# ABSTRACT

Title of Dissertation: EXAMINING THE EFFECTS OF STUDENTS' CLASSROOM EXPECTATIONS ON UNDERGRADUATE BIOLOGY COURSE REFORM

Kristi Lyn Hall, Doctor of Philosophy, 2013

Dissertation Directed By: Edward F. Redish
Department of Physics

In this dissertation, I perform and compare three studies of introductory biology students' classroom expectations — what students expect to be the nature of the knowledge that they are learning, what they think they should be (or are) doing in order to learn, and what they think they should be (or are) doing in order to be successful. Previous work has shown that expectations can impact how students approach learning, yet biology education researchers have been reluctant to acknowledge or address the effects of student expectations on curricular reform (NRC, 2012). Most research in biology education reform has focused on students' conceptual understandings of biology and the efficacy of specific changes to content and pedagogy. The current research is lacking a deeper understanding of how students perceive the classroom environment and how those perceptions can shape students' interactions with the content and pedagogy. For present and future reforms in biology to reach their full potential, I argue that biology education should actively address the different ways students think about and approach learning in biology classes.

The first study uses a Likert-scale instrument, adapted from the Maryland Physics Expectations Survey (Redish, Saul, & Steinberg, 1998). This new survey, the Maryland Biology Expectations Survey (MBEX) documents two critical results in biology classrooms: (i) certain student-centered pedagogical contexts can produce favorable changes in students' expectations, and (ii) more traditional classroom contexts appear to produce negative epistemological effects.

The second study utilizes a modified version of the MBEX and focuses on students' interdisciplinary views.  This study documents that: (i) biology students have both discipline-specific and context-specific classroom expectations, (ii) students respond more favorably to interdisciplinary content in the biology courses we surveyed (as opposed to biology content introduced into the physics courses we surveyed), and (iv) biology faculty are not fully "on board" with interdisciplinary and integrative curriculum initiatives commonly endorsed in the current reform literature.

The third study is a case study of students' classroom expectations. From this data corpus, I have identified distinct patterns of biology-specific classroom expectations. I believe these expectations have important implications for how researchers should approach curricular reforms in the future.

# EXAMINING THE EFFECTS OF STUDENTS' CLASSROOM EXPECTATIONS ON UNDERGRADUATE BIOLOGY COURSE REFORM.

By

Kristi Lyn Hall

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2013

Advisory Committee:
Prof. Edward F. Redish, Chair
Prof. Todd J. Cooke, Dean's Representative
Dr. Janet E. Coffey
Prof. Andrew R. Elby
Prof. Daniel M. Levin

# Acknowledgements

Faculty, friends, and family members have all helped me to complete this dissertation. I would like to express my gratitude to these individuals for their support and assistance.

Joe Redish has been a strong and supportive advisor to me throughout my graduate school career. I want to thank you Joe for challenging me to find my own voice. Todd Cooke also deserves credit for being a wonderful mentor. We were in uncharted territory with this project, but you were never willing to give up and you were such a strong advocate for me. Always the calm within the storm, I am forever grateful. I want to thank Janet Coffey for her patience, her endless wisdom, and for helping me with the tone and discipline of my writing. Janet, you are simply the best. I have been especially fortunate to know Andy Elby. His strong, yet gently worded opinions and his willingness to share them have been great assets to me and to many others at Maryland. Andy, thank you for always engaging in new ideas and your willingness to invest your time (which is scarce) and your energy (which is abundant) in improving others' work. Your concern for graduate training and the future of education research at Maryland is an inspiration to us all. In the short time that I have had to work with Dan Levin, he has had an enormous impact on the present project and a lasting effect on the way that I think about education research. Dan, your effort to improve the quality of this dissertation and your willingness to provide consistent, thoughtful, comments shows a strong dedication to graduate education. Thank you. I did not meet Jessica Watkins until my third year of graduate school, but I could not have analyzed this data without her. Thank you Jessica for keeping me focused on the important questions. Finally, I appreciate the cooperation of all the biology professors who bravely consented to my interviewing and surveying their students.

I also want to thank the good friends I have made at Maryland and beyond for their support throughout my time in graduate school. I owe my sanity to you. The Physics Education Research Group was a wonderful place for a biologist to call home. Thank you Lisa for your willingness to grab a coffee with me on demand and thank you Patty for being such a generous and wonderful person. When I became your Teaching Assistant my first year of graduate school, I had no idea you would redirect my entire graduate career. I am glad you did.

I also gratefully acknowledge the institutional support that I received while working on this project. In particular, I thank the National Science Foundation and the University of Maryland.

I want to thank my parents, Deb and Kevin, for their constant encouragement. Thank you for always believing in me. To the rest of my family, including my sister, Mallory, thank you for loving and supporting me through the years. I would not be the person I am today without you.

I most want to thank my husband Ari for accepting nothing less than completion from me. Your encouragement was appreciated more than you will ever know.

# Table of Contents

# List of Tables

# List of Figures

# EXAMINING THE EFFECTS OF STUDENTS' CLASSROOM EXPECTATIONS ON UNDERGRADUATE BIOLOGY COURSE REFORM.

## I. Chapter 1: Introduction

### A. Topic of Study

This dissertation reports on how pedagogical reforms affect students' classroom expectations in three different sections of an undergraduate organismal biology course. In this dissertation, I have chosen to focus explicitly on a specific subset of students' expectations that appear to be particularly salient for curricular reform. I refer to them as classroom expectations. Classroom expectations refer to a predictive set of ideas or assumptions students make regarding the nature of the classroom experience. Classroom expectations can be further classified into three categories: (1) epistemological expectations — what students expect to be the nature of the knowledge that they are learning, (2) learning expectations — what it is that they think they should be (or are) doing in order to learn that knowledge, and (3) performance expectations — what it is that they think they should be (or are) doing in order to be successful in a particular course. For each of these subcategories, students can (and often do) have multiple or competing sets of expectations. For example, what students think they should be doing to learn might not be what they think they should be doing to succeed in a class (Elby, 1999). Educators and policy makers have previously argued for the importance of curricular and pedagogical reforms in biology (AAAS, 2011; AAMC-HHMI committee, 2009; National Research Council, 2003). Such efforts to rethink biology curriculum are critical to improving biology education; however, these efforts will not reach their maximum potential until reformers also account for students' classroom expectations and how those expectations inform students' understanding of the learning process.

Much research has shown that students bring misconceptions about science content into their classes that can affect their learning, often in negative ways (Hammer, 1996a; National Research Council, 2000; Nehm & Reilly, 2007). In addition to the preconceptions about content, students also bring misunderstandings about what counts as knowing and understanding, about what kinds of knowledge and learning their courses are trying to teach, and about what is appropriate for them to do to learn it. Just as students' preconceptions about content can hinder their learning, students' expectations about how to construct knowledge can constrain their approach to education, even in reformed classrooms. In physics education, for example, researchers have documented that student views about physics knowledge (e.g., as formulas rather than as concepts expressible in equations), negatively affects their approaches to learning (Hammer, 1989; Lising & Elby, 2005). Similarly, students who view biology as a set of disconnected facts to be absorbed and regurgitated are likely to view any information from their professor as additional information to be memorized, not as tools to construct a deeper understanding of biology.

Student expectations impede not just individual learners but also systemic reform. Prior experience in undergraduate physics suggests that what is usually interpreted by instructors or researchers as student conceptual difficulty is often a manifestation of a mismatch or misalignment between the student's and the instructor's epistemological expectations (Elby, 2001; Hall, Watkins, Coffey, Cooke, & Redish, 2011; Hall, 2010; Hammer, 1989, 1996a, 1996b; Redish et al., 1998). These misalignments generally center on what counts as "learning" or what types of activity are appropriate in a specific learning context.

