning in answering the CLASS questions. After asking students if they agree or disagree with a statement from the CLASS-Bio survey, I asked them why they agreed or
disagreed with the statement. For example, I asked Stephanie why she agreed with the statement that learning biology is important for everyone, not just students in biology, and she stated “because biology is life, it’s all around and you can’t get away from it” (interview 1). This is a vague statement, so I then asked her to explain what she meant by “biology is life”. I asked students to elaborate until their responses provided enough information that it was clear why they answered the way they did. Sample questions from each of the interviews can be seen in Appendix 4. Follow up questions were asked to determine what students themselves see as important to their attitudes and beliefs about biology and learning the subject. These follow up questions were based on students responses, thus they changed from interview to interview, but in general they were similar to the example provided above, in which I asked them to explain why they answered the way they did, or to elaborate on their answers if they were not clear.

Two researchers analyzed all interview transcripts for student responses using grounded theory for coding and thematic analysis (Glaser & Strauss 1967; Fossey, Harvey, McDermott, & Davidson, 2002; Merriam, 1998; Saldana, 2013). Data were analyzed in two parts, first to identify themes as they emerged from the individual data and second to identify the common themes across the interviews (Fossey et al., 2002; Saldana, 2013). Initial inter-rater reliability between the first two coders was calculated at 84% prior to any discussion. The researchers met to discuss the data and reached agreement on the themes relevant to this study, and after discussion inter-rater reliability
was calculated at 98%. The 2% that were not agreed upon were left out of subsequent analysis and discussion. In order to ensure reliability, an additional researcher read one quarter (approximately 25%) of the transcripts and determined the same categories (100% agreement).

The categories that emerged from the interview transcripts lined up with the themes explained in the theoretical framework. In order to confirm that the data from interview transcripts aligned with the theoretical framework of the study, the researcher integrated the categories from the theoretical framework (Fig. 6) with the themes and sub-categories from the transcripts (Table 5).

Table 5. Alignment between emergent themes from interviews and the characteristics of epistemologies outlined in the theoretical framework

<table>
<thead>
<tr>
<th>Interview Category/Theme</th>
<th>Associated Theme(s) from Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitudes (positive or negative)</td>
<td>Enjoyment</td>
</tr>
<tr>
<td>Connections</td>
<td>Conceptual Connections/Memorization; Real World Connections</td>
</tr>
<tr>
<td>Experience (in class, in college, “Learning How to Learn”)</td>
<td>Conceptual Connections/Memorization; Problem Solving Skills and Reasoning</td>
</tr>
<tr>
<td>Interest</td>
<td>Enjoyment; Real World Connection</td>
</tr>
<tr>
<td>Grades</td>
<td>Problem Solving Skills and Reasoning</td>
</tr>
<tr>
<td>Quantitative Skills</td>
<td>Problem Solving Skills and Reasoning</td>
</tr>
<tr>
<td>Thinking Ability (Expert/Novice Thinking)</td>
<td>Conceptual Connections/Memorization; Problem Solving Skills and Reasoning; Real World Connections</td>
</tr>
</tbody>
</table>

61
Observation Data

Observation notes were coded to see if any patterns were seen between and within the instructors’ lectures, which was used to determine if students’ interactions in class with each other or the lecturers corresponded with changes in their epistemic views over the course of the semester. The codes or themes were allowed to emerge from the observations in much the same way as the interview transcripts (Fossey et al., 2002; Saldana, 2013). Inter-rater reliability for this portion of the data was calculated to be 92% between the two researchers who coded the qualitative data (the same two researchers coded interview transcripts and classroom observation data). Following a discussion between the two 100% agreement was reached.

Findings

Survey Results

Survey results indicated that students in this intermediate level biology course showed slight though statistically insignificant improvement in their epistemologies about biology and learning biology during the semester, overall and in all categories except one, in which they remained stable (Problem-Solving Effort) (Table 6). None of these positive shifts were significant ($p>0.05$).
Table 6. Pre- and post-instruction scores indicating percent agreement with experts on the CLASS-Bio for the intermediate level biology majors course, ± standard error. None of the shifts was significant (p=.05). Percentages included in this table represent the average percent agreement with expert-like responses.

<table>
<thead>
<tr>
<th>CLASS Category</th>
<th>Pre-Instruction</th>
<th>Post-Instruction</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>64.1±1.7</td>
<td>65.4±1.9</td>
<td>0.49</td>
</tr>
<tr>
<td>Conceptual Connections/Memorization</td>
<td>62.1±2.2</td>
<td>62.8±2.6</td>
<td>0.68</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>74.0±2.7</td>
<td>75.5±2.5</td>
<td>0.78</td>
</tr>
<tr>
<td>Problem Solving-Difficulty</td>
<td>64.3±2.7</td>
<td>67.3±3.0</td>
<td>0.07</td>
</tr>
<tr>
<td>Problem Solving-Effort</td>
<td>60.7±2.3</td>
<td>61.0±2.2</td>
<td>0.96</td>
</tr>
<tr>
<td>Problem Solving-Strategies</td>
<td>53.1±2.6</td>
<td>56.0±2.6</td>
<td>0.57</td>
</tr>
<tr>
<td>Real World Connection</td>
<td>64.5±2.5</td>
<td>66.9±2.4</td>
<td>0.12</td>
</tr>
<tr>
<td>Reasoning</td>
<td>72.4±2.0</td>
<td>75.5±2.0</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Qualitative Findings

Interview Findings
Students’ responses to interview questions indicated that among intermediate- and upper-level college undergraduates there are several common themes relating to their attitudes and beliefs about biology and learning biology. There were also statements that the researchers coded as examples of either expert- or novice-like thinking.

Emergent themes. A total of 24 themes were originally uncovered in the
transcripts. After team discussions among the researchers it was agreed that the major themes could be collapsed and some could be subsumed under the major themes as subcategories. What remained after restructuring the data were seven major themes with sub-categories nested within them (Table 7).

Table 7. *Emergent themes and codes from interview transcripts.*

<table>
<thead>
<tr>
<th>Category/Theme</th>
<th>Subcategory</th>
<th>Associated Code(s)</th>
<th>Definition/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitudes</td>
<td>Negative Attitude</td>
<td>ATT-</td>
<td>Attitude(s) about a course or subject influences student’s attitudes during the semester</td>
</tr>
<tr>
<td></td>
<td>Positive Attitude</td>
<td>ATT+</td>
<td></td>
</tr>
<tr>
<td>Connections</td>
<td>Connections between classes and/or disciplines</td>
<td>CCCLASS</td>
<td>Student is able to make connections between classes</td>
</tr>
<tr>
<td></td>
<td>Connections between topics (w/in a course)</td>
<td>CC-TOP</td>
<td>Student is able to make connections between topics within a subject or course</td>
</tr>
<tr>
<td></td>
<td>Real world connections</td>
<td>RWC</td>
<td>Student is able to make connections between topics and their everyday life, or recognizes “real world” applications of topics</td>
</tr>
<tr>
<td>Experience</td>
<td>Experience in class</td>
<td>EXP CLASS</td>
<td>Student feels experience in one or more class(es) has improved their attitudes toward biology</td>
</tr>
<tr>
<td></td>
<td>Experience in college</td>
<td>EXP or EXP-ULC</td>
<td>Student feels experience in college and/or upper level courses has improved their attitudes toward biology</td>
</tr>
<tr>
<td></td>
<td>Learning how to learn</td>
<td>LHL</td>
<td>Student recognizes that they had to learn how to learn in college and doing so has improved their attitudes toward biology</td>
</tr>
</tbody>
</table>

Continued on next page
The overall frequency of comments regarding each theme is included in Table 8. In order to determine if there were shifts in epistemologies during the semester, frequencies were also calculated for early semester (defined as interviews 1 and 2) and late semester (defined as interviews 4 and 5). 

<table>
<thead>
<tr>
<th>Table 7 continued</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Experiences</td>
</tr>
<tr>
<td>Past Experiences</td>
</tr>
<tr>
<td><strong>Interest</strong></td>
</tr>
<tr>
<td>Career Focus</td>
</tr>
<tr>
<td>Enjoyment of Topic(s)</td>
</tr>
<tr>
<td>Enjoyment of Instructor</td>
</tr>
<tr>
<td>Intrinsic Interest</td>
</tr>
<tr>
<td><strong>Grades</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Quantitative Skills</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Thinking Ability</strong></td>
</tr>
<tr>
<td>Expert-like Thinking</td>
</tr>
<tr>
<td>Novice-Like Thinking</td>
</tr>
</tbody>
</table>
Table 8. *Frequency of comments from transcripts.*

<table>
<thead>
<tr>
<th>Overarching Theme</th>
<th>Subcategory</th>
<th>% of comments early in semester (n=178)</th>
<th>% of comments late in semester (n=202)</th>
<th>% of total comments (n=380)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attitude toward class/discipline</strong></td>
<td>Positive</td>
<td>2.2</td>
<td>2.5</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>8.4</td>
<td>1.9</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>Connections</strong></td>
<td>Between classes in biology and/or disciplines</td>
<td>16.2</td>
<td>20.8</td>
<td>18.9</td>
</tr>
<tr>
<td></td>
<td>Between topics within biology</td>
<td>7.3</td>
<td>5.9</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>Real World connections</td>
<td>11.8</td>
<td>14.3</td>
<td>13.0</td>
</tr>
<tr>
<td><strong>Experience</strong></td>
<td>In College/upper level courses</td>
<td>2.8</td>
<td>9.9</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>In all biology classes</td>
<td>12.9</td>
<td>10.8</td>
<td>12.2</td>
</tr>
<tr>
<td><strong>Interest in Biology</strong></td>
<td>“Learning how to learn”</td>
<td>8.4</td>
<td>11.8</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td>Intrinsic interest</td>
<td>11.8</td>
<td>13.8</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>Career interest</td>
<td>4.5</td>
<td>1.4</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>Enjoyment of a class</td>
<td>8.9</td>
<td>4.4</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>Enjoyment of an instructor</td>
<td>2.2</td>
<td>1.4</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Grades</strong></td>
<td></td>
<td>5.6</td>
<td>.99</td>
<td>3.2</td>
</tr>
<tr>
<td><strong>Quantitative Connections to Biology</strong></td>
<td></td>
<td>2.2</td>
<td>1.4</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>46.8</td>
<td>53.2</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Based on the frequencies, the ten most common categories that students mentioned in their interviews included: connections between biology classes and/or science classes (18.9% of total comments), connections between material in classes and the real world (13% of total comments), intrinsic interest in biology (13% of total comments), experience in biology classes at the college level (12% of total comments), what students termed “learning how to learn” (10% of total comments), being able to see a connection between topics within biology (6.6% of total comments), experience in college and upper-level courses (6.6% of total comments), enjoyment of a particular class (6.5% of total comments), having an negative attitude toward a class (5% of total comments), the importance of grades (3.2% of total comments), and career interest (2.9% of total comments). There were three additional themes or subcategories that were mentioned the least, including instructors of a course and quantitative skills as being important to biology (both with 1.8% of total comments), and having a positive attitude toward the subject or a course (0.2% of total comments).

In order to more straightforwardly report the findings, the four categories of factors that affect student epistemologies (as outlined in the Theoretical Framework) have been aligned with the codes and subcategories that emerged from the interview transcripts as described in the Methodologies section (Table 5; p. 53).

Conceptual Connections/Memorization. During interviews, all fifteen interview participants mentioned that being able to see a connection between scientific disciplines
was something that improved their attitudes toward biology. The majority of comments in the interviews were in regards to this theme (18.9%) and pertained to making connections between biology and other sciences, such as chemistry or anatomy, rather than a connection between topics within the field of biology. Only 6.6% of total comments were about making connections between topics within the subject of biology. Additionally, the majority of these comments came later in the semester (21% of comments in this category) rather than before the midterm exam (16.2% of comments in this category).

In their comments, students revealed that having experience in courses above the introductory level, or beyond pre-requisite courses such as chemistry and organic chemistry, has allowed them to make such connections between courses, as well as rely less on memorization:

“the more classes I took and the more I progressed, like through o chem and such, the more I found these connections” (Alice, interview 2)

and

“If I had stopped after my sophomore year, I basically would have not had any integration in my knowledge. I would maybe have been able to tell you about o chem or something like that, but I wouldn’t have been able to tell you about the organic chemistry in your body, which is what matters” (Jackson, interview 1).

Based on comments like these it is no surprise that the juniors and seniors—the “upperclassmen”—such as Alice and Jackson found more connections between
disciplines than did the lone sophomore in the course, Joey. Early in the semester he stated:

“I’ve never had to balance an equation in biology....At this point I just know about a hundred reactions and no context for it” (interview 2).

There was some change in his epistemologies related to this course, as at the end of the semester he said:

“this course has allowed me to see that maybe there is some overlap between classes, between disciplines”. (interview 5)

Related to this theme is the subcategory of what students themselves termed “learning how to learn” (10% of total comments). Early in their undergraduate careers several students felt that they were not equipped to learn at the college level, and thus felt like they were struggling to keep up. This struggle resulted in less positive attitudes toward biology, and in turn affected how they viewed learning in the subject. The majority of the interview participants felt that in early courses felt similarly to Michael, who summed it up best:

“the first two years, the pre-req years, are kind of like learning the alphabet and learning how to spell and all of that. Then the upper level courses, they’re more like the language and learning how to speak it” (interview 4).

Also related to learning how to learn, it was mentioned by all of the students that there is a difference between learning and memorization. They described memorization
as a way to get decent grades or pass exams, but they did not think it was associated with long-term learning or deeper understanding. All of the interview participants mentioned that they have utilized memorization during their college careers, particularly in the pre-requisite courses (such as introductory biology classes and the pre-requisite chemistry classes like inorganic and organic chemistry). Rhonda’s comment exemplifies most of the others’ when she stated that that both learning and memorization are important, but making a distinction between them:

“memorization does help sometimes, but you have to understand what you’re memorizing.... you have to understand what you’re memorizing before you know it....It’s [memorization] not going to help me apply the answer to other stuff”, but “you have to be able to recall it...to actually learn it” (interview 1).

Enjoyment. Having an intrinsic interest in biology made up 13% of the total comments. Nearly all students (n=14) stated that having a strong interest in the subject of biology has affected their epistemologies toward it, and toward learning. Most stated that they have always had a natural curiosity about the subject not related to their career goals. All fifteen said they would take a course in biology “just for fun”, for instance, one student stated that:

“besides having to learn the subject, or take classes like ecology or evolution, I would probably choose to do that anyway” (Jason, interview 4).
Like Jason, Michael had a very strong intrinsic interest that encouraged him to minor in biology and continue taking biology courses after changing his major to engineering:

“When I go home, I read books that are about physics and biology and stuff just because I’m interested. For fun, basically. That’s my convoluted sense of fun” (interview 1).

While most students did not waver during the semester about their high level of interest in the subject, one was honest about his level of interest overall, as a graduating senior:

“I’ve got the problem that’s deep in my bones” (Peter, interview 3).