## B. Problem Statement

To date, biology education researchers have primarily documented students' conceptual difficulties and have not focused on understanding students' expectations of how to approach learning in biology. Additionally, I have found scant evidence in the literature documenting cases of potential misalignments between the expectations of students and instructors in biology education. My own evidence suggests that biology students may at times by hampered by various assumptions they have made about the learning task itself (Hall et al., 2011). For example, it is not uncommon for students' to assume that learning biology means memorizing large chains of complex facts. Similar results have been reported in the biology education literature (Walker et al. 2008). Students who are preoccupied with trying to memorize may end up hindered in their ability to reason independently (Russ, Scherr, Hammer, & Mikeska, 2008).

While it seems reasonable that students' classroom expectations have direct implications for actual classroom behavior, little is known about the nature of these classroom expectations in biology or how these classroom expectations can be changed through specific pedagogical and curricular interventions. Filling this gap in the literature will require drawing from previous research in physics and mathematics education, but also needs novel perspectives from discipline-experts in biology to inform detailed investigations on student ideas about the nature of biological knowledge, how best to learn that knowledge, and how those ideas align to succeed in the classroom.

To investigate classroom expectations, this study incorporates a mixed-methods approach and will use classroom observations, interviews, and a newly developed self-report expectations survey, the Maryland Biology Expectations Survey (MBEX). The remainder of chapter I presents: (C) a brief review of the state of biology education research and motivation for the study, (D) the specific contributions to biology education, (E) the theoretical framework, (F) the learning contexts, and (G) the research questions.

## C. A Brief Review of the Current Trends in Biology Education Research and Motivation for Study

### *1. Biology reform: pedagogy and content*

In the past ten to fifteen years, many have called for curricular reform in undergraduate biology education (Handelsman, Miller, & Pfund, 2006; Hulleman & Harackiewicz, 2009; National Research Council, 1996, 1997, 1999, 2000, 2003; National Science Foundation, 1996). Most reformers have focused on curriculum or pedagogy. The reforms' explicit purposes are to help students develop deeper levels of understanding, transferable knowledge, and effective scientific reasoning skills (Michael & Modell, 2003). Often, changes reduce lecture time in favor of more interactive formats. The reports also urge instructors to cover material more deeply by incorporating collaborative exercises (Goodwin

& Davis, 2005; Reingold, 2005; Steen, 2005). Researchers have shown that for some students, these pedagogical strategies achieve positive learning outcomes, such as increasing self-directed learning behaviors and problem solving skills (Allen & Duch, 1998; Blumberg & Michael, 1992; Khodor, Halme, & Walker, 2004; Rawson & Quinlan, 2002). There is a growing body of data demonstrating the effectiveness of these specific strategies on mitigating students' conceptual difficulties (Boyes & Stanisstreet, 1991; Garvin-Doxas, Klymkowsky, & Elrod, 2007; Klymkowsky & Garvin-Doxas, 2008) and getting students to practice better critical thinking skills in the biological classroom (Walton & Rybarczyk, 2009; Walton, 2008).

### *2. Content and pedagogical reforms are insufficient to transform students' expectations of learning*

However, despite some positive outcomes, several semesters of data collected from students in a large, introductory undergraduate biology course indicate that: (i) student epistemological expectations about the nature of knowledge, as well as their expectations about their learning, influences how they interact with content and pedagogical reform efforts in class. I find that students' performance expectations, what they think they need to do in order to be successful, often conflict with reform goals or persist despite the reform objectives. In addition to student expectations, (ii) how the instructor implements and interprets the goals of reform is an important factor influencing students' epistemological orientations toward learning. I argue that, in addition to research based content and pedagogical interventions; curriculum reform initiatives should account for, and actively address, classroom expectations to increase the chance for effective implementation.

### D. Specific Contributions to Biology Education Research

This dissertation presents a body of research that makes five main contributions to biology education research:

First, I present a theoretical framework for the construction and understanding of an expectations survey, based on previous work in the physics education literature (diSessa, 1993; Elby & Hammer, 2001; Hammer, Elby, Scherr, & Redish, 2004; Hammer & Elby, 2002, 2003; Hammer, 1989, 1994, 1996a, 1996b, 2000; Lising & Elby, 2005; Louca, Elby, Hammer, & Kagey, 2004; Redish et al., 1998). The framework provides a body of knowledge about the implications of my view of knowledge on students' expectations of reform. As part of this discussion, I demonstrate that my understanding of the theoretical construct and my experimental methods and results can be packaged in a way that allows others to learn from and extend my findings in biology education.

Second, I review the newly developed Maryland Biology Expectations (MBEX) survey. I developed the MBEX to assess the effectiveness of course transformation in an introductory biology course. I argue that a positive shift in student classroom expectations is one, often overlooked, indicator of improved student interactions with specific conceptual and pedagogical interventions. Therefore, one goal in developing the MBEX is to design a tool to measure class-wide shifts in student classroom expectations over the course of a semester as a way to link epistemic and conceptual gains.

The third contribution presents the results of several semesters of MBEX survey and interview data. I took the data from three sections of an introductory organismal biology class — one lecture-only section and two reform-oriented sections over four semesters. By reform-oriented, I mean courses which employed a hybrid student-centered pedagogical strategy by combining traditional lectures with more progressive student-centered pedagogical strategies, such as group work. The data collected from the MBEX surveys and individual student interviews suggest that student expectations about learning biology affect the ways students interpret the classroom experience. For example, students who typically memorize facts may misinterpret instructions to "understand general principles" as a cue to memorize a new fact called a principle, rather than as a challenge to understand biology on a deeper, more comprehensive level.

The fourth contribution presents the motivation, development, validation, and results of modified version of the MBEX survey. In order to explore students' ideas about the value of incorporating interdisciplinary concepts into the curricula, I modified the third dimension of the MBEX survey (Interdisciplinary Perspectives versus Silo Maintenance) to be compatible with both the MBEX and the Maryland Physics Expectation Survey (MPEX) for use in both introductory physics and biology classes. I then compare the data from three sections of an introductory organismal biology class — one lecture-only section and two reform-oriented sections to the data from three introductory physics courses for life science majors over two semesters. The data I collected from the newly created Interdisciplinary Expectations Cluster (IEC) suggest that students have both discipline-specific and context specific expectations about learning. For example, students expected mathematics to be more valuable than physics to their biology education. This discipline-specific expectation persisted even after two semesters of physics instruction. Biology students also consistently responded more favorably to the incorporation of physics content into the specific biology classes we surveyed than vice versa.

The fifth contribution presents case studies of biology-specific examples of student classroom expectations, which, unlike the previous two contributions, address learning expectations on a macro level. Drawing primarily from student interviews, but also drawing from student responses to exam questions, field observation, and classroom performance data, these cases aid in defining a classroom expectation and illustrating expectations within a biology context. These cases also provide a demonstration of how student expectations affect actual (self-reported) behavior in class. Additionally, they are also useful and effective cases that help aid my understanding of how these complex and context-specific classroom expectations affect students' preconceptions of the learning context itself. As such, the case studies show the importance of these preconceptions to ongoing attempts at curricular reform.

## E. Theoretical Frameworks: Resources and framing

### *1. Resource framework*

This dissertation draws on two related theoretical frameworks. David Hammer introduced the first framework, "resources," into the literature, building on Andrea diSessa's "knowledge in pieces" work (diSessa, 1993; Hammer, 2000;

Smith, diSessa, & Roschelle, 1993). In 2000, Hammer described these "resources" as small, often subconscious units of thought that, when activated in the right contexts, are productive reasoning tools that students use to understand phenomenon (Hammer, 2000). Students can have an incalculable number of these resources, which they gain from everyday experiences, and which combine and recombine to form their conscious reasoning skills. Since David Hammer introduced the concept of resources, researchers have greatly expanded the framework (Hammer et al., 2004; Hammer & Elby, 2003; Reiner & Gilbert, 2000; Tuminaro, 2003). I intend to use the resource framework to aid my understanding of why students may express or display certain learning expectations in some contexts but fail to apply them in other contexts.

### *2. Epistemological framing*

Before I delve into a deeper discussion of student expectations, I must also address the importance of the learning context in shaping these student preconceptions or expectations. Education researchers have shown that the learning context is highly influential in shaping student expectations and vice versa (Scherr & Hammer, 2008; Schoenfeld, 1988). This means that students manifest different expectations in different contexts.

This dynamic perception process is often called framing (Goffman, 1997; Tannen, 1993a). In Tannen, framing means the set of expectations an individual brings to a social situation. These expectations affect what the individual notices and how he or she acts. In Goffman (1997), a frame is a person's generally tacit answer to the question, "What's going on here?"

Different frames activate in response to an individual's perception of context. In the classroom, this activation process can take many forms. For example, a student can frame the purpose of an activity as learning to memorize as much as she can as fast as she can or as learning to make sense of the information to the best of her abilities. While both of these framings are potentially appropriate in an instructional situation, they will lead the student to notice different things and to behave in very different ways.

Tannen's (1993) conceptualization of framing corresponds to an individual's forming of a locally coherent activation of resources (Bing, 2008). In particular, epistemological framing is the cognitive activity underlying a student's sense of "what type of activity is this?" Framing provides context, which a student uses to select among one or more resources. From this, I define framing as "a locally coherent activation of a network of resources that may look like a stable belief or theory" (Hammer & Elby, 2002).

Researchers in physics education have documented the effect of both epistemological expectations and context framing on student approaches to learning in pedagogically reformed courses. However, biology education researchers have only begun to identify similar expectations and approaches (Hall et al., 2011; NRC, 2012; Watkins, Hall, Redish, & Cooke, 2010).

Based on prior experience in physics education (Redish & Hammer, 2009), I hypothesize that students' expectations about the nature of the knowledge they are learning will strongly affect how students approach learning across contexts. In addition, I have further evidence to suggest that students have discipline-specific classroom expectations about what it means to “know” and “learn” in the context of their various science courses (Watkins et al., 2010). As a result, in order to understand the barriers to teaching scientific reasoning and critical thinking skills, I want to know how student classroom expectations manifest specifically in biology courses.

I surmise that present classroom expectations are largely the result of past experience with school and schooling; therefore, I begin to investigate these discipline-specific student classroom expectations by describing the traditional learning context in which students are constructing the majority of these classroom expectations. I then offer some of the contemporary criticisms of the traditional classroom context and describe some current attempts to improve the learning environment.

## F. The Learning Contexts

### *1. The lecture-only model: the typical biology classroom*

Traditional introductory biology classes are taught in large (100+) student lectures. Lectures are mostly oral presentations, often with PowerPoint or other visual aids and are intended to present information or teach people specific content about a particular subject. While lectures delivered by talented speakers can be highly stimulating, they often do not require much audience engagement and therefore, are often criticized as an ineffective teaching method. Despite the criticisms, lectures have survived in academia as a quick, cheap, and efficient way of introducing large numbers of students to a particular field of study. Few universities have invested in alternative teaching methods for the large majority of their courses.

### 2. *Criticism of the traditional lecture model*

#### a) *The traditional model emphasizes the wrong skills*

The traditional, lecture-only, pedagogical strategy is regularly derided as outdated and ineffective. Our society is becoming more technologically sophisticated and, while lectures are especially well suited to the transmission of factual and systematic knowledge, we are becoming less reliant on human cognition for these simple recall tasks. At the same time, lectures are often not able to engage students in the more individualized and skill-orientated ‘apprenticeship’ of becoming a scientific thinker. They do not provide the attention and interaction often required to develop the (increasingly valuable) communication, reasoning, and analytic skills students need to thrive in an increasingly science and technology-driven world (National Commission on Excellence in Education, 1983; National Research Council, 2003, 2009).

#### b) *The traditional model emphasizes the wrong types of knowledge*

Another challenge is that lecture-only classrooms tend to emphasize historical over current knowledge. As we add to our understanding at a rapid pace, there are now simply too many facts for students to memorize. As a result, some reformers stress that the way we commonly teach undergraduate biology has not kept pace with the radical advances made in experimental biology. Reformers urge instructors to teach students about the science we do today, and the science we will do tomorrow, rather than the science we did fifty years ago (National Research Council, 1996, 1997, 1999, 2000, 2003, 2009). While it is true that much of the content students are memorizing today is outdated to some degree, I feel that this concern still highlights the wrong issue. The real concern is not that students need to memorize more or different content, but rather students should not be primarily focused on memorizing content at all. Instead, instructors should focus on training students to think and reason about science.

#### *c) The traditional model discourages cooperation, resulting in negative student outcomes*

An additional criticism in the biology reform literature is that our current lecture driven pedagogy often excludes many students from pursuing science and related fields (Chang, Cerna, Han, & Sàenz, 2008; Maple & Stage, 1991; Tobias, 1990, 2000). While the exact mechanisms driving students away from the sciences are not certain, many hypothesize that the intense, lecture-driven pedagogy is partly to blame. Many scholars argue that many students find the traditional classroom environment stressful and counter-productive and they argue that lectures can prove especially challenging for certain student populations.

For example, a study showed that only thirty-six percent of white, 21% of black and 22% of Latino undergraduate students in STEM fields finished their bachelor's degrees in STEM fields within five years of initial enrollment. Nearly 22% of all students in the study dropped out after five years[1]. Many of these

---

[1] http://www.cnn.com/2011/US/05/17/education.stem.graduation/index.html

students leave the sciences (or science related fields) because they were turned off by the solitary and competitive, rather than cooperative, learning environment in their introductory courses (Seymour & Hewitt, 1997). These students felt alienated by the emphasis tests placed on basic skill performance rather than conceptual understanding. Some have argued that these students might have stayed in the science pipeline had they had a more progressive science education experience (Tobias, 1990).

Unsurprisingly, these reports recommend that the biological community rethink the way it teaches in order to provide more effective preparation for future biologists and health-care professionals and to make science more accessible and relevant in the world today (National Commission on Excellence in Education, 1983; National Research Council, 1996, 1997, 1999, 2000, 2003, 2009; National Science Foundation, 1996).

To counter this trend, major curricular shifts in the past two decades have promoted the study of science as an important societal and cultural phenomenon. One way researchers have encouraged students to think about science in these terms is by shifting the pedagogical focus away from the traditional model and by starting with students' everyday experiences (Tobias, 1992). The goal of such interventions is to help students to see "real-life" in science. For many students, such interventions have helped bridge the gap between the classroom experiences and their daily lives (Tobias, 1992).

### G. The Courses Under Study

I conducted research in three sections of BSCI 207, Organismal Biology

(OrgBio). This course is the third semester of a three-semester introductory biology sequence that is required of all biology majors. OrgBio follows courses presenting the fundamental principles of cellular and molecular biology (BSCI 105) and of ecological and evolutionary biology (BSCI 106). The course presents an overview of the diversity and functions of all organisms, with an emphasis on the unifying physical, chemical, genomic, and evolutionary principles governing life.

The conceptual organization of all three sections is almost identical and uses nearly the same syllabi. The main difference between the sections was in the amount of time dedicated to novel pedagogical approaches, such as inquiry-based activities and a student-centered approach, contrasted with a traditional lecture. In this dissertation, I refer to the section of OrgBio that used a traditional lecture model as OrgBio A. I refer to the two reform-oriented course formats as OrgBio B and C. OrgBio A and OrgBio B classes were composed of a mixture of honors and regular students, whereas OrgBio C was restricted to honors students.