Peter was able to articulate that while he still “loved” biology, he had “checked out” by the midterm in anticipation of graduation. Similarly, Rhonda felt that

“its sort of bittersweet. I’m graduating and I still want to keep my interest high in this sort of thing, but with my final finals coming up, it’s hard to keep that interest. Really hard, actually” (interview 5).

In looking at the frequency of comments related to enjoyment of biology and interest in the subject, there was little change over the course of the semester for this category, with early interviews and later interviews all revealing a high level of interest among all participants, even those graduating seniors who said that they were struggling to continue until graduation.

The only student who did not mention an innate interest in the subject was Joey, who instead stated that he was only interested in biology because it was “the best major
“for pre-med” students. While the other fourteen students did mention that biology was well aligned with their undergraduate objectives (which made up 3.9% of total comments), Joey’s interests were to be a doctor, and he made clear to the interviewer that the choice of the biology major was only related to his career goals.

**Real World Connections.** Being able to make conceptual connections between their classes and their everyday, non-academic lives was mentioned by all fifteen interviewees (making up 13% of the total comments) as being important to both their attitudes toward the subject and to learning the subject. Experts recognize that topics covered in classes have meaning in the “real world,” whereas novice learners may not always see such links; the students in this study seemed to support this assertion. For example, Alice, a senior, makes many connections between her everyday, non-academic life and her courses:

“I really like cooking, and organic chemistry taught me how ingredients will interact in a recipe…. Even applying that further, in a nutritional way, likes what it does in our system. Which way we can use fats and energy and how fats interact. Even what tastes good to us is biology” (interview 2).

Other students gave more superficial responses to how biology relates to their non-academic lives, for instance:

“I can now identify the type of mosquitoes that are biting me because of this class” (Stephanie, interview 5), or
“I notice all the time what I’m eating, drinking, and think about how it might be reacting in my body” (Julie, interview 3).

During the semester there was a change in the percentage of comments related to students being able to make real world connections with the material (from 11.8% to 14.4% of comments in this category). This is not surprising, as the instructors of the course make a point to emphasize everyday examples of the topics discussed.

Problem Solving. The interview transcripts revealed several patterns in regard to how students see problem solving as related to their attitudes and beliefs about biology. First, there were two themes in which most answers for the problem solving questions fell, those being quantitative skills and intrinsic interest in biology. Seventy percent of the students interviewed mentioned that quantitative skills are important for biology but often discourage them from putting in as much effort as they should (1% of the total comments). There was no change in the frequency of this theme during the course of the semester; it seems that for students like Julie, “math is too difficult” and this makes them “give up and study something else in biology” (interviews 2 & 4, respectively). However, there were several students who understood how important math is to biology. These students, like Keith, related that they

“may have to work a little harder but it’s worth it. Once you have the mathematics behind the results [referring to statistical tests that biologists run], you have even more support for the results and eventually for…the theory” (interview 1).
Responses to problem solving questions also seemed to prompt students to respond by describing their interest in a subject. For example, Sasha responded that she will “put more time into work” in a class or for a topic she enjoys (interview 4). Other students echoed this as well, including Nick, who stated that

“if I go into a class thinking it’s going to be awful and hard, it’s going to be awful and hard. And I’m not going to work as hard as a result” (interview 2).

Reasoning. Comments made during interviews that related to student reasoning ability were most often coded as examples of expert or novice thinking. This made it difficult to determine if there was a shift in students’ responses about reasoning over the course of the semester. However, one specific question was asked during the third interview that pertained directly to students’ scientific reasoning. It was asked of all 15 interviewees if they thought they used reasoning skills that they learned in biology in other areas of their lives. Only three of the fifteen students (20%) did not provide adequate answers or explanation for their answers. The majority of students provided thorough answers that show they understand scientific reasoning and how it can be used in their everyday lives:

“I use it all the time, for sure. Like when my mom tells me that I’ll catch a cold from being outside without a hat. I use a whole string of reasoning to explain why that is not true” (Stephanie) or
“trying to understand a concept and apply it to another set of parameters...applying what you know to other scenarios. That is necessary in biology and in life” (Keith).

However, the minority of students (20%) had difficulty providing an example of reasoning in their lives, like Julie:

“...besides like, the time management of it, no. I wouldn’t say that I can use scientific reasoning except in science” (interview 1, emphasis belongs to student).

When asked to elaborate on the “time management” statement, she explained that she uses the time management skills that she learned in studying biology when planning her time in other areas of her life. This statement indicates that she does not have a comprehensive understanding of what reasoning is, or how it can be used (in or out of science).

**Expert and Novice Thinking**

There were a large number of comments in the interview transcripts that pertained not to any of the themes or subcategories, but instead specifically to students’ thinking about biology and learning biology. These examples were discussed during the coding process to determine if there were patterns to the type of thinking that students exhibited. It was concluded after discussion between two researchers that such
comments were examples of either novice-like or expert-like thinking. These comments were coded and patterns of student thinking were revealed.

At the beginning of the semester novice-like thinking accounted for 55% of the comments coded for type of thinking, versus 32% of comments agreed upon as expert-like thinking. During later interviews there were more examples of expert thinking (68%) than of novice thinking (44%). These results lend support to the quantitative survey results as well, as they also show that students appeared to become more expert-like in their thinking about biology over the course of the semester. Examples of students’ expert and novice thinking based on the categories in the CLASS-Bio survey are included in Table 10.
Table 9. *Examples of expert and novice–like thinking form interviews. Names in parentheses following the examples are the students who stated such comments.*

<table>
<thead>
<tr>
<th>Novice Thinking</th>
<th>Expert Thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>There is only one scientific method (Sasha, Jim)</td>
<td>There is not a linear process in doing scientific research and research can be “messy” (Jackson, Keith, Michael)</td>
</tr>
<tr>
<td>The only good reason to study biology is to advance human health (Joey)</td>
<td>Everyone should learn biology, even if they are not biology majors (Jackson, Michael, Stephanie)</td>
</tr>
<tr>
<td>Tenuous connection between real world and biology concepts (Julie, Jennifer)</td>
<td>Able to make frequent and/or explicit connections between what they’ve learned in biology and the real world (Alice, Jason, Keith, Michael, Nick)</td>
</tr>
<tr>
<td>See biology research as only “lab work” (Rhonda)</td>
<td>There is creativity in science and in scientific research (Jason, Keith, Michael, Stephanie)</td>
</tr>
<tr>
<td>Knowledge in biology consists of “separate facts” and “is based on memorization” (Jennifer, Peter)</td>
<td>Knowledge can change, it is not “fixed or stable” (Nick, Xhin)</td>
</tr>
</tbody>
</table>
Observations & Student Comments on Instruction

In order to determine if the class assignments and instruction aligned with students’ changes in attitudes and beliefs during the semester of intermediate instruction, classroom observations and student responses to the end of semester survey of instruction were also consulted.

The lecture hall held approximately 200 people, small enough that the instructors could be heard in the back of the room without a microphone. The majority of the students sat in the front and middle rows, with the back three to four rows being left empty or reserved for teaching associates. The researcher took field notes on where the professor stood, what was presented to students, how the instructor interacted with students, and what the students were doing during the lecture.
Table 10. *Comparisons of professor behavior during classroom observations.* (Numbers in parentheses are the total number of students the category refers to; time with “min” indicates how many minutes spent on activity.)

<table>
<thead>
<tr>
<th>Code/Category</th>
<th>Professor A</th>
<th>Professor B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interaction with students prior to class</td>
<td>2, at podium</td>
<td>0</td>
</tr>
<tr>
<td>Instruction style</td>
<td>Lecture, from slides and notes</td>
<td>Discussion style with students</td>
</tr>
<tr>
<td>Slides/PowerPoint Presentation</td>
<td>Extensive information on slides</td>
<td>Minimal information on slides; figures/photos</td>
</tr>
<tr>
<td>Where in room did he deliver lecture</td>
<td>Front of room at podium</td>
<td>Walked across front of room</td>
</tr>
<tr>
<td>Answered student questions</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Asked students questions</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Asked students to elaborate on topics or answers</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Content</td>
<td>55 minutes</td>
<td>67 minutes</td>
</tr>
<tr>
<td>Review</td>
<td>15 minutes</td>
<td>29 minutes (incorporated into current material)</td>
</tr>
<tr>
<td>Student behavior during class</td>
<td>Taking notes on laptops; most laptops on slides; no talking among students</td>
<td>Discussion with instructor; talked and laughed; note-taking on laptops; most laptops on slides</td>
</tr>
<tr>
<td>Administrative Discussion</td>
<td>0 minutes</td>
<td>33 minutes</td>
</tr>
<tr>
<td>Peer interactions</td>
<td>9 minutes</td>
<td>0 minutes*</td>
</tr>
</tbody>
</table>

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were also consulted.

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The themes that arose with both the observations and the end of semester student assessment of instruction distributed by the department at the end of every semester (the Student Assessment of Learning Gains [SALG]; Seymour, Weise, Hunter, & Daffinrud, 2006) were that student enjoyment and perceptions of real world connectedness of the material increased during the second half of the semester.

The professor during the first half was noted by the researcher and the students to be more of a “traditional lecturer” and less interactive than the second professor (see Appendix 4 for observation protocol). He typically stood at the podium and though he did ask questions, he only called upon student volunteers from time to time. For instance, in the first observation he only called on four students who raised their hands with questions, and spent the majority of the time lecturing at the podium (67 minutes of 90 minutes). Students seemed attentive during the lecture but did not have any peer interaction nor any interaction with the professor.
Conversely, the second instructor was observed to be extremely interactive with students, asking them questions at random (3 times), leaving blanks in the lecture and asking students to take the lead in explaining topics on several occasions (5 times). Additionally, during his first lecture he asked for student input on how they wished to see participation handled during his portion of the course. These differences in instruction were also noted in the SALG, and line up with both survey data (i.e., students’ had slightly more favorable responses at the end of the semester) and interview data (see Table 10 for a comparison between the behavior and instruction of the two professors).

There is extensive research available on student evaluation of instruction, both historical and current. The common pattern that emerges is that student opinions of the course are colored by the instruction more so than by other factors (such as class size, grading, etc.), which is supported by the findings in this portion of the study (Aleamoni & Hexner, 1980; Marsh, 2007).

**Conclusion and Discussion**

This study contributes to research on student epistemologies about science, by studying students who are beyond the introductory level, with whom little epistemological research has been conducted in this area. While the survey results in part
confirm previous research, that students’ epistemologies about biology tend to improve as they move through college (Hansen & Birol, 2014), the interview results provide insight into factors that students see as important to learning biology and regarding their attitudes and beliefs about the subject.

This can help expand our understanding of undergraduates’ attitudes and beliefs about science and learning science, and is a first step in uncovering what students believe to be factors in their changing understanding and attitudes. Additionally, it supports the little existing research that students’ epistemologies become more expert like by graduation (Hansen & Birol, 2014). While more research with intermediate and upper level science students needs to be completed, this is an initial step to move this area of research forward to better understand all students’ attitudes and beliefs.

There are a couple of factors that may explain the results we see here. First, there is likely to be an instructor effect, as this course is team-taught, and second, a majority of the students are seniors, and one third of those are graduating seniors, contributing to an effect that we refer to as the “graduating senior effect”.

**Instructor Effect.** The course in which this research was designed to be team-taught, in order to provide students with teachers who are experts on the topics covered during their portion of the class. The two professors who taught during the semester of research are both male, and have both taught this and other biology courses many times. They have both received positive evaluations from students in end of semester surveys on
instruction as well. However, one is described in instructor evaluations as “more entertaining” and “more interactive” than the other. In fact, during the interviews students commented on the professors’ different teaching styles, including the first professor being “more classical” in his teaching, meaning he focuses more on lectures. Comments about the second instructor cite his humor, his interaction with students, and his emphasis on creating interaction between students. Perhaps if the more “entertaining” instructor taught the entire semester and not just half, some or all of the categories would have shown significant increases. The other factor is that one instructor could have taught material that better engaged students; the first instructor taught symbiosis, a topic the majority of interview participants (%) stated was review for them. The second instructor taught vector borne diseases, and this was a new topic not covered in introductory courses and perhaps the students found this more interesting.

*Graduating Senior Effect.* The second factor at play here may be that the majority of the students in this course are not actually at the intermediate level, rather they are mostly seniors (51% are seniors, two-thirds of which identified themselves as graduating seniors). The fact that they are nearly done with undergraduate work could contribute to the less than significant increases we saw, as their interest may have waned by the end of the semester in anticipation of graduation. The student interviews supported this hypothesis, as a majority of those interviewed were upperclassmen, stated that they felt this course was simply review, and all three graduating seniors admitted that at some
point they “checked out” after midterm examinations. When questioned about this
directly, Peter admitted that being a graduating senior did affect his attitudes, saying, “I
have the problem that’s deep in my roots” (interview 3).

Finally, given the existing literature on students’ attitudes and beliefs toward
science and learning science, it is entirely possible that cognitive maturation also plays a
role in students’ attitudes and beliefs. While much is known about cognitive
development in children and adolescents, less is understood about how adult learners
continue to mature in both their cognitive and mental development (Perry, 1970; Kuhn,
Cheney, & Weinstock, 2000; Schaie, 1994). It is conceivable that undergraduates simply
need to reach a certain age or level of experience before their epistemologies about
biology mature and can reach expert level. More research comparing student
epistemologies to their cognitive development could help explicate the answer to such
questions.

It is important to note that even though the majority of interview themes aligned
with the epistemological categories in the theoretical basis of the study, there is a great
deal of overlap among and between said categories. For instance students’ level of
interest in a topic or a course seems to, per their own comments, be related to the level of
difficulty of the subject, the amount of time they will spend on a problem, and their
overall attitude toward the subject or the class. Or, their views of how knowledge is
structured in biology is dictated by not only their level of interest but also how they feel
that they best learn a certain topic. This bears mentioning to illustrate how intertwined affective factors can be to one another and to learning; explicating which factors are related to students’ attitudes, beliefs about a subject requires a good deal of research.

While research with introductory science students shows that their epistemologies become more novice-like after a semester of instruction, this study indicates that their attitudes, beliefs, and views of biology improve with more experience and courses in their undergraduate careers, though the changes seen here are not statistically significant. This is interesting, as not much work has been done with students outside of the introductory courses in science classes, and further qualitative research could help explicate the progression of student epistemologies.
References


Chapter 4:  
Undergraduate Student Scientific Reasoning Across Years and Majors  
and in an Undergraduate Biology Course  

Abstract

Scientific reasoning is essential to becoming a professional scientist, but there is still little research on its development in science and engineering majors at the undergraduate level. It is relatively unknown how students’ abilities to reason scientifically varies across disciplines and years in school, or how reasoning ability may change during the course of undergraduate coursework. The first portion of this study, a large-scale descriptive study, utilized the Lawson Classroom Test of Scientific Reasoning (LCTSR) to characterize science students’ reasoning abilities across multiple majors and years in undergraduate coursework. The second and third portions of this study looked specifically at biology majors in a 3000-level course to describe their scientific reasoning abilities and delve deeper to determine if there are factors—such as attitudes and beliefs about biology, GPA, or standardized test scores—that may be related to biology majors’ scientific reasoning ability. It was found that overall physics majors earned the highest averages on the LCTSR. Physics students were followed by engineering, chemistry, and life sciences majors, respectively, though none of the four disciplines showed any significant improvement during the four years of undergraduate studies. Among biology students in
an intermediate level course, LCTSR averages were 73%, higher than their scores in the first phase of the study. Qualitative interview data suggested that students are in general at least comparable to their peers in other disciplines based on coding of their reasoning.

**Introduction**

Scientific reasoning has, in recent years, received more attention at the tertiary level. There are various reasons for this, including the impetus for higher education to address skills needed in the workforce and to include skills that students will need for future success in multiple careers as well as everyday life (Achieve, Inc.; 2012; Ding, 2014; National Research Council [NRC], 2012; Ruiz-Primo, Li, Wills, Giamellaro, Lan, Mason, & Sands, 2012). Existing literature in science education agrees that scientific reasoning is an important skill, and that reasoning abilities, including hypothesis generation, evaluation of claims, and making accurate conclusions, are essential to the enterprise of science as well as to everyday life (Ding, Wei, & Mollohan, 2014; Lawson, Clark, Cramer-Meldrum, Falconer, Sequist, & Kwon, 2000; Zeineddin & Abd-El-Khalick, 2010; Zimmerman, 2000).

Scientific reasoning has been defined in multiple ways in the literature, and has been linked to both content knowledge and student epistemologies about science, at least in
physics (Coletta & Phillips, 2005; Ding, 2014; Lawson, 2004; Meltzer, 2002). The current study is an effort to continue the research into student scientific reasoning abilities and to characterize reasoning ability of different science, technology, engineering, and mathematics majors at the undergraduate level. In addition, a characterization of biology major scientific reasoning and it’s relation to several factors (including epistemologies, grade point average in college, and test scores) was examined. In particular, this investigation looks at four separate research questions in relation to scientific reasoning and epistemologies, including:

1. How does scientific reasoning ability compare across years in school (freshman-senior) and between majors (including biology, chemistry, engineering, and physics) at the undergraduate level;

2. How do intermediate level biology majors score on the LCTSR;

3. How are epistemologies and scientific reasoning ability related in biology majors at the intermediate level; and

4. What other factors, such as amount of content learning, entrance test scores, and grade point average, are related to undergraduate biology majors’ scientific reasoning?

Background and Theoretical Framework

There is no denying that learning is complex and involves many layers, including both affective and cognitive factors (Bransford, Brown, & Cocking, 2000). For instance,
not only is content learning important, but affective factors such as attitudes toward a subject and beliefs about knowledge are as well. Existing research offers little explanation as to how skills such as scientific reasoning may be related to other factors that influence learning.

*Scientific reasoning defined.* There are multiple operational definitions to be found for scientific reasoning, which vary from simple (i.e., evidence based reasoning, or reasoning used in scientific inquiry) to complex and multifaceted. Some researchers define it as the process of making conclusions (inferences) from given information (Kuhn, 2002; Lawson, 2004) or include in the definition that hypothesis generation, the coordination of theory and evidence, hypothetical-deductive reasoning, and probability are all important during the scientific inquiry process (Lawson, 2004; Morris, Croker, Masnick & Zimmerman, 2012; Zeinnedin & Abd-El-Khalick, 2010). This study takes the perspective that scientific reasoning can be described as a complex melding of components that encompass the following: coordination of theory and evidence, hypothesis generation and hypothetical-deductive processes, planning and running experiments, and evaluating the evidence—all of which contribute to the overall ability to critically reason through an argument or problem (Kuhn, 2002; Lawson, 2004; Lawson et al., 2000; Zimmerman, 2000). This is represented in Figure 7.
There are several trends found in the existing literature regarding student scientific reasoning at the tertiary level, including the link between reasoning and content knowledge, the relationship between epistemologies and scientific reasoning ability, and finally the lack of conclusions about these relationships.

Research regarding scientific reasoning at the undergraduate level has not always yielded positive results. For example, a study of 24 American colleges and universities determined that by the end of their second year in college nearly half of the students
surveyed did not show significant improvement in their scientific reasoning (Arum and Roksa, 2010). In this survey, students’ reasoning was measured by the Collegiate Learning Assessment (CLA; Benjamin & Chun, 2003), in which they were asked to analyze data, consider evidence, generate conclusions, and provide written responses to a “real world” problem. Nearly half (45%) of the students failed to show significant improvement in their scores after two years of tertiary level instruction (Arum and Roksa, 2010). This “evidence of limited learning” regarding critical thinking and reasoning at the tertiary level in US institutions has been an impetus to improve instruction at American colleges and universities (Arum and Roksa, 2010; p. 54).

Students in other nations exhibit similar patterns. For instance, in a cross-national comparison between first-year undergraduate American physics students and their Chinese counterparts it was found that while the Chinese students outperformed the American’s in content knowledge they scored nearly the same on the test of scientific reasoning (Bao, et al., 2009). Similarly, another study further investigated the scientific reasoning ability of Chinese physics students at the tertiary level. Ding and colleagues (2014) compared two tiers of Chinese institutions (similar to research 1 and vocational institutions in the U.S.) and three majors (engineering, physical science, and science education) across four years of undergraduate work. The results indicated that while there were significant differences between Tier 1 and Tier 2 institutions, and that the engineering students outperformed the science students and the physical science students
in turn outperformed the education students, there was relatively little variation within each major and across the four years in student scientific reasoning ability. In essence such studies are showing that tertiary level instruction does not seem to significantly improve students’ scientific reasoning abilities.

Content knowledge and scientific reasoning ability. Most investigations into the relationship between content learning and reasoning ability have been conducted in physics education research. For instance, studies have found that there are strong, positive correlations between reasoning and learning gains as tested by physics concept inventories such as the Force Concept Inventory (FCI) (Coletta & Phillips, 2005; Nieminen, Savinainen, & Viiri, 2012). Additionally, research has indicated that there is actually a direction to this relationship, and that scientific reasoning could be a confounding variable that precludes content learning (Lawson, 2004; Meltzer, 2002).

Content knowledge and student epistemological beliefs. Epistemologies have been extensively studied in science education for decades, and can be defined essentially as one’s attitudes and beliefs about what constitutes knowledge and learning (Hofer & Pintrich, 1997). At the tertiary level, much research about students’ epistemologies has been with introductory students. Research conducted in these large introductory science courses, across disciplines, has shown that introductory science students become more novice in their views of science during these early required courses. Similar results have
been shown in chemistry (Barbera, Perkins, Adams, & Wieman, 2008), life sciences (Ding & Mollohan, 2015; Semsar, Knight, Birol, & Smith, 2011), and physics (Adams, Perkins, Dubson, Finkelstein, & Wieman, 2004; Redish, Saul, & Steinberg, 1998). There are several reasons for this possible regression in attitudes and beliefs about scientific fields, including that students’ do not always recognize that the material is relevant to their other courses or to their lives (Ding & Mollohan, 2015), that the traditional type of lecture instruction common among these courses could play a role (Buehl & Alexander, 2006; Cam & Geban, 2011; Gobert, O’Dwyer, Horowitz, Buckley, Levy, & Wilensky, 2011; Hammer, 1994; Hammer & Elby, 2003; Holschuh, 1998; Hoskins, Lopatto, & Stevens, 2011; Tsai, 2005), and because students often view knowledge in scientific disciplines as discrete facts that they must memorize (Hammer, 1994; Lising & Elby, 2005; Redish, et al., 1998). Unfortunately, there has been little research done with upper-level undergraduates. One longitudinal study did show that these early novice shifts do not seem to persist through until graduation, though until further research is conducted it is unknown where students begin to transition back toward more expert beliefs, and what factors are associated with the change(s) (Hansen & Birol, 2014).

While there is debate about how specialized these beliefs can be, it is generally believed that by the time students reach college their epistemic opinions are “formed” and “differentiated” (Buehl & Alexander, 2006; p. 29). There is ample literature to support the domain-specificity of epistemological beliefs (see for instance Carey &
Smith, 1993; Chen & Pajares, 2006; Hofer, 2000;). This study is based on the domain-specific research begun by physics education researchers and continued across a variety of scientific disciplines (Adams et al., 2004; Barbera et al., 2008; Lising & Elby, 2005; Hammer, 1994; Redish, et al., 1998; Semsar et al., 2011). Discipline-based educational research (DBER) offers several benefits, including detailed alignment of the instrument(s) used to collect data and discipline-based generalizations of findings.

In addition to characterizing students’ epistemologies, there has been research to support the idea that epistemologies can have an impact on the teaching and learning of science but only with physics students (Lising & Elby, 2005; Redish et al., 1998; Sharma, Ahluwalia, & Sharma, 2013). This study is trying to determine if epistemologies have a similar impact for biology majors.

**Combining scientific reasoning and epistemology.** The research regarding scientific reasoning and epistemologies across disciplines demonstrates a connection between the factors involved in learning (Figure 3). For instance, there is research to suggest that reasoning skills as well as attitudes and beliefs toward a discipline may both be important influences on content learning (Adams et al., 2004; Coletta & Phillips, 2005; Hammer & Elby, 2003; Moore & Rubbo, 2012, among others). How important a role each plays, and how these factors relate to one another when learning biology is still not completely clear. The theoretical framework for this study is grounded in all of the research previously discussed, and in the end combines the factors of epistemology,
content learning, and scientific reasoning with the understanding that there is a dynamic relationship among all three. A study involving path analysis of these relationships lends credence to this framework. A causal model was developed by Ding (2014) showing relationships (based on the coefficients above the arrows) between both reasoning and students’ pre-instructional epistemologies on conceptual gains (Figure 8).

![Diagram](image)

Figure 8. Path analysis (from Ding, 2014) showing the strength and direction of the relationships between reasoning skills, pre-and post-instructional epistemologies, and learning gains.

This analysis translates to the framework for this study, and can be reimagined as in Figure 10.
Comparison of Scientific Reasoning Ability Across Undergraduate Years and Majors

Methods
In order to compare scientific reasoning ability on a large scale across both year in school and STEM majors, survey data was collected in a number of courses, including biology (including biology and other life science majors such as neuroscience), chemistry (including chemistry, biochemistry, and pre-pharmacy students), engineering (representing different engineering majors such as chemical, computer science, electrical, and mechanical), and physics (including astronomy, astrophysics, and physics). Students
were recruited in each respective class and they completed the survey during the same class period; all were given up to 40 minutes to complete the instrument. Some instructors awarded credit or extra credit for participation, where others simply stated it was a required class assignment (with no points); because of the large number of departments and instructors each was allowed to treat participation as they saw fit in their particular course(s).

Participants. This portion of the study took place on the main campus of The Ohio State University. All students were surveyed during the same term, within the first 8 weeks of an fourteen-week semester. Table 11 shows the number of students from each year and major who participated in this survey study.

Instrument. The Lawson Classroom Test of Scientific Reasoning (Lawson et al., 2000) was utilized for this investigation. The LCTSR was initially designed for use at the undergraduate level (Lawson, 1978; Lawson et al., 2000) and has been used extensively with secondary and tertiary level students (see for instance, Bao et al., 2009; Ding, Wei, & Mollohan, 2014; Han, 2013; Schen, 2007). It was administered as a pencil and paper test and consists of twelve pairs of questions in a two-tiered, multiple-choice format. The questions are paired so that students choose an answer to a reasoning-based question and then choose an answer choice to correspond to why that was their answer; a sample question from the LCTSR is shown in Figure 10
Table 11. *Participant breakdown for each major and year for comparison of scientific reasoning ability across undergraduate year and major.*

<table>
<thead>
<tr>
<th>Major</th>
<th>Year</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freshman</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>Sophomore</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Junior</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Senior</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td><strong>Total Chemistry</strong></td>
<td><strong>83</strong></td>
</tr>
<tr>
<td>Life Sciences</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freshman</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Sophomore</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Junior</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>Senior</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td><strong>Total Life Sciences</strong></td>
<td><strong>419</strong></td>
</tr>
<tr>
<td>Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freshman</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>Sophomore</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>Junior</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Senior</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td><strong>Total Engineering</strong></td>
<td><strong>309</strong></td>
</tr>
<tr>
<td>Physics</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freshman</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Sophomore</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Junior</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Senior</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td><strong>Total Physics</strong></td>
<td><strong>176</strong></td>
</tr>
<tr>
<td></td>
<td><strong>GRAND TOTAL</strong></td>
<td><strong>987</strong></td>
</tr>
</tbody>
</table>

The LCSTR has several advantages, including having reliability and validity estimates calculated for use with undergraduate populations (Han, 2013; Lawson et al., 2000; Schen, 2007) and the questions are based on several different types of reasoning,
including control of variables, correlational reasoning, hypothesis generation, hypothetical-deductive reasoning, probabilistic reasoning, and proportional reasoning (Figure 1). These sub-skills align with the multidimensional framework of scientific reasoning that was used in this study. The reliability calculation for this study was $\alpha=.79 \pm 3.96$ SD, indicating an acceptable level of reliability for the use of this instrument in this sample.

Students in all courses were given up to 40 minutes to complete the survey and were reminded by the researcher to answer honestly and take the questions seriously.
Figure 10. Sample question from the Lawson Classroom Test of Scientific Reasoning (LCTSR) (Lawson et al., 2000).

Results for Comparison of Scientific Reasoning Across Undergraduate Years and Majors
The overall results for each major and year are included in Figure 11, below. Physics students scored the highest on the LCTSR instrument, ranging from 83%-87% depending on the year in school. Engineering students scored the second highest, with averages between 78%-81%. Chemistry was the third highest, ranging from 56% to 59% average, and life sciences scored the lowest averages on the LCTSR of the four groups, with scores ranging from 50-52%.

Figure 11. Differences in scientific reasoning skills among science and engineering majors of different years in undergraduate as measured by the LCTSR. Error bars represent standard error.
In addition to overall differences in LCTSR performance, each major was compared in the sub-skills of control of variables, correlational, hypothetical-deductive, probabilistic, proportional reasoning (Figure 12). The same general trends are seen in each sub-skill as were evidenced in the overall comparisons between science and engineering majors; that is, physics students scored the highest averages across all sub-skills, followed by engineering students, chemistry students, and life science students, respectively.
Figure 12. Breakdown of each sub-skill of scientific reasoning tested by the LCTSR, by major and year.

The two-way analysis of variance (ANOVA) showed a significant effect on scientific reasoning skills for major \(F(3, 416.78)=0.000, p<0.05\), and no significant effect of year in undergraduate on scientific reasoning skills \(F(4, 23.06)=0.120, \)
There was no significant effect of the combination of year and major on scientific reasoning skills \( F(10, 15.12) = 0.284, p > 0.05 \). This indicates that while year in undergraduate does not play a significant role in students’ scientific reasoning skills, their major does.