### *1. Reform format: the active learning classroom*

In response to the challenge that traditional lectures fail to engage many students, some individual groups of university biology faculty have developed undergraduate biology education reforms aimed at changing the content or pedagogical structure of the curriculum. The reforms' purposes are to help students develop: (i) deeper levels of understanding, (ii) transferable knowledge, and (iii) effective scientific reasoning skills (Derting & Ebert-May, 2010; Ebert-May, Brewer, & Allred, 1997; Michael & Modell, 2003).

Often, one essential component to this approach to reform is student-centered pedagogy. Student-centered pedagogy approaches an individual's learning as an active, cooperative, and social process (Shor, 1992). Rather than transmit knowledge from teacher to student, the learning process is negotiated, and authority is shared between educator and learner (Shor, 1992). Research on student-centered pedagogy, like that on active learning and inquiry-based pedagogical approaches, has documented student learning gains in, for example, conceptual learning and argumentation skills (Blumberg & Michael, 1992; Blumenfeld et al., 1991; Ebert-May et al., 1997; Eisobu & Soyibo, 1995; Niaz, Aguilera, Maza, & Liendo, 2002; Springer, Stanne, & Donovan, 1999).

Another essential component to these reformed classrooms is usually the introduction of "active learning" components into the curriculum. Such efforts use interaction in place of extensive lecturing. One commonly seen form of active learning used in the sciences involves introducing either group-based classroom learning activities or inquiry-based laboratories into the classroom. For some students, these pedagogical strategies achieve a number of positive learning outcomes, such as increased self-directed learning behaviors and improved problem-solving skills (Allen & Duch, 1998; Blumberg & Michael, 1992; Khodor et al., 2004; Rawson & Quinlan, 2002). The reports also urge instructors to more intensely cover material by including collaborative exercises that allow students to practice working in groups to solve problems (Goodwin & Davis, 2005; Reingold, 2005; Steen, 2005). Collaborative learning helps students break larger problems into individual shares and builds communication and critical thinking abilities (Schoenfeld, 1988). Data reveal that introducing these “active” classroom learning activities and inquiry-based laboratories eases student conceptual difficulties (Boyes & Stanisstreet, 1991; Garvin-Doxas et al., 2007; Klymkowsky & Garvin-Doxas, 2008) on many relevant topics, such as energy flow and randomness, and gets students to practice better critical thinking skills in the biological classroom (Walton & Rybarczyk, 2009; Walton, 2008). Demonstrating that active learning can “work” was an important first step to reform (Michael, 2006).

### *2. Criticism of the current “active learning” reform models: the problem with conceptual and pedagogical reforms alone*

While content and pedagogical goals for curricular change in biology education are important first steps toward reform, they are not sufficient. Learning to think scientifically means learning to make sense of a basic web of principles as well as concepts, and it means learning to reason — using both principles and concepts in new situations flexibly and productively. A student’s ability to make sense of different or novel situations and to bring to bear the appropriate cognitive assets depends significantly on their expectations — what students bring from their previous experience with similar situations and from their interpretation of cues in the current environment that tell them “what’s going on” and what is appropriate behavior in this situation.

Research in psychology and physics learning has demonstrated that expectations play a dramatic role in how individuals perceive the situations they find themselves in and what they pay attention to in those situations. Research from psychology has demonstrated that expectations cause people to ignore important cues even in potentially life-threatening events. For example, pilots in a flight simulator ignored a plane parked in their path on a runway in order to read data projected on the windscreen (Most, Scholl, Clifford, & Simons, 2005). Physics researchers showed that certain students understood specific concepts in certain contexts, but then failed to use that knowledge and insights in other contexts (Lising & Elby, 2005). The physics researchers concluded that this finding was probably not due to a lack of conceptual understanding. A more plausible explanation was that the students had different expectations for each of the learning tasks, which affected the students' preconceptions of what types of knowledge were appropriate to bring to each task.

### H. Dissertation Research Questions

Presently, the predominant focus in biology education research is either uncovering student misconceptions or creating curricula to prevent or dispel those specific misconceptions (National Research Council, 2012). Biology education researchers have dedicated less effort to describing the underlying interactions and expectations that are driving the misconceptions they attempt to identify and dispel. A long and detailed catalog of student difficulties in biology does not aid our understanding of the underlying cognitive processes the students use to either successfully or unsuccessfully negotiate their biology classes (Hammer, 2000).

Another problem with current research strategies is that a lot of the current research relies heavily one measure, usually gains on conceptual inventories, as evidence for learning. In these cases, a single score from a concept inventory, such as the Biology Concept Inventory (BCI), or a statistically significant gain on various pre/post tests provide the operational definition of successful instruction (Klymkowsky & Garvin-Doxas, 2008). However, it is questionable whether a single pre-post comparison provides sufficient evidence for learning. For example, research in physics learning has shown that results from concept inventories are often misleading because student difficulties are often the result of epistemological, not conceptual, miscues (Lising & Elby, 2005). Answering a question incorrectly on a concept inventory does not mean a student completely lacks the knowledge to answer the question correctly. An alternative possibility is that they have the knowledge needed, but don't recognize its relevance. By only describing the specific misconceptions, and not the contexts in which they occur, we limit our ability to provide a complete picture of student ability and knowledge in multiple contexts (Hammer, 1996a, 2000; Smith et al., 1993). In addition, a statistically significant gain on a pre/post test cannot in itself identify the multiple dimensions that may have contributed to the reported gains. In other words, simply showing gains on a post-test tells us little, if anything, about how those gains were achieved. Relying almost entirely on one measurement poses a significant problem in drawing a comprehensive picture of student learning. If we are going to create lasting reforms, it is imperative that we use more comprehensive ways to assess and examine how students perceive the knowledge that is presented to them and their views about knowledge and learning.

Conceptual and pedagogical innovations will continue to make significant contributions to biology reform; however, the current biology education research has left several important gaps in our understanding. Therefore, I have three central research questions:

1. *What are the specific epistemological orientations and expectations toward learning that students bring to their introductory biology classes?*

2. *How are these expectations changed as the result of one semester of instruction in various learning environments?*

3. *How do students' expectations and epistemologies affect their participation in an introductory biology course?*

My first central question relates to students' preconceptions as viewed through the lens of students' epistemologies and expectations (Redish & Hammer, 2009). Research on curricular change and my own data suggests that many students may not benefit from altered content or pedagogy unless the reforms also take into account students' understandings of what it means to learn in a biology course (Bing & Redish, 2009; Redish, 2009a). Thus, while it is important to understand and challenge students' conceptual misconceptions, we also need to address and explore students' views regarding the meanings of "knowing" and "understanding" in biology, and what kinds of knowledge and learning their courses reward (National Research Council, 2000).

In almost all traditional biology courses, and even in many reformed courses, it is assumed that students will acquire both the required content knowledge and the ability to engage in sophisticated scientific reasoning from engaging in class activities (Redish & Hammer, 2009). Traditional lectures and even “actively” reformed classrooms allow some students to achieve these goals, but many still do not. Therefore, altering content or course activities may be insufficient unless instructors are also willing to address their students’ expectations as well as to make explicit their own expectations regarding scientific reasoning.

My second question looks at the effect of various pedagogical strategies, such as student-centered pedagogy on students’ ideas about the nature of biological knowledge and learning. While much of the previous research in biology reform has focused on the effect of pedagogy on conceptual goals, my goal is to show that certain classroom pedagogy can have an equally strong impact on students’ expectations about learning.

Answering my third central question — how do students’ expectations effect their participation in an introductory biology course, should help us to both overcome student resistance to reform, and open a path for creating pedagogy that fosters not only improved conceptual understanding, but also helps us characterize the educational contexts most likely to promote epistemological growth.

I have organized my work along these three empirical questions because they are central to understanding the ways in which students come to learn knowledge in biology. These questions help us critically examine how current perspectives have failed to fully capture the breadth of ways of knowing and the resources available to students in science and how these ways of knowing may play out in the classroom. While my work follows a framework based on these three questions, I address other questions in answering those three:

1. *How do we define the discipline-specific expectations (or components of expectations) that we see which shape student learning behaviors?*

2. *How does the initial state of students in university biology differ from the views of experts?*

3. *What is an appropriate way to measure the affect of these student classroom expectations this context?*

4. *Do biology-specific expectations differ from what we have learned about student expectations in other contexts (i.e. physics?)*

5. *How do contextual factors shape these classroom expectations? How do they affect our measurements?*

# II. Chapter 2: Literature Review

## A. Introduction

In the past three decades, science educators have released hundreds of reports urging institutions to improve the state of nation's science courses (National Research Council, 2012; Tobias, 1992). While many of these reports focus on improving the quality of the science content, other efforts have tried to explain the learning process in order to manipulate the learning contexts. In order to understand the impact of student classroom expectations in an undergraduate course, the current literature in three distinct areas of research is relevant: (i) the literature on past and current higher education biology reform efforts, (ii) the literature on student expectations and epistemologies of science, and (iii) the literature on learning contexts. These three areas provide a foundation for understanding the effect of student expectations from several bodies of literature. I will also identify several gaps in the current literature as well as highlight areas for future investigation.

## B. A Brief History of Biology Reform

As mentioned previously, introductory undergraduate biology courses often fall short of truly engaging students in the subject matter. The traditional, lecture-only curriculum has been proven less effective than group-based, alternative learning formats, yet the lecture-only structure persists and predominates in the postsecondary domain. Lectures remain popular for a number of reasons, despite overwhelming evidence that they do not help students learn very well. It appears that a majority of universities believe they lack the resources, space, or trained personnel needed to implement evidence-based learning techniques, such as active learning, in the classroom (Tobias, 1992).

Yet, despite the difficulties, there is a small, but rapidly growing trend in higher biology education. More faculty are using innovative teaching methods in college biology classrooms and more are reporting on the results of those reforms. To that end, this section on the history of biology reform will include the following relevant topics: (1) a brief introduction to the current state of reform efforts in biology, (2) a description of some early reform efforts, (3) a definition of active learning pedagogy, and (4) a discussion of where we go from here.

### *1. The current "wave" of biology education reform*

Since the mid 1990s, dozens of national reports (National Research Council, 1996, 1997, 1999, 2000, 2003, 2009; National Science Foundation, 1996) have urged teacher educators, policy makers, administrators, and curriculum developers to rethink the way we teach math and science in our schools. In the first section of chapter II, I distinguish active learning from traditional pedagogical practices, distinguish between various active learning approaches, and provide compelling evidence that instructors should incorporate active learning approaches into the classroom. Accordingly, this section of chapter II (i) discusses the education community's early reform efforts, which among other things, led to the rise of active engagement as a method of teaching and, (ii) conducts an in-depth analysis of what active engagement is, how well it works, and what the education community should do next.

### *2. Early reform efforts*

In order to begin to understand the current dissatisfaction with the state of our schools, let us first examine the contemporary reform efforts within the broader historical context of reform. In 1986, the National Science Board issued a report entitled *Undergraduate Science, Mathematics, and Engineering Education* (National Science Board, 1986). This report, referred to as the *Neal Report*, called for increased support and funding for undergraduate science, mathematics, and engineering education programs and led to the creation of the undergraduate education division of the National Science Foundation. Following the *Neal Report*, many other national publications have called attention to the changing needs of science students (National Research Council, 1996, 1997, 1999, 2000, 2003, 2009; National Science Foundation, 1996).

In the mid 1990s, The National Science Foundation, The National Academies, and The Howard Hughes Medical Institute also began to look at the growing need in higher education. During that period, those organizations regularly published reports detailing the need for major changes to undergraduate science education (National Academy of Sciences, 1990, 1991, 1992). Then, in 1995, the National Academy of Sciences held a national convocation in Washington, D.C. to mark the beginning of the “Year of National Dialogue.” Co-sponsored by the National Research Council and the National Science Foundation, the convocation brought together, for the first time, representatives of all the major segments of higher science education. The organizers’ goal was to bring leaders together in all levels of STEM education to devise comprehensive plans to improve higher education. Since that first meeting, those leaders have attended many subsequent symposia and forums to address the problems facing STEM education, from improving K-12 science and teacher preparation to improving STEM education for undergraduates.

Another major report that had a dramatic impact on undergraduate biology education is the publication of *BIO2010: Transforming undergraduate education for future research biologists* (National Research Council, 2003). In this report, the NRC detailed how the then current curricular structures and pedagogical practices were no longer adequate to teach students how real scientists communicate, interact, and collaborate. With the development and rapid advancement of molecular biology, the field is becoming more quantitative and research more interdisciplinary, requiring practitioners to utilize concepts and methods drawn from other scientific disciplines. The conceptual, epistemological, and methodological connections drawn between biology and the physical sciences, mathematics, and computer science are rapidly becoming deeper and more extensive. Accordingly, educational institutions must better prepare students with improved interdisciplinary training and a greater emphasis on applications-based education. The NRC recommended active learning pedagogy as a potential means for providing students with such enhanced preparation.

One the most prominent movements to come out of these broad calls to reform was the establishment of “active learning” pedagogy as a more effective alternative to the transmission approach. The term active learning refers to multiple models of instruction that are learner-centered; and, therefore, seek to engage the learner in meaningful sense-making activities. Bonwell and Eison were two of the first to publish results on the effectiveness of this type of instruction (Bonwell & Eison, 1991). In their report to the Association for the Study of Higher Education (ASHE), they wrote about a variety of curricular approaches aimed at promoting “active learning.” Some have argued “active learning” is not a unique theory of teaching and, instead developed out of earlier theories, such as discovery learning (Mayer, 2004). Nevertheless, the higher education community took up active learning with great enthusiasm, and the evidence supporting its effectiveness is compelling (Allen & Tanner, 2005; Bonwell & Eison, 1991; Ebert-May, Batzli, & Lim, 2003; Ebert-May et al., 1997; Michael, 2006; Skinner & Hoback, 2003; Smith et al., 2005; Udovic, Morris, Dickman, Postlethwait, & Wetherwax, 2002).

### 3. *Active learning pedagogy*

#### a) *What is active learning?*

One of the greatest challenges to understanding and then evaluating active learning in the context of biology reform is that the term “active learning” has come to represent a myriad of pedagogical techniques and practices. Many commentators question what differentiates active learning from traditional biology education. Such uncertainty stems from the fact that many of the features of the traditional lecture format (i.e. laboratories, reading assignments, etc.) are also strategies individuals have advocated in the active learning literature (Bonwell & Eison, 1991). With so many different constructs, many practitioners now understand active learning pedagogy to mean anything that is not a lecture.

Before I evaluate the effectiveness of active learning in the context of the current biology reforms, I must do two things: (i) articulate a definition of active learning and (ii) distinguish our general definition from the various subcategories present in the literature. To be clear, I cannot provide universally accepted definitions for all of the terms of art associated with active learning since different authors in the field have interpreted terms differently.