Table 12. *Two way analysis of variance results for major, year, and major * year on student scientific reasoning skills. Significant results are in **bold.**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major</td>
<td>1250.047</td>
<td>3</td>
<td>416.682</td>
<td>33.150</td>
<td>.000</td>
</tr>
<tr>
<td>Year</td>
<td>92.233</td>
<td>4</td>
<td>23.058</td>
<td>1.834</td>
<td>.120</td>
</tr>
<tr>
<td>Major * Year</td>
<td>151.261</td>
<td>10</td>
<td>15.126</td>
<td>1.203</td>
<td>.284</td>
</tr>
<tr>
<td>Error</td>
<td>12443.856</td>
<td>990</td>
<td>12.570</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>329969.000</strong></td>
<td>1008</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Discussion of Comparison of Student Scientific Reasoning Abilities Across Undergraduate Majors and Years**

Scientific reasoning, which involves skills such as correlational, hypothetical-deductive, and probabilistic reasoning, is an important ability for practicing scientists and
students alike. In order to engage in the process of science, it is important to know how to control variables and to test and validate hypotheses and claims. However, student improvement in scientific reasoning ability has been disappointing, as seen in the results of several studies, including this one (Arum & Roska, 2010; Bao et al., 2009; Ding et al., 2014). While there are differences seen between the science and engineering majors in this study (such as physics majors performing better than other science and engineering majors), all of the groups show little change between freshman and senior years. Given that students are not scoring at the expert level (90% or above) on the LCTSR instrument, a ceiling effect does not seem to be at play here. Perhaps there could be other confounding factors, such as instrumentation concerns, administration differences between the groups, or factors related to differential sampling.

Instrument Choice. While the LCTSR has been used widely and was originally developed to be used with undergraduate students, there have been concerns raised about the instrument. For one, the last update to the instrument was in 2000, and while natural laws have not changed the context in which they are taught and tested has changed. This test could be considered “dated”, in that the scenarios it presents to students may not be relevant or interesting to today’s students. Additionally, it is an entirely multiple choice instrument. While this makes it easy to score, it also eliminates the nuances in student thinking. Open-ended responses would help researchers gain insight into students’ thinking that are influenced in the current multiple-choice version used in this study; the
multiple-choice format tends to guide and influence students’ handling of information to fit the provided options, whereas they may have had interesting insights that were not included as one of the options that could have been as right or wrong as the listed choices.

*Administration Differences.* In this study, all care was taken to ensure that administration was as similar as possible between all courses so that this would not be a confounding factor. In reality, given the number of departments with which the researcher had to coordinate and collect data, this was more difficult than planned. While all instructors made time for the administration of the questionnaire in their respective classes, some offered incentives such as class points where others did not. Autonomy given to instructors was often the tradeoff for gaining access to students and data, thus small differences in incentives may have differentially encouraged (or discouraged) students when taking the test.

*Sample.* While overall this study provides a large sample size (n=987), it does not guarantee a representative sample from each major and each year. Future research should ensure that there is an equal number of students among majors and years to make sure that there is not any kind of effect on the outcome. Additionally, the researcher acknowledges that this study is a “snapshot” of students’ scientific reasoning ability across different majors and years in undergraduate work; it is not longitudinal. While the university at which the data was collected has, if anything, become more selective in the
students it admits each year, it has maintained standards for more than four years that likely ensure that students at the different levels are comparable from year to year. Ideally, future research would look at a similar study but following students throughout their undergraduate careers rather than at one point in time.

Characterization of Scientific Reasoning Ability Among Intermediate-Level Biology Majors

Methods

Participants. Participants in this portion of this study were students in an intermediate level (3000-level) biology course at a large state university in the midwestern United States. The course was designed to be taken following the required introductory course sequence and focuses on integrating biology concepts with one another and to other scientific disciplines. It was team-taught by two faculty members with experience teaching all levels of biology. However, while the class was designed to be taken immediately following the introductory course sequence, the enrollment is often predominantly juniors and seniors. In this sample, the nine interview participants are representative of this enrollment, as 67% were seniors and 33% were juniors; there were no sophomores represented in this sample.

Interview Participants. Interview participants (n=9) met with the researcher once
during the semester to respond to questions from the LCTSR instrument and to follow up with reasoning behind their answers. The average length of the interviews was just over thirty minutes (33.6 minutes), and there were seven females and two males included in this sample. The participants’ average grade was 87.5%. Given that the average grade for the entire class was an 81%, these students in general reflected the class overall (both being within the range required to earn the letter grade of B in the course).

Interview Questions. Interview participants were asked five questions from the LCTSR were asked to see if their answers were correct and if their reasoning was in alignment with the correct answer (all interview questions can be found in Appendix X.) All questions were adopted from the LCTSR but modified in this study to be open-ended rather than multiple choice questions. This was done to ensure that the students gave their own answers and that they were not influenced by the answer choices provided on the instrument. With multiple choice questions, there is a possibility of imposing specific responses, or influencing a student’s response and making them open-ended eliminated the risk of potential imposition, ensuring students’ true responses (Treagust, 1998).

Qualitative coding. Responses from the nine interviews were analyzed by the researcher and were scored for correct answers and for accurate reasoning behind the answers. A scoring scheme (Table 15) was developed and used for each question. A second researcher looked at five of the nine transcripts and the two researchers agreed nearly 100% of the time on the score.
Table 13. *Coding scheme and associated points for scoring in the qualitative portion of this study.*

<table>
<thead>
<tr>
<th>Coding Scheme</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Answer/Correct Reasoning</td>
<td>2</td>
</tr>
<tr>
<td>Correct Answer/Incorrect Reasoning</td>
<td>1</td>
</tr>
<tr>
<td>Incorrect Answer/Correct Reasoning</td>
<td>1</td>
</tr>
<tr>
<td>Incorrect Answer/Incorrect Reasoning</td>
<td>0</td>
</tr>
</tbody>
</table>

**Results for Characterization of Scientific Reasoning Ability Among Biology Majors**

Results from the second portion of the study, looking into the scientific reasoning ability of biology majors from a qualitative perspective, indicate that overall, the biology majors in the intermediate level course do understand how to reason through problems. This was seen with both the contextualized and decontextualized questions asked from the LCTSR. Table 16 displays the results of the qualitative coding of all transcripts. Each question was coded out of two points, with one point being given for correct answers to the question and one point being awarded for accurate reasoning behind the answers.
Table 14. *Scoring for the interview questions about scientific reasoning.* Each question was scored on a 2 point scale; Interview questions can be found in Appendix D.

<table>
<thead>
<tr>
<th>Coding/Scoring</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Answer correct/Reasoning</td>
<td>9</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>correct</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Answer incorrect/Reasoning</td>
<td>0</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>correct</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Answer incorrect/Reasoning</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>correct</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Answer incorrect/Reasoning</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>correct</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Question 1, was answered correctly and using correct reasoning by all nine students (100% of the time). Question 2 was answered incorrectly and with incorrect reasoning by five students (56%) more often than it was answered correctly with correct reasoning (four students, 44%). Question 3 was answered correctly and with the correct reasoning by the majority of students (5 students, 56%). Question four was answered correctly by almost all of the students (8 students, 89%), though one student answered incorrectly with incorrect reasoning. Finally, question five was answered by all nine students correctly, and they all used correct reasoning (100%). Each question will be discussed individually in the results that follow.

*Interview question 1.* The first question asks students to consider two clay balls
of equal shape and size, and describe how the weights of the two balls might differ after one is flattened into a pancake. The nine interview participants all answered correctly and supported their answers with correct reasoning. This question was answered correctly in the larger scientific reasoning study 98.7% of the time, thus it seems like it may be simple for college level science majors as they would have all had experience in learning about the concepts of volume and mass.

*Interview question 2.* Question two asked students to look at a drawing of two identical cylinders filled to the same level with water, and into one is placed a glass marble and the other a steel marble (both the same size). They were asked what happens to the water level in the cylinder with the steel marble in comparison to the one with the glass marble, which tests students on the concept of displacement. More students than not provided the incorrect answer with incorrect reasoning in response to the question (56%). The difficulty could have come from the fact that the question stem contains a distractor about the weight of the two balls, which may have confused some students. For example, students who responded correctly stated something similar to “displacement would be the same because they are the same size and shape” (Student 1). However, an example of an incorrect response includes mention of weight in the answer:

“*they’re the same size, but the metal one would be much heavier...so this one [points to glass marble] is lighter and it goes to the sixth line, and this one is going to go higher*” (Student 7).
All five students who missed this question used the rationale of weight to support their answers.

Question 3. Question three asks students to think about four test tubes that contain fruit flies and which of two variables the flies respond to, shown below in Figure 13. The question is asking them to consider whether the flies are responding to gravity (measured by the position of the test tubes; horizontal or vertical) or to the red light to which all tubes are exposed.

![Diagram of test tubes](image)

Figure 13. Diagram provided to students to answer interview question 3.

The correct response is that the flies are responding to gravity, which is justified by the fact that the two horizontal tubes have equal numbers of flies on each end whether there is covering or not, and the vertical tubes have many more flies at the top of the tubes whether or not there is covering on the tube. However, the three students who used
incorrect reasoning were led to the incorrect response, exemplified by Student 3, who answered that they were responding to the light and provides an incorrect justification as well:

“if you look at the two that are standing up, there’s 19 for without the covering and just 18 for the tube that has the covering. And when it’s like horizontal, the one that is covered they want to go toward the light because the dark part they don’t like only has 9. The other one is half and half, because there is light everywhere and they don’t have to choose one side over the other”.

One student answered correctly but gave faulty reasoning:

“It has to be something with the vertical position. This one is tough.... The only thing I can use to draw similarities between I & III and II & IV is that it seems like they are going toward red light in the vertical position but not in the horizontal ones. But then, the red light is through all of them. So I guess it has to be position of the tube” (Student 2).

This student seemed to understand that it was gravity (measured here by the position of the tubes) that the flies were responding to, but she struggled to give a justification.

*Interview question 4.* This question relates to the diagram below (Figure 14), of a birthday candle in a pan of water. Students were asked why the candle went out after the glass was placed over it and into the pan of water, and why water rushed into the glass.
All nine (100%) responded correctly to the first part of the question, explaining that the lack of oxygen caused the candle to extinguish. Nearly all of them (n=8, or 89%) responded correctly to the second question about why the water rushed into the glass, citing pressure changes. One student said she simply did not know and could not guess what caused the water to rush up into the glass (this after giving her ample time to think), though she said that she “should remember this, because I’ve had physics” (Student 8).

Interview question 5. The last interview question asked students to think about whether or not Farmer Brown’s conclusion that there has to be a link between size of the mice and the color of their tails is correct or not (Figure 15). All nine of the students (100%) were able to answer correctly and provide an accurate rationale for their answer, such as

“it looks like it, because the one with the black tails tend to be fat, and the ones with the white tails tend to be thin, or thinner” (Student 5).
Others offered considerations pertaining to limitations of Farmer Brown’s conclusions, saying “he only collected mice from one part of his field” (Student 3), or “he needs to collect a larger sample from other parts of the field to make sure it’s not like this one” (Student 6). Additionally, students stated that there could be a conclusion not related to genetics: “the mice could prefer different habitats and you could also assume that those with black tails live in an environment with more food, or outcompete the skinny ones” (Student 5). Finally, students made a distinction between correlation and causation in their answers, which Student 7 sums up well:

“he can say there is a correlation but not causation. There would need to be more tests to make sure if there is a causation.... It’s just, like, an observation. Sure the larger ones have this tail and the smaller ones have this kind of tail, and that’s a starting point, but there is no direct evidence....”
Discussion of Characterization of Intermediate Level Biology Students’ Scientific Reasoning Ability

In the second portion of the study, qualitative findings indicated that biology students in their upper division course work were able to correctly answer selected questions from the LCTSR, and were, for the most part, able to provide ample and correct reasoning to support their answers in these cases. Only one question, regarding displacement, seemed to cause students confusion, resulting in a majority getting the answer and reasoning incorrect. While displacement is something biology students should understand, perhaps because the question was decontextualized and separate from a biological scenario it caused misunderstanding. However this seems unlikely, as the
students in this case study answered the two other decontextualized questions correctly and were able to utilize accurate reasoning to support their answers.

**Factors related to biology student epistemologies and scientific reasoning**

**Methods**

To determine if there are factors related to student scientific reasoning and epistemologies, in this portion of the study educational data was collected along with the use of two surveys. The additional data collected included cumulative undergraduate GPA, number of courses taken, and standardized test scores.

**Participants.** Students in this sample (n=230) were enrolled in one of two sections of an intermediate-level biology course (which is described for the previous portion of this study) at a large state research institution in the midwestern United States. These students were mostly juniors (n=82; 36% of total) and seniors (n=110; 49% of total). Only 15% of the sample was made of up sophomores (n=38) and the overall response rate was 84%.

**Instruments.** Two surveys were used in this portion of the study, the Colorado Learning Attitudes about Science Survey for use in Biology (CLASS Bio) (Semsar et al., 2011) and the Lawson Classroom Test of Scientific Reasoning (LCTSR) (Lawson et al., 2004). Besides being often used to survey college undergraduates, both also had
additional benefits, such as being discipline specific (in the case of the CLASS Bio) and providing not only an overall picture of scientific reasoning, but also a breakdown of specific reasoning types that make up the broader view of scientific reasoning, such as correlational, hypothetical-deductive, and probabilistic reasoning. Finally, because of the multidimensional nature of these instruments, they align well with the overarching theoretical framework of this study. In this study, the reliability for the LCTSR was calculated as $\alpha = .817$ (±6.19 SD), and the reliability for the CLASS-Bio was calculated at $\alpha = .540$ (±5.30 SD).

\textit{LCTSR Administration.} Students were recruited in both sections of the class during the first week of the semester. The LCSTR was administered as an in-class, paper and pencil assignment and students were given 40 minutes to complete the instrument. Prior to passing out the packets, the researcher reminded the students to take the questionnaire seriously, and to support this both instructors gave students points for participation.

\textit{CLASS Bio Administration.} During the same time that students were recruited for the LCTSR, the researcher explained the online CLASS Bio survey. The survey was made available to students via the course homepage for a week beginning after the class session in which they were recruited for the research. As incentive, both professors offered points for completing the survey, and the researcher reminded the students mid-week and just before the close of the survey via the course homepage.
Results for factors related to biology student epistemologies and scientific reasoning

Biology students who took the LCTSR scored 73% overall on all questions of the instrument. These students scored highest on probabilistic reasoning (94%). Control of variables (66%) was the next highest average, followed by hypothetical-deductive reasoning (62%). Biology students scored the lowest in correlational and proportional reasoning (both 61%) (Table 16).