In an attempt to define the construct, I turn to one of the early advocates of active learning pedagogy. Bonwell & Eison (1991) attempted to distinguish "active learning" techniques from other, more traditional pedagogical approaches (i.e. recitations or lectures). In their construct, an episode of "active learning" must contain the following features: (i) the students must read, write, discuss, or problem-solve; (ii) the episode must place an emphasis on developing "thinking skills" over transmitting information; and (iii) the activity must allow students to engage with the content they are learning in deeper and more complex ways, by requiring them to analyze, evaluate, and synthesize information. In sum, active learning "involves students in doing things and thinking about the things they are doing" (Bonwell & Eison, 1991).

Admittedly, this definition has several problems. While it makes a great deal of intuitive sense, and absolutely reflects the types of learning we all want students to do, the definition lacks the specificity and clarity necessary to implement these ideas successfully across a broad range of contexts.

According to Bonwell and Eison's definition of active learning, whether the class was traditional or reformed would turn on whether the students must “think” about the material they are learning. Proving the presence or absence of a transient internal process such as higher order thought (or trying to quantify it) is much more difficult than simply showing gains of conceptual understanding via pre/post comparison.  It is tempting to focus on the “doing” part of the definition instead of the “thinking” part of the definition.

Bonwell and Eison describe a myriad of techniques educators can employ. Activities range from reading and solving problems, to role-play and peer coaching. From the paper subtitle, *How Can Active Learning Be Incorporated in The Classroom*, Bonwell and Eison appear to treat active learning as a thing or activity educators should insert into a classroom in between other, presumably less “active” teaching and learning moments (1991). From this perspective, the ultimate goal of these activities is somewhat unclear. Are these activities supposed to be part of an ongoing process of conceptual change in which the students begin to approach learning in a new way or are they simply a means to increase student participation?

Since Bonwell and Eison, many authors have tried to conceptualize active learning pedagogy and measure its effectiveness, usually by focusing on the, admittedly imperfect, “doing” part of the definition. A more recent article by Prince (2004) is just one example. Deriving his definition of active learning from Bonwell and Eison, Prince defines Active learning “as any instructional method that engages students in the learning process” (Prince, 2004).  Accordingly, Prince views active learning much like Bonwell and Eison do.  Prince paraphrases Bonwell and Eison when he writes, “active learning requires students to do meaningful learning activities and think about what they are doing" (Prince, 2004). Prince goes on to say clarify that while active learning may include some traditional activities such as homework, the term mostly refers to activities embedded in the classroom that allow the learner to become a participant in the learning process. Prince acknowledges that because of the diffuse nature of the field, it is difficult to examine the effects of various approaches simultaneously. In his writing, he refers to collaborative learning, cooperative learning, and problem-based learning. He then attempts to focus on the "core elements" that unite each specific approach as individual methods in the broader category of active learning.

Using Prince (Prince, 2004), the distinctions between collaborative learning, cooperative learning, and problem-based learning are as follows:

> Collaborative learning can refer to any instructional method in which students work together in small groups toward a common goal.
>
> As such, collaborative learning can be viewed as encompassing all group-based instructional methods, including cooperative learning.
>
> [T]he core element of collaborative learning is the emphasis on student interactions rather than on learning as a solitary activity.

Examples of collaborative learning include: Model building, enactments, and various other forms of group work.

> Cooperative learning can be defined as a structured form of group work where students pursue common goals while being assessed

> individually. [T]he core element held in common is a focus on cooperative incentives rather than competition to promote learning.

An example of cooperative learning would include a group laboratory assignment where teams work together to solve problems, but then each would hand in individual laboratory reports for assessment.

> Problem-based learning (PBL) is an instructional method where relevant problems are introduced at the beginning of the instruction cycle and used to provide the context and motivation for the learning that follows. It is always active and usually (but not necessarily) collaborative or cooperative using the above definitions. PBL typically involves significant amounts of self-directed learning on the part of the students.

Since the definition of PBL varies widely, multiple categories exist. However, all PBL approaches require that students' work together to solve complex problems that have applicability to both their coursework as well as practical applications.

Despite Prince's efforts to define the core elements that unify these three approaches to active learning, direct comparisons between various studies on active learning remain difficult. Such difficulty results from the many overlapping core elements of each approach. Therefore, it is most useful to think of active learning as a term that encompasses a constellation of individual approaches, some of which contain similar elements. If we view active learning in such a manner instead of as a single method, we recognize that each method (collaborative learning, cooperative learning, and PBL) is best assessed separately. For that reason, this dissertation attempts to look for efficacy from studies that used several different and distinct approaches to active learning as reported in the biology education literature. However, all active learning approaches can still be described as pedagogical approaches that alter the traditional lecture format in order to promote higher levels of student engagement and improve student reasoning through group activities (Prince, 2004).

### *b) Research on the effectiveness of active learning*

Since the Bonwell and Eison, the biological community has continued the efforts to change the content of introductory biology courses (Baldwin, Ebert-May, & Burns, 1999; Ebert-May et al., 1997; Goodwin & Davis, 2005; Reingold, 2005; Steen, 2005). The reforms are designed to improve students' conceptual understanding, and reasoning skills (Michael & Modell, 2003).

In many of these studies, the authors were able to show that a more interactive and collaborative classroom helped to foster student greater student engagement and reasoning skills compared to lecture based classrooms. For example, in Jimenez-Aleixandre, Rodriguez, & Duschl (2000), the authors demostrated that student-centered, problem-based pedagogy helped students improve argumentation skills. In another example, Armbruster & Patel (2009) documented significant improvement in student engagement, satisfaction, and increased academic performance as a result of a classroom reforms that incorporated active, problem-based learning units mixed with traditional lectures.

Broadly speaking, many of these reform projects would fall under the umbrella of active learning as described by Bonwell and Eison (1991). Often presented or perceived as a radical change from traditional instruction, there is a growing body of data speaking to the effectiveness of these specific strategies on improving student conceptual difficulties (Boyes & Stanisstreet, 1991; Klymkowsky & Garvin-Doxas, 2008) and getting students to practice better critical thinking skills in the biology classroom (Walton, 2008). Like other reform initiatives popularized in the early 1990s, a number of these reports also now recommend that instructors adopt reformed pedagogical strategies, such as inquiry-based laboratories to improve student performance and understanding.

Primarily using pre/post and comparative studies, these reform-minded curricular approaches show student learning gains in several specific domains including: (i) better integration of technology in constructing knowledge, (ii) collaborative learning skills, (iii) development of problem-based learning skills, (iv) use of concept mapping, (v) getting students to confront ideas on controversial issues, and (vi) building scientific argumentation (Blumberg & Michael, 1992; Eisobu & Soyibo, 1995; Niaz et al., 2002; Rawson & Quinlan, 2002; Springer et al., 1999; Williams, Ebert-May, Luckie, & Hodder, 2004).

One of the most well cited studies of active learning in the biology education literature is *Innovation in Large Lectures — Teaching for Active Learning* (Ebert-May et al., 1997). Motivated by the national calls to reform, the authors of this study attempted to improve the level of students' science literacy by implementing an active, inquiry-driven classroom pedagogy (National Commission on Excellence in Education, 1983; National Research Council, 1996). The study presented two different implementations of active learning strategies at two universities.

The first case in Ebert-May et al. compared the pre-class and post-class science literacy of students in traditional lecture-based classroom to students enrolled in a course that emphasized student-centered, collaborative learning. In both the traditional and student-centered classrooms, students were assessed in the following ways: students were asked to demonstrate biological literacy by communicating scientific ideas to peers, by their scores on a self-efficacy survey, by their scores on the National Association of Biology Teachers (NABT)/National Science Teachers Association (STA) High School Biology Examination, and, finally, by a their scores on a process skills instrument. The process skills instrument assessed students' abilities to: understand conceptually a testable scientific question, to design a method for answering that question, to interpret quantitative relationships, and to explain results.  In addition to the pre and post class scores on the survey, NABT/STA exam, and process skills instrument, the authors also conducted focus group interviews with students from each class section at the end of the semester “to determine students' perceptions of the course design and of their learning accomplishments in the context of the course goals” (Ebert-May et al., 1997).