<table>
<thead>
<tr>
<th>LCTSR Reasoning Category</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>73%</td>
</tr>
<tr>
<td>Control of Variables</td>
<td>66%</td>
</tr>
<tr>
<td>Correllational Reasoning</td>
<td>61%</td>
</tr>
<tr>
<td>Hypothetical-Deductive Reasoning</td>
<td>62%</td>
</tr>
<tr>
<td>Probabilistic Reasoning</td>
<td>94%</td>
</tr>
<tr>
<td>Proportional Reasoning</td>
<td>61%</td>
</tr>
</tbody>
</table>

These same students took the CLASS Bio survey. Figure 16 displays the results for student epistemologies. The percent favorable responses for this group of biology students was 72% overall, and ranged from a high of 78.5% (for the category of Real World Connections) to a low of 67.3% (for the category of Problem Solving Difficulty).
In addition to the two surveys, educational data was collected for the students in this sample in order to determine what, if any, factors may be associated with scientific reasoning among biology students. All data was matched and correlation with scientific reasoning was calculated for the following variables: cumulative undergraduate GPA, epistemologies (as determined by the CLASS Bio scores), the number of courses taken in undergraduate program, and standardized test scores (ACT).
Between scientific reasoning and cumulative GPA, $r=0.090$ ($n=230$), indicating a very weak (if any) relationship between the two variables. Correlation between scientific reasoning and epistemologies was calculated as $r=0.081$ ($n=230$), indicating that there is essentially no relationship between scientific reasoning and epistemologies among these biology students. Between scientific reasoning and the number of undergraduate courses taken, $r=0.022$ ($n=231$), implying no relationship among these two factors. Finally, the correlation between scientific reasoning and standardized test score (in this study the ACT was used), $r=-0.039$ ($n=186$), which also implies no relationship between these characteristics.

**Discussion of Factors related to biology student epistemologies and scientific reasoning**

Regarding biology student epistemologies in the intermediate level course, the results of the CLASS Bio survey indicate that they are improved from students sampled in introductory courses (in which percent favorable responses range from 48.6-69.1%). However, given that percent favorable responses range from 67.3-78.5% among intermediate level students we can see that there is still a way to go to reach the 90% threshold that represents expert level in the literature (Semsar et al., 2011, for instance). The same is true of the LCTSR data, representing their scientific reasoning abilities.
While they are “experts” in probabilistic reasoning (94%), there is room for significant improvement in all of the other four reasoning sub-skills as well as overall.

Regarding the correlation data between scientific reasoning and a host of other factors (including cumulative GPA, epistemologies, number of undergraduate courses taken, and standardized test score), the results indicated that there is no relationship between scientific reasoning and any of these characteristics, except for possibly a weak relationship between reasoning and cumulative GPA.

Given that this study has a respectable sample size (n=230) and involved matched data it is possible that these variables are not directly related with one another, and that other factors are at play in the disappointing results we see regarding lack of development of scientific reasoning during undergraduate coursework. The most obvious of these factors seem to include both prior knowledge and a lack of explicit instruction, which have been mentioned in previous research (Ding, 2014; Johnson & Lawson, 1998). Additionally, students at the undergraduate level simply may not have had adequate training in reasoning or in the sub-skills tested by the LCTSR. Perry (1970) was the first to note college students experience developmental sequences during their tertiary level epistemic development. This development, he speculated, consists of an “ongoing, qualitative reorganization” in meaning making as they learn (Hofer & Pintrich, 1997; p. 91). Because of the ongoing development of their epistemic commitments, it is entirely possible that significant changes in reasoning will not come about until students are
immersed in the process and daily endeavors of science, or get such practice in graduate school (Nisbett, Fong, Lehman, & Cheng, 1987).

With these findings there is more evidence to support the fact that higher education is not changing students’ scientific reasoning abilities in any significant way while they are undergraduates, indicating that we need to turn our attention to the implications that this has for teaching and learning at the tertiary level.

**Implications**

Lawson and colleagues (2004) concluded that students who have the ability to think formally—i.e., those who can reason abstractly and well—are more capable of learning abstract concepts. Given this link between content learning and reasoning ability, it is important to ensure that our college graduates can have the most of both. Nurturing the scientific reasoning skills in our students is important. Additionally, there are studies which suggest that student epistemologies might directly influence content learning in physics; therefore, considering student attitudes and beliefs about the subjects we teach is equally important (Lising & Elby, 2005; Zeineddin & Abd-El-Khalick, 2010).

Reaching students on each of these levels need not be difficult. For instance, helping students realize that the reasoning skills that they use in their courses and labs may seem apparent to us, but they may need prompting in order to see these connections themselves. Helping students realize that “scientific” reasoning can be used in other
domains and even in their everyday life can move them in the right direction (Ding et al., 2014; Kuhn, 1992). Similarly, ensuring that students see the relevance of the coursework to their everyday lives and to their future careers can improve their attitudes and beliefs about the subject, whether it is biology, engineering, or physics (Ding & Mollohan, 2015; Zeineddin & Abd-El-Khalick, 2010). Encouraging epistemic growth in our students can encourage not only positive attitudes toward science disciplines but also inspire students to stay in fields they may perceive as difficult.
References


Han, J. (2013). *Scientific reasoning: Research, development, and assessment.* (Doctoral dissertation, The Ohio State University)


Chapter 5:
Conclusions, Directions for Future Research, and Implications for Instruction

Conclusions
Students’ epistemologies—that is, their attitudes, beliefs, and views of knowledge and of knowing—are known to affect learning in a variety of disciplines, including science disciplines. Discipline-based science education research has allowed biology education researchers to confirm what has been found with other fields such as physics and chemistry, namely that majors in large-enrollment courses exhibit a novice-like shift in their attitudes and beliefs about biology and learning biology during a semester of introductory instruction; indeed the first study in part confirms these findings. However, what most of the research does not consider is other populations, such as the non-majors who need to complete biology as a natural science GE requirement at most colleges and universities. The findings from the first study (Chapter 1) extend research in introductory courses to the non-science majors in such courses, in this case an introductory biology course. It was these results that were surprising, revealing that in this sample the non-majors did not show these same negative shifts, in fact they even improved in several categories.
At the tertiary level, research into student views about science has almost exclusively been conducted at the introductory level and while that is a good starting point research needs to move beyond what is known and begin exploring other populations such as intermediate, upper-level or graduating students. With the second and third studies in this dissertation (Chapters 3-4) the goal was to move epistemology research forward to also include these intermediate and upper level majors.

The goal of the study in Ch. 3 was to begin to describe what intermediate level biology majors look like in terms of their epistemologies, as well as see if there are factors related to changes in their epistemologies. By utilizing a mixed methods design, the researcher was able to get more detail about students’ views of biology and what they feel has influenced or changed their epistemologies. The survey results indicated that these students did not shift positively or negatively in their views about biology and learning biology, and the qualitative portion of the study revealed that students see experience in college and “learning how to learn” as the most important factors in their improving epistemic views. Additionally, these students showed an intrinsic interest in biology that perhaps enabled them to see the importance of the subject in a way that other students may not consider.

The goal of chapter 4 was a slightly different, shifting instead to the topic of scientific reasoning. The first portion of that overall study, the large quantitative study, enabled the researcher to compare life sciences, physical sciences, and engineering
majors across each discipline and through all four years of undergraduate coursework. The findings here reflect what has been found in several cross-nation comparisons, such as those done in China showing that although there are some differences in reasoning ability as measured by the LCTSR among the science disciplines and between science and engineering disciplines, however over the course of undergraduate course work there is little to no significant improvement in any of these groups’ scientific reasoning abilities (Bao et al. (2009); Ding, Wei, & Mollohan, 2014). This has implications for both research and instruction.

**Future research with introductory science students**

Thus far, research into student epistemological beliefs has looked at the phenomenon in order to explicate how epistemological beliefs develop over time and their relation, if any, to academic achievement (Kizilgün, Tekkaya, & Sungur, 2009). Some researchers have studied classroom and instructional implications of epistemological beliefs, however, this has mostly been done in physics education (see for instance Hammer, 1994; Hammer & Elby, 2003; Redish, Saul, & Steinberg, 1998). It would behoove other disciplines, such as biology, to also investigate instructional interventions to see what works. Much is being done currently with learner-centered instruction and developing process skills through authentic research with both majors and non-majors (Hurney, 2012; Lopatto, 2007). In addition to this type of work, further
research into scientific literacy among both majors and non-majors is necessary. The AAAS calls for *Vision and Change* in undergraduate biology education, so investigations into what helps students learn in regards to scientific literacy are needed (AAAS, 2009; Woodin, Carter, & Fletcher, 2010).

It is likely that as students experience success or failure in a subject, or if they excel at something or do poorly in a subject, it will contribute to their beliefs about knowledge (Hammer, 1994). Qualitative research into different aspects of epistemic understanding, such as problem-solving and reasoning in a subject is necessary to better understand how students use these abilities to learn.

Given that there is a paucity of research regarding students’ attitudes and beliefs toward learning at the intermediate level, Chapter 3 provides some much-needed insight into what students above the introductory level are thinking about biology and learning biology. As an attempt to characterize the epistemologies of this population of students, this study has expanded the current literature to include another important group that seems to be left out. While there were not significant differences in their pre- and post-instructional epistemologies the survey results confirmed what has been found in a longitudinal study, namely that the novice-like shifts do not persist past the introductory level (Hansen & Birol, 2014), there is more work needed in this field. The qualitative results enhance these findings, indicating that there are certain factors that students see as important to changing their attitudes and beliefs about biology, including having
experience in college and upper level coursework, having an intrinsic interest in the subjects, and being able to recognize a connection to the course material and the “real world”. Given that intermediate level students seem to be aware of their attitudes and beliefs and can articulate what factors have improved their attitudes toward biology, it seems that more research could be done with this population to better understand how these factors relate to their understanding of course material.

Implications for Undergraduate Biology Instruction

Existing research showed that instruction should explicitly address students’ attitudes and beliefs about the discipline they are learning, or the epistemological underpinnings that students possess may not always be helpful to their learning in the subject (Bromme, Kienhues, & Stahl, 2008; Hammer & Elby, 2003). Lessons centering on students attitudes and beliefs need not be difficult to incorporate, and can include learner-centered techniques (see for instance Hurney, 2010), conducting formative assessment as you teach and taking some time to understand from where confusions are arising (Allen & Tanner, 2005), and having students to reflect on their learning (Gauci, Dantas, Williams, & Kemm, 2009; May & Etkina, 2002) can all help them develop the “productive epistemological resources” to encourage future growth (Hammer & Elby, 2002; p. 9). Future instruction of all undergraduates may be impacted—and improved—
by using some of these techniques and considering the research when planning instruction.

Science education research has suggested several ways to improve instruction in order to advance scientific reasoning ability, including an emphasis on inquiry-based instruction (Gerber, Cavallo, & Mereck, 2001) and explicitly addressing reasoning in our lessons (Ding 2014; Lawson et al., 2000).

Taken together, these three investigations contribute to the ever-expanding volume of literature on student epistemological growth and begin to make connections between affective factors such student attitudes and beliefs about scientific disciplines, and their scientific reasoning ability in order to improve skills and understanding.
References


Complete Bibliography


Ding, L. (2013). Long live traditional textbook problems!—Constraints on faculty use of research-based problems in introductory. *International Journal of Science and Mathematics Education, 1*-22


Appendices

Appendix A. Syllabus for the science major course surveyed in Spring 2013.

BIOLOGY 1113 – ENERGY TRANSFORMATION AND DEVELOPMENT
Independence Hall 100, MWF 10:20AM-11:15AM
SPRING 2013

INSTRUCTORS: Dr. Sarah Ball, 292-2113 (Office) or 602-1640 (Google Voice), 
ball.1766@osu.edu
OFFICE HOURS: MWF 11:30-1 and Tues. 11-1

Dr. Michael Weinstein, 688-0164, 975 BioSci Bldg.,
weinstein.41@osu.edu
OFFICE HOURS: Mondays and Tuesdays, 1:00-2:30 pm

COURSE COORDINATOR: Amy Kulesza, 247-0029 (kulesza.5@osu.edu) 255F Jennings Hall, 247-0029
OFFICE HOURS: By appointment

ASSISTANT COURSE COORDINATOR: TBA


ADDITIONAL READINGS: New York Times articles and others, as announced or as listed in lab materials
DESCRIPTION: Biology 1113 is a course that, together with Biology 1114, is designed to give the student an in-depth experience in the biological sciences. Science majors, including many health professionals, are the intended audience. The sequence will meet your General Education Curriculum in the Natural Sciences. **IF YOU DO NOT HAVE A STRONG SCIENCE BACKGROUND OR INTEREST, YOU MAY BELONG IN BIOLOGY 1101-1102; CONSULT YOUR ADVISOR.**

PREREQUISITE (or concur): Chem 1110 (101), 1210 (121), 1610, or 1910H (201H), or permission of course coordinator.

**NATURAL SCIENCE GEC**

**Goals/Rationale:**
Courses in natural sciences foster an understanding of the principles, theories and methods of modern science, the relationship between science and technology, and the effects of science and technology on the environment.

1. Students understand the basic facts, principles, theories and methods of modern science.
2. Students understand key events in the development of science and recognize that science is an evolving body of knowledge.
3. Students describe the inter-dependence of scientific and technological developments.
4. Students recognize social and philosophical implications of scientific discoveries and understand the potential of science and technology to address problems of the contemporary world.

In Biology 1113, Biological Sciences majors meet the GEC Natural Science Learning Objectives in multiple ways. The course, in conjunction with Biology 1114, is an in-depth study of the laws, structures, and interrelationships within the biological universe. Students gain an understanding of the foundations of modern biology by studying cell structure and function, bioenergetics, genetics, and early animal development. In the laboratory activities, students not only apply the biological concepts introduced in lecture, but also learn scientific reasoning and methods. Through the study of the history and key discoveries in biology, Biology 1113 students learn the details of the interrelationship between technology and scientific methods in the modern investigative study of biology, and gain an appreciation of the social and philosophical ramifications of our knowledge of biology and biological discoveries.
LECTURE SCHEDULE AND TEXTBOOK READING ASSIGNMENTS:
(It will be to your benefit to complete reading assignments before coming to class.)

<table>
<thead>
<tr>
<th>Class</th>
<th>Date</th>
<th>Topic</th>
<th>Chapter(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/7</td>
<td>Introduction to the Course and The Nature of Science</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1/9</td>
<td>Themes in the Study of Life and Why Chemistry Matters</td>
<td>1 &amp; 4</td>
</tr>
<tr>
<td>3</td>
<td>1/11</td>
<td>Why Water Rocks! What Are You Made Of? Large Biological Molecules and Their Functions</td>
<td>3 &amp; 5</td>
</tr>
<tr>
<td>4</td>
<td>1/14</td>
<td>Macromolecules (cont.)</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>1/16</td>
<td>A Look Inside the Cell</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>1/18</td>
<td>A Look Inside the Cell (Cont.) and The Great Divide: The Cellular Membrane</td>
<td>6 &amp; 7</td>
</tr>
<tr>
<td></td>
<td>1/21</td>
<td><strong>MLK Holiday, no class</strong></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1/23</td>
<td>The Cell Membrane (Cont.)</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>1/25</td>
<td>How Cells Stay in the Loop: Cellular Communication</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>1/28</td>
<td>Communication (Cont.)</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>1/30</td>
<td><strong>Exam I</strong></td>
<td></td>
</tr>
<tr>
<td>11#</td>
<td>2/1</td>
<td>An Introduction to Metabolism: Energy Flow and Life’s Needs; ATP</td>
<td>8</td>
</tr>
<tr>
<td>12</td>
<td>2/4</td>
<td>Cellular Respiration</td>
<td>9</td>
</tr>
<tr>
<td>13</td>
<td>2/6</td>
<td>Respiration (cont.)</td>
<td>9</td>
</tr>
<tr>
<td>14</td>
<td>2/8</td>
<td>Photosynthesis: Feeding the World One Plant at a Time</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>2/11</td>
<td>Photosynthesis (Cont.) and The Cell Cycle: Mitosis, control and What Happens When it Goes All Wrong</td>
<td>10 &amp; 12</td>
</tr>
<tr>
<td>16</td>
<td>2/13</td>
<td>The Cell Cycle (Cont.)</td>
<td>12</td>
</tr>
<tr>
<td>17</td>
<td>2/15</td>
<td>Cancer</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>2/18</td>
<td>Cancer (cont.)</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>2/20</td>
<td>Wrap-up</td>
<td></td>
</tr>
<tr>
<td>20#</td>
<td>2/22</td>
<td><strong>Exam II</strong></td>
<td></td>
</tr>
</tbody>
</table>
**NOTE:** The final exam begins 20 minutes earlier than the usual lecture time★

**BIOLOGY LEARNING OUTCOMES**

Successful students will be able to:

1. The Chemistry of Life
   a. Identify examples and list characteristics and general functions of the major classes of biological macromolecules (carbohydrates, lipids, proteins, nucleic acids).
2. The Cell
a. Explain the activities in the cell by relating cellular structure and cellular function.

b. Explain the mechanisms and structures involved in mitotic and meiotic cell division, and explain the different roles for and consequences of each.

c. Explain the forms of energy utilized in biological systems and the laws of thermodynamics that govern them.

d. Explain the energy transformations involved in fermentation, cellular respiration, and photosynthesis (including orderly chemical transformations, the relevance of redox reactions, and electron/proton transport).

e. Describe the nature and function of enzymes and describe major mechanisms used to control their activity.

f. Describe the cellular response to its environment (e.g. membrane transport, signal transduction).

g. Describe how the loss/failure of cellular control mechanisms can cause cancer.

3. Genetics

a. Explain the transfer and modification of heritable traits from parents to offspring.

b. Describe the nature and expression of heritable information at the molecular level, including DNA replication, DNA repair, transcription, protein synthesis.

c. Apply Mendelian genetics to solve monohybrid and dihybrid crosses.

d. Identify examples of non-Mendelian patterns of inheritance.

e. Explain how genetic expression is controlled in prokaryotes and eukaryotes.

f. Explain cellular reproduction, growth, and differentiation in the context of organismal development.

g. Describe characteristics of viruses and bacteria (e.g., life history genome type and content, exchange of genetic material).

h. Describe the experimental basis and select applications of recombinant DNA technology.

4. Nature of biological science and society

a. Describe the development and evaluation of scientific explanations of natural phenomena.

b. Apply biological concepts in the assessment of contemporary issues.

c. Explain how evolution accounts for the unity and diversity of life.

**GRADING POLICY:** There are two portions to the course, Lecture and Laboratory/Recitation. Each contributes to your grade as indicated in the table below:

<table>
<thead>
<tr>
<th>Material</th>
<th>Lecture Points</th>
<th>Recitation/Lab Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midterm #1</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Midterm #2</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

156
<table>
<thead>
<tr>
<th>Assignment</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midterm #3</td>
<td>100</td>
</tr>
<tr>
<td>Final exam</td>
<td>100</td>
</tr>
<tr>
<td>Post-lecture Quizzes (~1x/week)</td>
<td>110</td>
</tr>
<tr>
<td>(10pts each, with no quiz the week of an exam)</td>
<td></td>
</tr>
<tr>
<td>Clicker Questions (daily)</td>
<td>38</td>
</tr>
<tr>
<td>In class activities (time permitting)</td>
<td>20</td>
</tr>
<tr>
<td>Lab Summaries and Quizzes</td>
<td>220</td>
</tr>
<tr>
<td>Lab Final</td>
<td>50</td>
</tr>
<tr>
<td>Overall Lab Performance</td>
<td>20</td>
</tr>
<tr>
<td>Writing Project</td>
<td>40</td>
</tr>
<tr>
<td><strong>Total for each section</strong></td>
<td><strong>568</strong></td>
</tr>
<tr>
<td><strong>Course total:</strong></td>
<td><strong>898</strong></td>
</tr>
</tbody>
</table>

**EXAMS:** There will be three midterm exams administered during the normal lecture period, in the normal lecture room, **on the dates listed on the lecture syllabus.** The format of exams is up to the discretion of the instructor. You will be responsible for material presented in lecture, recitation, and in the reading assignments. Exam hard copies will NOT be returned to students and copies of exams will not be posted on Carmen. The **final exam** will be held in the **normal lecture room but NOT at the normal time.** It will emphasize the material after the third midterm exam. **Please see Jessica Johnson (johnson.5406) if you have questions about exam scores, or if you believe there is an issue with your scantron.**

**POST-LECTURE QUIZZES:** There will be a post-lecture quiz over the topics for the week on Fridays **EXCEPT** those designated by pound signs (#) on the lecture schedule. The **quiz will be visible for the duration of the week, but the actual quiz will open on Carmen on Friday at 11am, and must be completed by Sunday at 11:59PM.** These quizzes will require you to apply and synthesize material learned throughout the week. You will have **one attempt** at the quiz. **Plan in advance:** loss of power or internet access is not an excuse for a makeup quiz.

**CLICKER QUESTIONS:** We will use clickers every time we meet in lecture to allow students to become active participants. You will be responsible for having your clicker, and making sure it works. No makeup opportunities will be available for missed lectures or non-responding clickers. **If you answer (participate in) 50% of the day’s clicker questions, you will earn one point for the day.** If you answer less than 50% of the questions, you will earn a 0 (zero) for the day. **These will cover the textbook Chapter assignments for each lecture and lecture material and will contain multiple-choice questions.**
*Please note that responding to clicker questions as a proxy for another student will result in BOTH students being reported to the Committee on Academic Misconduct and immediate loss of ALL Lecture Participation points for the course.

**CLICKER REGISTRATION:** At the beginning of the semester, we will provide instructions on how to register your clickers so that we will be able to link your clicker number to your student number; this allows us to know who was in class, and who answered what. Proper registration is **required** after the second Friday of the semester. After that time, points will no longer be applied retroactively.

Clickers can be purchased in the bookstore and must be properly registered. See the course page on Carmen for more information. **Check your grade on Carmen to verify you are earning points associated with clicker usage.** If you are having clicker issues, please contact [Jessica Johnson (johnson.5406)].

**COMMENTS FROM THE FACULTY:** For this course, you will be responsible for material presented in the lectures and the corresponding reading assignments in the text and other outside sources. New material presented in recitation may also be on the exams. The material from the laboratory portion of the course will be tested separately.

In order to prepare for the exams, we recommend the following:
- Read the text before coming to lecture. Become familiar with new terms.
- Take detailed notes in lecture and pay particular attention to topics not discussed in the text and the handouts.
- Write down any questions that you may have so that you can ask your TA during recitation or ask Dr. Ball or Dr. Weinstein during their office hours.
- Be sure to keep up with lecture material and textbook readings. This course moves very rapidly and builds on previous material. Plan to spend at least 6 hours per week studying the lecture material and reading the textbook. One hour spent early equals two or more hours just before the exam.
- You will need to learn many new terms to pass the course and to understand the lectures. Learning biology is like learning a new language.
- Be sure that you reserve enough time for this course. If you work more than 20 hours per week, this should be the only major science course you are taking.

**COURSE POLICIES:**

**ENROLLMENT:** The size of the class is limited by the number of spaces in the both the lecture hall and in the laboratory. If you are currently on the waitlist you should attend the lectures and talk to the Course
Coordinator, Amy Kulesza, about availability.

**SCHEDULING ISSUES:** All requests to change sections, add or drop the course, etc. are handled by the Course Coordinator, Amy Kulesza (kulesza.5@osu.edu), or through the Center for Life Sciences Education (CLSE) office (292-9861), JE260.

**CONTACTING TAs:** Each TA will have office hours and will give you a telephone number and e-mail address at which they can be reached. Contact information for TAs is also posted on Carmen. In an emergency, TAs can also be reached by calling the CLSE Office in 260 Jennings Hall at 292-9861. A message will be left in the appropriate TA mailbox in JE247 and the TAs will return your call within 24 hours.

**CONTACTING THE FACULTY:** The faculty are very happy to talk with you about the class material and your future careers in biology, etc. However, due to the large enrollment, we must restrict contact to office hours or appointments. To make an appointment, contact us after class or by e-mail. If you cannot reach us, call the CLSE Office at 292-9861. There is always someone there between 7:30 am and 4:30 pm. They will relay a message. Please direct routine questions about course procedures to your TA. **For questions regarding lab enrollment/absences or ODS, please contact Amy Kulesza.**

**HANDOUTS:** There will be many handouts for this course, all of which are provided to you in digital format as documents posted on Carmen. Carmen can be accessed online at www.carmen.osu.edu. All students are responsible for downloading and reading the syllabus, as well as downloading and printing posted documents in a timely manner for use in class/lab/recitation.

**GRADE DISPUTES:** It is the student’s responsibility to follow his/her progress in the course throughout the semester. Questions about grading mistakes or grades that are missing should be directed to your TA **within one week** after the posting of graded class material to Carmen. Grade disputes brought to the attention of your TA or the Course Coordinator more than ten (10) class days after they have been posted will not be considered.

**LECTURE EXAM MAKE-UPS POLICY:** If you are too ill to take an exam or must miss for another legitimate reason (the funeral of a family member, for example), you must contact the Course Coordinator, Amy Kulesza, within 24 hours of the exam. Make up exams will be given only to students who produce, at the make up or before, documentation of a legitimate reason (at the time of the absence) for missing a quiz or exam. Medical excuses will be considered only if you have been treated by a medical professional on the day of the exam (excuses from the student health center website will not be accepted). **The exam must be made up within one week of when it was given.** If you anticipate having to miss an exam due to attendance at a university sanctioned event or other qualifying conflict, you must contact the Course Coordinator at least one week in advance of the exam and supply written documentation signed by an appropriate official. Valid excuses are limited to problems that are "beyond the student's control, such as military duty, intercollegiate athletic or academic activities, funerals, etc. Written documentation of these activities must be provided.
Students arriving late to an exam may take the exam in the time remaining. Once someone has completed the exam and left the room, however, students arriving late may take the exam in the time remaining but with a 25% penalty. Lack of transportation, loss of electricity, travel plans, etc. are not considered valid excuses. If suitable documentation is presented a make-up exam will be given. **The format of makeup exams is at the discretion of the instructors.**

**ADDITIONAL POLICIES ON EXAMINATIONS AND OTHER COURSE ASSIGNMENTS:** To ensure that all students receive fair and equal treatment, the following polices regarding examinations and other course assignments will be implemented:

- Every student is required to complete all course assignments. Students are not allowed to drop their lowest quiz, exam, report grade, etc.
- Every student is required to take a final examination. The final is to be administered at the scheduled time (as per the Master Schedule) during finals week.
- Students are not allowed to earn "extra-credit." Student grades are based solely on those assignments listed in the syllabus (i.e., examinations, quizzes, laboratory summaries, etc.).

**ACADEMIC MISCONDUCT:** Students may work in cooperative groups, however each student is responsible for completing assignments in his/her own words. It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term “academic misconduct” includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-487). For additional information, see the Code of Student Conduct [http://studentlife.osu.edu/csc/](http://studentlife.osu.edu/csc/).

**ACCESSIBILITY:** Anyone in need of an accommodation based on the impact of a disability should contact the Course Coordinator, Amy Kulesza, to arrange an appointment as close to the beginning of the semester as possible. At that time, you can discuss the course format and explore potential accommodations to meet your needs. Students with disabilities that have been certified by the Office for Disability Services will be appropriately accommodated and should inform the instructor as soon as possible of their needs. The Office for Disability Services is located in 150 Pomerene Hall, 1760 Neil Avenue; telephone 292-3307, TDD 292-0901; [http://www.ods.ohio-state.edu/](http://www.ods.ohio-state.edu/).”

**SEXUAL HARASSMENT:** OSU considers sexual harassment to be unacceptable behavior that prevents opportunities for learning. While all members of the staff
involved in this course have been trained in the OSU sexual harassment policies and procedures, this is not true for all students. Students are expected to follow the university code of conduct at all times and report any concerns about questionable or unwanted behavior to either their TA or Amy Kulesza.

**ISSUE RESOLUTION:** The CLSE believes that student concerns are usually most effectively addressed by the staff closest to the situation. Therefore, students are ordinarily expected to address issues or concerns with their TAs first. If the issue cannot be resolved by your TA, or for some reason you feel that you absolutely cannot address your concern with your TA, please feel free to contact your Course Coordinator (listed on this syllabus) or Assistant Director Matt Misicka ([misicka.1@osu.edu](mailto:misicka.1@osu.edu)).

**UNIVERSITY ESCORT SERVICE:** To promote safety on campus, transportation across campus is offered by the OSU Department of Public Safety. Service is available between 7:30 pm and 3:00 am during Au and Sp semesters. Call 292-3322 to schedule a pick-up. You must provide at least one hour notice (http://www.ps.ohio-state.edu/sss/escort_info/).

**LABORATORY/RECITATION**

Laboratory and recitation are an integral part of the course. They are designed to compliment as well as supplement the lecture. You may first encounter something in lab before you have it in lecture or vice versa. It is expected that you come prepared to lab having read in the lab manual the chapter that will be presented. Labs do not necessarily go in the order presented in the manual—check the schedule at the end of this syllabus.

**Laboratory Assignments**

Laboratory exercises will begin on Monday, the first full week of classes. **ATTENDANCE IN LAB/RECITATION IS REQUIRED.** Laboratory grading and assignments will be discussed by your TA. In recitation, new material will be presented and lab quizzes will be administered, which provide you with the opportunity to add points to your grade. Because this class uses an absolute grading scale, it is important to collect as many points as possible. Recitation quizzes and the lab final will be in a multiple-choice format.
Laboratory assignments generally consist of reading through the exercise(s) that you will be performing that day. This reading is important because all group members are expected to contribute equally in ALL lab work. Your participation in each exercise will be evaluated by your TA each period. Groups are required to turn in only one lab summary on which all group members sign their name. Assignments are due at the end of the lab period unless otherwise stated in the syllabus or announced by your TA. All lab group members will receive the same score for each graded lab assignment IF all members participated equally in the work each day. Those who do not will receive a grade of ZERO for that day’s work.