The second case in Ebert-May et al. involved a larger classroom environment. Instead of creating fixed, collaborative groups, this second case involved less formal group activities. To improve science literacy in this large class, instructors infused traditional lectures with cooperative learning segments and included student-centered, in-class experiences, simulations, and discussions. The instructors also attempted to make the lectures more personal by calling on the students by name. To encourage interaction and active learning throughout the lectures, students were often asked to interact, debate, or discuss ideas with neighboring students or create models of biological systems.

From these two cases, Ebert-May et al. concluded that qualitative evidence from student interviews and evaluations substantiate the positive nature of the cooperative learning environments in large lectures. The authors found that cooperative, active learning pedagogy was an effective strategy to foster a learner-centered classroom and help students become active participants in the learning process. The authors also found that the focus on active learning did not decrease students' conceptual understanding or exam performance.

Since Ebert-May et al., many other researchers have done similar studies which demonstrate that students are more responsive and learn more effectively in collaborative classroom environments compared to traditional lecture driven classrooms (Laws, Sokoloff, & Thornton, 1999; McClanahan & McClanahan, 2002; Michael, 2006; Prince, 2004; Sokoloff & Thornton, 1997; Udovic et al., 2002).

These results reflect trends across discipline areas. For example, in a comparative study of undergraduate physics students, those engaged in classes emphasizing active learning show better Force Concept Inventory results (FCI) than peers taking traditional lecture method courses (Hake, 1998). The fractional gains on the FCI were roughly twice as high in classes promoting engagement than in traditional courses. Statistically, this was an improvement of two standard deviations above the traditional courses. Other results supporting the effectiveness of active-engagement methods are heavily reported in the physics education literature (Hake, 1998; Laws, Sokoloff, & Thornton, 1999; Redish et al., 1998; Scherr & Hammer, 2008). Redish et al. show that the improved learning gains correlate with the nature of active engagement and not to extra time spent on a given topic. While not explicitly in biology, the studies of Hake et al., Redish et al., and Laws et al. provide considerable support for introducing active engagement methods, particularly for improving students conceptual difficulties. In summary, substantial support exists for the core elements of active learning. Introducing some of these approaches into lectures can significantly improve several domains of the learning experience, including student recall. Further, there is ample evidence to support the benefits of student engagement; in other words, simply knowing that active learning can "work" in any context, is an important first step to biology reform (Michael, 2006).

In further support of active learning strategies, more recently, the Association of American Medical Colleges (AAMC) and the Howard Hughes Medical Institute (HHMI) released *Scientific Foundations for Future Physicians* (AAMC-HHMI committee, 2009). This report defines the scientific competencies for future medical school graduates and for undergraduate students who want to pursue a career in medicine. *Scientific Foundations for Future Physicians* recommends that undergraduate pre-medical education move away from requiring a static list of compulsory courses to developing a set of competencies. This main idea is that requiring competencies over specific courses will allow for greater flexibility in instruction as well as “innovative and interdisciplinary science curricula, maintain scientific rigor, and allow premed students at the undergraduate level the flexibility to pursue a strong liberal arts education” (AAMC-HHMI committee, 2009). There is no doubt that this line of research on active learning has made and will continue to make significant contributions to biology reform; however, more work is needed to achieve meaningful, lasting reforms.

### *c) Critiques of active learning*

According to Bonwell and Eison’s definition, active learning requires students to “[do] things and then [think] about them,” which implies that active learning is more than sitting and listening (Prince, 2004). In other words, students learn better by “doing.” At least one report, (Bruner, 1977), has suggested that students who are actively engaged in school are more likely to recall information and there are many reports that have documented the effectiveness of active learning techniques in multiple domains (Michael & Modell, 2003; Michael, 2006).

However, active learning has also been criticized as an incomplete solution to student difficulty in the classroom. One reason for the dispute is that critics of active learning pedagogy claim that there is little evidence illustrating exactly what mechanisms of each approach foster particular desired learning outcomes. Yet another challenge to active learning is that there appears to be a profound difference between being behaviorally and cognitively active during learning, and those two activities have not been shown to be mutually inclusive. If the end goal is creating cognitive engagement, some argue that the sole focus should be on maximizing students' cognitive engagement, with or without behavioral activity. Despite some vocal detractors, the implementation of active learning pedagogy has gained widespread popularity as a radical improvement to traditional lecture throughout the biology education community.

Just as each active learning approach (collaborative learning, cooperative learning, and PBL) consists of more than one element, each approach also affects more than one learning outcome. When deciding whether an approach "worked" in a given context, measurable outcomes such as factual knowledge, student attitudes, and student retention in the discipline should be taken into account (Prince, 2004). However, consistent data on how any approach impacts all of these learning outcomes is not comprehensively available, making multi-outcome assessments difficult. Further, not all of the support for active learning is compelling (Mayer, 2004; Michael, 2007). Despite the inconsistencies, there is a large body of empirical support for active learning (Allen & Tanner, 2005; Armbruster & Patel, 2009; Bonwell & Eison, 1991; Ebert-May et al., 1997; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; McClanahan & McClanahan, 2002; Michael & Modell, 2003; Michael, 2006, 2007; Skinner & Hoback, 2003; Sokoloff & Thornton, 1997; Walker & Cotner, 2008).

However, given the differences in all these approaches labeled as active learning, it is not always clear what authors are promoting when they make broad claims supporting the adoption of active learning.

In addition, where data is available on multiple learning outcomes, it often includes mixed results within studies. For example, some studies with medical students suggest that clinical performance is slightly enhanced while performance on standardized exams declines slightly (Albanese & Mitchell, 1993). Other studies concluded that some methods of active learning appeared to promote higher achievement while others appeared to have negative effects (Norman & Schmidt, 2000). From these accounts, it seems reasonable to assume that active learning means different things to different people, and some senses and implementations of active learning might be more effective than others. Accordingly, determining whether active learning “works” or not is often left open to individual interpretation.

Another significant problem with assessing active learning is that many relevant learning outcomes, such as critical thinking and student attitudes, are difficult to measure. For example, a few of the explicit goals of the *BIO2010* initiative are to foster deeper levels of understanding and effective scientific reasoning skills (Michael & Modell, 2003; National Research Council, 2003). However, deep, long-term, understanding and effective reasoning are often difficult constructs to define and quantify. As a result, surveys of active learning often rely only on the test result gains. This makes it difficult to know whether these methods are achieving both the conceptual and reasoning goals.

Deciding what level of improvement is considered significant is also a problem. As discussed previously, it is often difficult to quantify the overall effect of interventions and several studies (over decades) have indicated that, sadly, standard measures of academic achievement, such as exam scores, are not always particularly sensitive to instructional approaches (Dubin & Taveggia, 1968). While newer studies have shown more positive results, in most cases, assessing what works still requires looking at a broad range of learning outcomes, interpreting data carefully, quantifying the magnitude of any reported improvement and having some idea of what constitutes a “significant” improvement in the given context. The last, of course, is somewhat a matter of opinion, given initial goals set out by the authors coupled with the effort it took to achieve the gains. However, in making a determination of significance, it is almost always beneficial to look at standard statistical measures, such as effect sizes and absolute values in determining the value of learning gains. Despite the complications with obtaining reliable data on its effectiveness in the classroom, there is little doubt that some of the evidence for active learning remains compelling, and enthusiasm for adopting active learning is obvious.