Lab/recitation quizzes will include fairly detailed material from completed labs and may include general information about an exercise that will be performed the day of the quiz (refer to the lab syllabus grid for details). This is one more reason why it is wise to come to lab prepared for each day’s work. Lab quizzes will be conducted on an individual basis and each student will be responsible for his/her own performance on these testing events.

A student who arrives late, after the class has completed a quiz in lab/recitation will not receive a makeup quiz unless she/he can provide a valid written excuse as an explanation for the late arrival. No quiz will be provided without the written excuse. If a student arrives during the quiz period, the student may take the quiz, but will not receive extra time for its completion; she/he must turn in their quiz with the rest of the class.

Graded assignments will be returned to you within one week after they were turned in. All lab scores are posted on Carmen no later than the day the graded assignment is returned. You then have 10 business days in which to check your grade for possible errors in grading or to inquire about a grade not yet posted.

Biology 1113 Laboratory Policy

General information: Attend only the class section in which you are enrolled. TAs cannot enroll you into a different section. If you would like to change your section, complete a section change form in the CLSE office and talk to Ms. Kulesza as soon as possible prior to attending the section you wish to attend.

Laboratory Safety: Eating, drinking, smoking and chewing tobacco is prohibited in lab. Open-toe shoes and flip-flops cannot be worn in the lab room. Treat all chemicals with respect and care. Please be cautious when using them, and use any safety equipment provided. There currently is one procedure in the photosynthesis lab that pregnant women should avoid; your TA will announce this in lab. If you are pregnant, suspect you may be pregnant at that time, or are particularly sensitive to chemicals, please notify your TA before this exercise is performed.

A safety review will constitute a part of the initial class discussion, and a summary of this review must be handed in by EACH student in the class. The minimum grade required on the Safety Review in order to be allowed to continue in lab is 80%. Upon achieving
this grade, each individual will sign a form that indicates that he/she understands the laboratory safety rules.

**Make-Up Labs/Recitations:** If you miss a lab, you must contact your TA within 48 hours. Lab is an integral part of this course. All make up work requires a valid written excuse from a doctor, athletic coach, or other person involved with the absence (preferably before the event occurs if it’s a planned absence). Your TA will not accept or give any make up work without a written excuse. All make up lab work must be completed and received within one week of the original assignment date (unless very unusual circumstances apply), or else you forfeit all points for that lab. Therefore, it is essential that you contact your TA immediately if you miss a lab, or if you know in advance that you cannot attend lab on a specific date. Anyone who misses three (3) labs/recitations (excuse or unexcused) in a given semester will receive a failing grade for the course. No one will receive a make-up for work/quizzes missed after the third missed period (i.e., from the 4th period missed onward), even if that individual has a valid excuse.

Please Note: This is NOT a correspondence course; it is a laboratory course.

**Late assignments:** Any lab assignment turned in late must be placed in your lab TA’s mailbox in room 247 Jennings between the hours of 8:00 am and 5:00 pm weekdays. You are required to record your assignment in the assignment log notebook and time-stamp your assignment with the time stamp machine, both located just inside the doorway. Recording and stamping your assignment is for your benefit to make sure your paper is received and gets proper credit. Assignments not recorded and time stamped will be assumed as received on the day of TA pick up. Late assignments will lose 25% of the available points for up to three (3) days after the due date. Assignments will NOT be accepted after more than three days.

**Point Distribution in the Laboratory/Recitation**

The laboratory/recitation component of Biology 1113 is worth 330 points of the total 898 for the course:

<table>
<thead>
<tr>
<th>Points</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Lab Safety Review</td>
</tr>
<tr>
<td>165</td>
<td>11 Lab Assignments @ 10-20 points each</td>
</tr>
<tr>
<td>50</td>
<td>5 Quizzes @ 10 pts each</td>
</tr>
<tr>
<td>40</td>
<td>Writing Project: Impacts of Scientific Research on Society</td>
</tr>
<tr>
<td>20</td>
<td>Overall Performance: Attendance (includes arriving on time); Participating in Lab/Recitation Discussions; Contributing to Group; and Clean-up</td>
</tr>
<tr>
<td>50</td>
<td>Lab Final</td>
</tr>
<tr>
<td>330</td>
<td>Total</td>
</tr>
<tr>
<td>Designation on Carmen</td>
<td>DATE (start of the week)</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Safety, Ex. 1</td>
<td>7 Jan.</td>
</tr>
<tr>
<td>Ex. 2</td>
<td>14 Jan.</td>
</tr>
<tr>
<td>Ex. 3</td>
<td>21 Jan.</td>
</tr>
<tr>
<td>Ex. 5</td>
<td>28 Jan.</td>
</tr>
<tr>
<td>Ex. 5</td>
<td>4 Feb.</td>
</tr>
<tr>
<td>Ex. 6</td>
<td>11 Feb.</td>
</tr>
<tr>
<td>Ex. 7</td>
<td>18 Feb.</td>
</tr>
<tr>
<td>Ex. 8/Ex. 11</td>
<td>25 Feb.</td>
</tr>
<tr>
<td>Ex. 9/Ex. 11</td>
<td>4 Mar.</td>
</tr>
<tr>
<td>11 Mar.</td>
<td>SPRING BREAK – NO LABS</td>
</tr>
<tr>
<td>Ex. 10/Ex. 11</td>
<td>18 Mar.</td>
</tr>
<tr>
<td>Ex. 4</td>
<td>25 Mar.</td>
</tr>
<tr>
<td>Ex. 4</td>
<td>1 Apr.</td>
</tr>
<tr>
<td>Date</td>
<td>Activity</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>8 Apr.</td>
<td>Lab Final Review</td>
</tr>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab</td>
<td>15 Apr.</td>
</tr>
<tr>
<td>Final</td>
<td></td>
</tr>
<tr>
<td>22 Apr.</td>
<td>No labs this week</td>
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<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B. Non-majors biology course syllabus.

Biology 1101: An Introduction to Biology
Spring 2013

Lecture: M, W, F 10:20-11:15am, Hitchcock Hall 131
Lab/Recitation: 3 hours per week; consult your class schedule

Lecturer: Dr. [Name], Ph.D., Course Lecturer,
240B Jennings Hall (614) 688.4445
Email: rothacker.1@osu.edu

Office Hour: Monday and Wednesday after lecture Schedule appointments prior to showing up.
Course Coordinator: Adam Andrews; andrews.171@osu.edu; 255B Jennings Hall; 614-247-6345
Head TA: [Name]; sovic.2@osu.edu

Prerequisites
Required: None. Background knowledge consistent with the standards established for high
school science by the Ohio Department of Education will be required.

Required Materials:
(Please note the lab syllabus on pages vii-xvi)

-Internet Access: CARMEN and an OSU email are also necessary to be an active participant in
the course. You must activate your OSU email account to have access to CARMEN. The Carmen
URL is http://carmen.osu.edu and Biology 1101 should be listed under My Courses on your
Carmen homepage. The username to logon is your OSU name.# and the password is the one
you use with all OSU email and registration systems. If you have a problem logging in or using
Carmen, contact 688-HELP or carmen@osu.edu. You must also keep up to date on your OSU
email account. IMPORTANT: I will only send email to your official OSU email account.

Additional materials
- 3-ring binder for containing lecture notes and lab handouts.
- Basic calculator for some of the labs, problem sets, and exams.
- Appropriate (old) clothes and closed toed shoes for labs.

**********************************************************************************
Goals and Objectives for the GEC Natural Science Category

Students understand the principles, theories, and methods of modern science, the relationship between science and technology, the implications of scientific discoveries and the potential of science and technology to address problems of the contemporary world.

Expected Learning Outcomes:
1. Students understand the basic facts, principles, theories and methods of modern science.
2. Students understand key events in the development of science and recognize that science is an evolving body of knowledge.
3. Students describe the inter-dependence of scientific and technological developments.
4. Students recognize social and philosophical implications of scientific discoveries and understand the potential of science and technology to address problems of the contemporary world.

Course pedagogy: I strongly encourage a student-active environment, where the content is open and through informed discussion (and yes I will be lecturing too) we will explore the science and help in the teaching of each other. I expect participation, and encourage relevant questions. Courses in natural sciences foster an understanding of the principles, theories and methods of modern science. This course provides students with an understanding of the diversity of life, with lectures and discussions that address cell theory, evolution, genetics, and natural history of life. Discussions of scientific investigations of biological diversity help students understand the core fundamental principles of biology, including historical and modern application of these principles. Everyday interactions of science, technology and society are identified throughout the course, and assignments give students opportunities to personally consider these interactions through active learning. Biology 1101 is designed to help prepare students to make intelligent, informed decisions about Biology evolution, the history of life that they will face in their life.
Biology 1101 Course Learning Objectives:

- Students will recall current and historical aspects of energetics, genetics, evolution, ecology, and cellular structure and function.
- Students will describe biological processes related to energetics, genetics, evolution, ecology, and cellular structure and function.
- Students will analyze the current and future significance of energetics, genetics, evolution, ecology, and cellular structure and function on society.
- Students will apply skills that demonstrate their scientific literacy by communicating about the content and validity of articles related to science in the popular press.
- Students will value the study of biology.
- Students will demonstrate an understanding of the nature of science. This includes (1) the way that scientist develop and evaluate explanations of natural phenomena using criteria fundamental to scientific inquiry and (2) the understanding that science is a human endeavor.
- Students will work productively and effectively in a group.

Professor & Student Responsibilities: My responsibility is to help students understand the nature of biology and biological diversity and will be using various methods to do this in order to incorporate the diversity of students and learning styles. I will strive to make the course interesting and well organized and promise to come to class prepared. I will try to present concepts in an interesting fashion. However and regardless of what I do, your ultimate success in this course depends on you and your efforts. Your responsibility is to prepare daily for the course having read the material required for the day, making flow charts or reading notes, by reviewing notes, completing assignments, and preparing for quizzes. Daily study and prep has been shown to be the best way to acquire course content and successfully navigate exam prep. Given the volume of content we will be covering during the quarter, daily preparation (30-60 minutes/day) is the only way to keep up with this course.

Grading:
Posting of Grades: After grades are posted you will have 10 days from the date of posting to challenge any grade or inquire regarding any un-posted grade; after that time, grades are final.

There is no curve and grades are not rounded!

Evaluation:

<table>
<thead>
<tr>
<th>Evaluation Source</th>
<th>Evaluation number</th>
<th>Points</th>
<th>Grading Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carmen quizzes</td>
<td>14</td>
<td>140pts (10pts ea.)</td>
<td>A = 93 - 100%</td>
</tr>
<tr>
<td>Midterm 1:</td>
<td>1</td>
<td>100pts.</td>
<td>A- = 90 – 92%</td>
</tr>
<tr>
<td>Midterm 2:</td>
<td>1</td>
<td>100pts.</td>
<td>B+ = 87 – 89%</td>
</tr>
<tr>
<td>Final exam:</td>
<td>1</td>
<td>150pts.</td>
<td>B- = 80 - 82%</td>
</tr>
<tr>
<td>Lecture Participation:</td>
<td>70pts (1-10 ea.)</td>
<td></td>
<td>C+ = 77 - 79%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C = 73 - 76%</td>
</tr>
</tbody>
</table>
NY Times Essays: 4 100pts (25pts ea)  C- = 70 - 72%
Lab Exercises 14x20 280pts  D+ = 67 - 69%  D = 60 - 66%
TA points: 40pts  E = 0 - 59%
TOTAL POINTS = 980

KEEP IN MIND, YOU START EACH SEMESTER WITH A PERFECT SCORE,

YOUR JOB IS TO MAINTAIN IT!

Course Content and Evaluations
Readings, Videos & Activities: For several of the topics we will explore in the course, we will use videos and/or activities relevant to the topic at hand to be worked out or explored in class in an active learning environment. Handouts and additional readings may be supplied and will be posted to Carmen. All course content is appropriate material for exams, including content covered in the laboratory exercises.

NYTimes summaries: WE WILL be collecting reading summaries throughout the term, submitted to the Carmen dropbox (only!) – see the syllabus for due dates and conditions. WHAT WE LOOK FOR IN SUMMARIES: Summaries tell us that you have digested another person’s ideas thoroughly and that you understand what an author is communicating without intruding your own opinion. A summary allows us to know exactly what you are trying to communicate and whether it is in your own words. Summaries tell us whether you comprehend the point of the readings and can distinguish information that is essential from information that is supportive from information that is superfluous. In addition, by limiting you to 1-3 pages, each word becomes more valuable for its accuracy, precision, and nuance. Writing a good summary takes time and effort. It is evident when you put it off. All course content is appropriate material for exams. Late submissions will be accepted for 24 past the due date for a maximum of 75% credit. No credit will be awarded if submitted more than 24 hours late.

In-class activities: For several of the topics we will explore in the course, we will use videos and/or activities relevant to the topic at hand to be worked out or explored in class in an active learning environment or through out-of-class activities or readings. Handouts and
additional readings may be supplied and will be posted to CARMEN. There will be a variety of in-class activities and methods of active learning used in the course. These will include but are not limited to embedded lecture questions, think-pair-share, case studies, worksheets, etc. Some but not all of these are graded, however all in-class assignments are not announced ahead of time so you are required to be in lectures in order to receive the points. All course content is appropriate material for exams.

**Lecture participation:** This will be measured using a variety of think-pair-share type assignments turned in at the end of each class. There will be numerous opportunities to earn these points throughout the term so in case you happen to miss a lecture for one reason or another you will have an opportunity again. There will be no make-ups on any particular assignment given the number of opportunities to earn points throughout the term, which will exceed the maximum number of possible points.

**Lecture quizzes & exams** will cover both *readings and lecture and lab* material including any handouts. The final exam is comprehensive. All exams will be mixed format and may include, but limited to, multiple choice, True/False and matching.

**Carmen Quizzes:** There will be 14 on-line quizzes, each worth 10 points (10 questions each). The format will be multiple choice, and will be administered through Carmen. You will have two opportunities to take each quiz over a 72 hour window (will be active on Friday immediately after lecture (11:15am) until the start of class on Monday (10:20am), and your best attempt will be the counted score. Quizzes submitted after the deadline will not be counted. A time limit of 10 minutes (1min /question) will be strictly imposed for each quiz attempt. Attempts exceeding the time limit will earn a score of zero. Questions will be drawn from a pool, so each quiz attempt may differ slightly in its content. Please be aware that collaboration is not permitted on the quizzes and will be considered acts of academic misconduct. Due to the generous period of time you have to complete the quizzes, extensions and makeup opportunities will not be given except in the most extreme of situations. You are strongly encouraged not to wait until the last minute to complete the quiz as technological issues (ie internet or power failures, etc.) will not be grounds to extend the quiz window. Should a
Students with disabilities that have been certified by the Office for Disability Services will be appropriately accommodated and should inform the course
coordinator, Adam Andrews as soon as possible of their needs. Please do this within the first two weeks of the semester. Only the course coordinator is authorized to sign ODS forms. Please fill out those parts of the proctor sheet forms that are to be completed by the student before bringing the form for signature. This will help us ensure that your individual needs will be met appropriately and fairly. The Office for Disability Services is located in 150 Pomerene Hall, 1760 Neil Avenue; telephone 292-3307, TDD 292-0901; http://www.ods.ohio-state.edu/.

Food and Drink: Drinks in the lecture will be allowed, however if I find that you are not cleaning up after yourselves, I will prohibit them from further lectures. Food and drinks of any sorts are prohibited in the lab.

Email etiquette: Emails are a written form of communication between two or more individuals. Here are a few important points to remember when composing email, particularly when the emails recipient is your advisor, instructor or even your peer(s). Additional resources on effective emailing: http://www.emailreplies.com/

- Be sure to include a meaningful subject line; this helps clarify what your message is about and may also help the recipient prioritize reading your email, and prevent spam filters from removing it.
- Open your email with a greeting for the intended recipient (s). eg: Dear Dr. Jones, or Ms. Smith:
- Use full sentences, with the standard spelling, punctuation, and capitalization. THERE’S NOTHING WORSE THAN AN EMAIL SCREAMING A MESSAGE IN ALL CAPS. Do not use emoticons (😊, 😊), acronyms or other text message shorts for full words or phrases (unless appropriate to the circumstance, Eg. DNA, RNA, ect.).
- Write clear, short paragraphs and be to the point; professionals and academics alike see their email accounts as business. Don't write unnecessarily long emails or otherwise waste the recipient's time.
- Be sure to reread the message for clarity and check spelling and grammar before clicking “send”
- Be friendly and cordial, but don’t try to joke around (jokes and witty remarks may be inappropriate and, more commonly, may not come off appropriately in email).
- And most importantly, be professional, this communication represents you!

Academic Misconduct:

It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term “academic misconduct” includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-487). For additional information, see the Code of Student Conduct http://studentlife.osu.edu/csc/. We will adhere to this policy. Keep your eyes where they belong, submit your own work or cite according to MLA standards, and we will not have an issue. I surely hope this never needs my further attention.
Sexual Harassment

OSU has a strict policy regarding this and strives to maintain both an academic and working environment based on the principle of the dignity and worth of every human being. OSU and all staff and faculty in CLSE consider sexual harassment to be unacceptable behavior and counterproductive towards learning. While all members of the staff involved in this course have been trained in the OSU sexual harassment policies and procedures, this is not true for all OSU students, the University prohibits and will not tolerate any acts of sexual intimidation, harassment, or abuse regardless of gender, sexual orientation, religion or race. Such behaviors violate the privacy and dignity of individuals, and are a violation of federal and state laws. **Like all misconduct, I hope that this never needs further discussion**, however I am available if needed to address issues related to this or will put you in contact with the appropriate personnel. Please report any concerns about questionable or unwanted behavior to Dr. Rothacker or Mr. Andrews as soon as possible.

Section Changes
All section changes and adds are done by the Course Coordinator. Due to the need to keep up-to-minute availability of seats in each recitation, the lecturer and TAs are unable to sign any permission forms.

Issue Resolution
The CLSE believes that student concerns are usually most effectively addressed by the staff closest to the situation. Therefore, students are ordinarily expected to address issues or concerns with their TAs first. If the issue cannot be resolved by your TA, or for some reason you feel that you absolutely cannot address your concern with your TA, please feel free to contact Adam Andrews (andrews.171@osu.edu) or Assistant Director Matt Misicka.
### BIO1101

#### Lecture and Lab Schedule

**TENTATIVE**

<table>
<thead>
<tr>
<th>Week/Date</th>
<th>Lecture Topic</th>
<th>Phelan 2nd ed.</th>
<th>Lab Exercise (Lab Manual chapter)</th>
<th>Assignment Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1/7</td>
<td>Introduction to the science of biology, Early earth and the Chemistry of Life</td>
<td>Ch 1 Ch 2.1-2.6 Ch 10.1-10.2 Ch 20.7-12</td>
<td>Exercise 1: How does science work?</td>
<td></td>
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<tr>
<td>1/9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 1/14*</td>
<td>Macromolecules</td>
<td>Ch 2.7-2.21, Ch 22 Ch 3</td>
<td>Exercise 2: What are these macromolecules we’re eating for dinner?</td>
<td></td>
</tr>
<tr>
<td>1/16</td>
<td>Macromolecules</td>
<td></td>
<td></td>
<td>-Quiz 1*</td>
</tr>
<tr>
<td>1/18</td>
<td>Cell Structure and Function</td>
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<td></td>
<td>-Quiz 2*</td>
</tr>
<tr>
<td>3 1/21*</td>
<td>Martin Luther King day: NO CLASS</td>
<td>Exercise 4: How do plants and yeast function?</td>
<td></td>
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<tr>
<td>1/23</td>
<td>Energy flow, Metabolism, and diet Photosynthesis</td>
<td>Ch 4.1-4.11 Ch 22.1-3</td>
<td>-NY Times Essay 1 (1/25 @ 11:59P)</td>
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<tr>
<td>4 2/1</td>
<td>Cellular Respiration and “Diets”</td>
<td>Ch 4.12-4.17 Ch 22 Ch 5.1-5.2</td>
<td>Exercise 6: What is the structure of DNA and how does it replicate?</td>
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<tr>
<td>2/28*</td>
<td>DNA Structure &amp; Replication. In-Class Activity</td>
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<td>-Quiz 3*</td>
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<tr>
<td>5 2/4*</td>
<td><strong>Midterm 1</strong></td>
<td>Ch 6.1-6.18</td>
<td>Exercise 5: How do organisms grow?</td>
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<tr>
<td>2/6</td>
<td>Mitosis</td>
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<td>-Quiz 4*</td>
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<tr>
<td>2/8</td>
<td>Meiosis</td>
<td></td>
<td></td>
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<tr>
<td>6 2/11*</td>
<td>Mendel and Genetics Molecular genetics and gene expression</td>
<td>Ch 7 Ch 5.3-5.9</td>
<td>Exercise 7: How do you get from a gene to a protein?</td>
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<td>2/13</td>
<td>Molecular genetics and gene expression</td>
<td></td>
<td></td>
<td>-Quiz 5*</td>
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<tr>
<td>2/15</td>
<td>Molecular genetics and gene expression</td>
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<td>-NY Times Essay 2 (2/15 @ 11:59P)</td>
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<td>Week</td>
<td>Dates</td>
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<td>Lecture Topic</td>
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<td>7</td>
<td>2/18*</td>
<td>Ch 5.11-5.17, Ch 6.17-6.18</td>
<td>“Ghost in your genes” Biotech, Gene therapy “Cracking your genetic code”</td>
<td>Exercise 8: How are human genetic traits inherited?</td>
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<td>2/25*</td>
<td>Ch 14.1-14.5, Ch 15</td>
<td>Climate ecology, Biomes and Ecosystems, and Organismal Ecology</td>
<td>Exercise 9: How does the environment select for characteristics of organisms?</td>
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<td>Midterm 2</td>
<td>Exercise 15: How does energy flow through the environment?</td>
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<td>Diversity of life: Prokaryotes, Diversity of life: Intro to Eukaryotes</td>
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<td>11</td>
<td>3/25*</td>
<td>Ch 12.1-12.12, Ch 17, 18</td>
<td>Diversity of life: Plants (evolution and diversity)</td>
<td>Exercise 14: How do we define the diversity of plants?</td>
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<td>12</td>
<td>4/1*</td>
<td>Ch 12.1-12.12</td>
<td>Diversity of life: Plants (evolution and diversity) Ethnobotany</td>
<td>Exercise 16: How do pollutants affect the environment?</td>
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Be sure to have read the readings for discussion prior to the lecture for which they are posted

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<tr>
<th>Date</th>
<th>Course</th>
<th>Chapter</th>
<th>Notes</th>
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<tbody>
<tr>
<td>4/22*</td>
<td>Conservation Biology</td>
<td>Ch. 16</td>
<td>Recitations only</td>
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<td><strong>FINALS</strong></td>
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| 4/24   | Final Exam: Wednesday, April 24; 10:00-11:45 AM in Hitchcock Hall 131
| 5/1    | Makeup Exam: Wednesday, May 1; 9:00 a.m. in Jennings Hall 270 |

-Quiz 14*
Appendix C. Interview questions from study investigating intermediate biology students’ scientific reasoning abilities (in Chapter 4).

1. Suppose you are given two clay balls of equal shape and size. The two balls weigh the same. One is flattened into a pancake shaped-piece, and the other is left as a ball. What happens to the weight of the two balls? Why? (*Modified question 1 from the LCTSR*)

2. Here are two drawings of cylinders filled to the same level with water. They are identical in shape and size. In one we put a glass marble, and the water rises to the sixth mark. If we put the steel marble in to the other cylinder, what will happen with the water? Why? (*Modified question 3 from the LCTSR*)

3. Twenty fruit flies are placed in each of four glass tubes, shown here (points to diagram). The test tubes are sealed and Tubes 1 & II are partially covered with black paper. Tubes III and IV are not covered. The tubes are placed vertically and horizontally, as shown in the figure. The flies are then exposed to red light for five minutes. Following the exposure, the number of flies in the uncovered parts of each tube are shown in the figure. What does this experiment show that flies respond to? Why do you say that? (*Modified question 11 from LCTSR*)

4. The figure below shows a drinking glass and a burning birthday candle in a pan of water. When the glass is overturned and placed over the burning candle, into the pan of water, the candle quickly goes out and the water rushes up into the glass (show in the figure). Why does the candle go out? Why does the water rush up into the glass? How could you provide evidence that your explanations are correct? (*Modified question 21 from LCTSR*)

5. Farmer Brown observed the mice that live in his fields. He noticed that all of them were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there was a link between the size of the mice and the color of their tails. He captured all of the mice in one part of his field and noticed the following: (show student the diagram of the mice). What can Farmer Brown conclude from his observations? What could he do to provide more evidence for his conclusions? What variables do you see as important in this situation? (*Modified question 19 from LCTSR*)
Appendix D. Sample questions from each of the five interviews held for the study in chapter 5.

<table>
<thead>
<tr>
<th>Interview</th>
<th>Sample Questions</th>
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| 1         | • Why did you choose biology as your major?  
            • Is there only one “scientific method”? Please explain your answer.  
            • Is scientific knowledge changing and tentative, or fixed? |
| 2         | • How has this class been going? Explain to me what topics are being covered.  
            • Your professor has you reading scientific literature from journals for your homework. How has this use of “real life” research helped your understanding?  
            • How do you usually study for exams in biology? |
| 3         | • How did the exam go? Describe the exam for me. (format and questions)  
            • Do scientists invent or discover knowledge in their fields?  
            • Does science mean different things to different people? |
| 4         | • What, if anything, is the goal of science, and how do scientists achieve this goal?  
            • What if a biologist gets unexpected results from her experiment—what happens then?  
            • Is science ever wrong? If so, how is it corrected? |
| 5         | • Does what you’ve learned in your previous classes affect what you are learning in your current classes? How so?  
            • How does knowledge in biology form, and how does it become “accepted”?  
            • Does learning biology change your views of how the world works? |

**Questions asked throughout the semester**

• Do you see any connections between what you learn in biology class and what you learn in other science classes?  
• Do you see any connections between what you’ve learned in class and the real world, or your everyday, non-academic life?  
• What is your current level of interest in biology? Why do you think this is your current level of interest?
Appendix E. The Colorado Learning Attitudes about Science Survey for Biology (CLASS-Bio) as it looked on the course homepages for Studies 1, 2, & 3.

Here are a number of statements that may or may not describe your beliefs about learning biology. You are asked to rate each statement by selecting a number between 1 and 5 where the numbers mean the following:

1. Strongly Disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly Agree

Choose one of the above five choices that best expresses your feeling about the statement. If you don’t understand a statement, leave it blank. If you have no strong opinion, choose 3.

We are asking that you express your own beliefs. Your answers will not affect your grade. Your instructor will never see your individual answers, only whether you participated and the class results as a whole. This information will be very helpful to us in an effort to design more effective biology courses.

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<tr>
<th>#</th>
<th>Statement</th>
<th>1</th>
<th>2</th>
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<th>5</th>
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<tbody>
<tr>
<td>1</td>
<td>My curiosity about the living world led me to study biology.</td>
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<td>2</td>
<td>I think about the biology I experience in everyday life.</td>
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<td>After I study a topic in biology and feel that I understand it, I have difficulty applying that information to answer questions on the same topic.</td>
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<td>3</td>
<td>Knowledge in biology consists of many disconnected topics.</td>
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<td>4</td>
<td>When I am answering a biology question, I find it difficult to put what I know into my own words.</td>
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<td>5</td>
<td>I do not expect the rules of biological principles to help my understanding of the ideas.</td>
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<td>6</td>
<td>To understand biology, I sometimes think about my personal experiences and relate them to the topic being analyzed.</td>
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<td>If I get stuck on answering a biology question on my first try, I usually try to figure out a different way that works.</td>
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<td>8</td>
<td>I want to study biology because I want to make a contribution to society.</td>
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<td>9</td>
<td>If I don’t remember a particular approach needed for a question on an exam, there’s nothing much I can do (legally!) to come up with</td>
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Biological principles are just to be memorized.

It is important for the government to approve new scientific ideas before they can be widely accepted.

Learning biology changes my ideas about how the natural world works.

To learn biology, I only need to memorize facts and definitions.

Reasoning skills used to understand biology can be helpful to my everyday life.

It is a valuable use of my time to study the fundamental experiments behind biological ideas.

If I had plenty of time, I would take a biology class outside of my major requirements just for fun.

The subject of biology has little relation to what I experience in the real world.

There are times I think about or solve a biology question in more than one way to help my understanding.

If I get stuck on a biology question, there is no chance I'll figure it out on my own.

When studying biology, I relate the important information to what I already know rather than just memorizing it the way it is presented.

There is usually only one correct approach to solving a biology problem.

When I am not pressed for time, I will continue to work on a biology problem until I understand why something works the way it does.

Learning biology that is not directly relevant to or applicable to human health is not worth my time.

Mathematical skills are important for understanding biology.

I enjoy explaining biological ideas that I learn about to my friends.

We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question to preserve your answers.

The general public misunderstands many biological ideas.

I do not spend more than a few minutes stuck on a biology question before giving up or seeking help from someone else.

Biological principles are just to be memorized.
For me, biology is primarily about learning known facts as opposed to investigating the unknown.

Scientists may make different interpretations based on the same observations.

Scientists follow the same step-by-step scientific method.

When scientists use the scientific method correctly, their results are true and accurate.

Scientists use their imagination and creativity when they collect data.

Scientists use their imagination and creativity when they analyze and interpret data.

Unlike many other professions, science is almost always a solitary endeavor.

Scientific investigations usually come to a definitive end, allowing the science to move on to a brand new question.

Everyday problems and observations frequently inspire scientific investigations.

The same hypothesis or theory is often tested in many different ways.

Scientists may have different interpretations of the same observations.

If an observation is made in the correct way, its meaning is straightforward and is not subject to interpretation.

The process of science is not a simple recipe; it is a complex process.