### *4. Where we go from here*

Although the results vary in strength, there is support for multiple forms of active learning within biology education. Some of the findings, such as the benefits of student engagement, are not likely to be refuted anytime soon. However, other results do appear to challenge traditional assumptions about biology education. For example, several studies have revealed that students will remember more content if brief activities are introduced to the lecture (Allen & Tanner, 2005). This goes against the traditional format of most biology classes that present a tsunami of biological facts designed to elaborate on lengthy textbook readings. Similarly, the support for collaborative and cooperative learning calls into question traditional assumptions that assert a competitive environment based on individual test scores is the best for promoting high achievement. Evidence suggests that faculty should structure their courses to promote collaborative and cooperative environments. While the entire course need not be team-based, (Springer et al., 1999) extensive and credible evidence suggests that non-traditional models are one way of promoting academic achievement and positive student attitudes in undergraduate biology courses.

This growing movement of biology educators urges a rethinking of introductory biology courses to foster more sophisticated ways of thinking about biology and effective scientific reasoning skills. To accomplish these goals, most efforts so far focus on content and pedagogy: instructors are urged to "get over coverage" and, instead, concentrate on incorporating collaborative active learning strategies and other reformed pedagogical approaches in order to emphasize thinking over memorization (Handelsman et al., 2006). While this seems plausible and indeed serves as the starting place form many of the course reforms in the classes I observed, previous research and my own data now suggest that many students may not benefit from these changed courses unless the reforms also take into account — and try to change — students' epistemologies and expectations (Hall et al., 2011; Watkins et al., 2010). By this, I mean their views about what counts as knowing and understanding in biology and about what kinds of knowledge and learning specific courses reward (National Research Council, 2000). In order for these reforms to be successful, it is also important to consider the students' own expectations, goals, and objectives, independent of those set out by the course and the instructor. I have found that students may not automatically be "on board," with the implicit goals set out for them by their instructors and, instead hold their own expectations about learning in biology (Hall et al., 2011). When such misalignments go ignored and unaddressed in the classroom, it may undermine even carefully orchestrated reforms.

### C. Review of Epistemological Literature

After reviewing the epistemological literature, I define epistemology as students' ideas about knowledge construction and learning (Hammer & Elby, 2002; Lising & Elby, 2005).

The current education literature has repeatedly documented that students bring naïve epistemological beliefs, theories, or expectations into their classes and has shown that those ideas and understandings can have a negative impact on learning (National Research Council, 2000). Some of these papers attempt to separate and distinguish between epistemological constructs, such as beliefs, theories, or expectations, other times they do not. I argue that all three are related, but distinct epistemic constructs. The research supports their effect on student behavior in the classroom.

In the epistemological domain, much of the research has conceptualized student epistemologies in terms of stable or semi-stable discipline-independent developmental stages (Belenky, Clinchy, Goldberger, & Tarule, 1986; Perry, 1970). Viewed this way, students naturally advance from less sophisticated to more sophisticated understandings over time (Belenky, Clinchy, Goldberger, &

Tarule, 1986; Perry, 1970, Hofer & Pintrich, 1997).

In addition to the domain general view of student epistemologies, researchers have also examined students' epistemologies in specific disciplines such as math (Schoenfeld, 1988) and physics (Hammer, 1994; Roth & Roychoudhury, 1994).

Both the domain-general and discipline-specific lines of research have shown that students express naïve, unproductive, or unsophisticated views about what counts as "knowing" and "understanding" and about what kinds of knowledge and learning their courses are trying to teach (Watkins & Elby, 2013-in press).

In physics, researchers have shown that students commonly view physics knowledge as consisting of many unrelated pieces of information (Hammer, 1994; NRC, 2012). This belief often leads students to approach learning in physics by memorizing formulas rather by attempting to connect these formulas to broader physical concepts (Hammer, 1994; Redish, Saul, & Steinberg, 1998).

In chemistry, researchers used a Likert-style survey to document that introductory students enter general chemistry I with expectations that differ significantly from those of their faculty. The authors also report that student expectations also tend to decline (rather than improve) after one semester of chemistry instruction. However, these negative trends appear to correct if students continue to take chemistry classes during the sophomore and junior years. (Grove & Bretz, 2007).

These discipline-specific epistemologies and expectations have been documented using a variety of methods, including surveys such as the Maryland Physics Expectations Survey (MPEX), the Colorado Learning Attitudes about Science Survey (C-LASS), and the CHEMX survey (Adams et al., 2006; Grove & Bretz, 2007; Redish et al., 1998); multiple interviews with students (diSessa, Elby, & Hammer, 2002; Hammer, 1994); and analyses combining classroom observations with interviews (Lising & Elby, 2005).

Building on previous research on discipline-specific epistemologies in math, chemistry, and physics education, more systematic work is also beginning in biology education. For example, Walker et al. (2008) documented students' epistemologies in biology. Walker et al. (2008) documented that students expressed the idea that biology knowledge  is "the accumulation of unambiguous facts" conveyed through instruction.  Similar to Walker et al., Hall et al. (2011) also documented that biology students expected biological knowledge to largely consist of specific facts provided by authority (i.e. a professor or textbook).

At the University of Colorado, Semsar et al. (2011) adapted the Colorado Learning Attitudes about Science Survey (CLASS) to conduct larger-N studies of these epistemologies and expectations in biology classrooms. The CLASS-Bio measures novice-to-expert-like perceptions about biology and probes a range of perceptions that vary between experts and novices — including enjoyment of the discipline, propensity to make connections to the real world, recognition of conceptual connections underlying knowledge, and problem-solving strategies (Semsar et al. 2011).  Sesmar et al. (2011) documented that students' attitudes shifted from more to less favorable in five out of the six introductory biology courses in which the CLASS-Bio was administered. From these results, the authors claim that students “become more novice-like in their beliefs during their introductory biology courses.”

Other studies in biology education have also examined student beliefs as a product of their biology course reforms. Using a Likert-scale survey, Hoskins, Lopatto, & Stevens (2011) reported that students’ epistemological beliefs improved after taking a C.R.E.A.T.E. (Consider, Read, Elucidate hypotheses, Analyze and interpret data, Think of the next Experiment) biology course. The C.R.E.A.T.E. method uses “intensive analysis of primary literature in the undergraduate classroom to demystify and humanize science” (Hoskins et al., 2011). Specifically, the authors found significant changes in students’ self-assessed understanding of the nature of science and epistemological beliefs (i.e. their sense of whether knowledge is certain and scientific talent innate). The authors concluded that their results reflect changes in students’ beliefs as a result of experiences in this course.

In examining different implementations of an interdisciplinary introductory biology course, Matthews, Adams, and Goos (2010) compared student responses to post-survey questions about the importance of math in biology. The first-year introductory course incorporated mathematics and computer programming in the context of modern biology. The authors claim that as a result of taking this course, biological science students gained a positive appreciation of the importance of mathematics in their discipline (Matthews et al., 2010). These studies mark the first steps toward unpacking and understanding some of the discipline-specific epistemologies in introductory biology courses.

Despite these early efforts and strong evidence in other disciplines that show understanding student epistemologies matter in creating successful reforms, the research in biology education still has a long way to go in addressing the ways in which students' epistemological perspectives can create barriers to their learning (NRC, 2012). To date, biology education research is still mainly focused on students' conceptual beliefs about science, mainly by mapping misconceptions, comparing novice to expert strategies, or identifying occurrences of conceptual "transfer" (Garvin-Doxas et al., 2007; Garvin-Doxas & Klymkowsky, 2008).

To date, much of the biology education literature (and education literature in general) has treated cognitive and epistemological outcomes as distinct, independent "variables." Future studies in biology education should recognize the interdependence of the epistemological and cognitive outcomes (NRC, 2012).

In this dissertation, I aim to highlight the importance of understanding how students' expectations of learning can change the trajectory of the learning process. To this end, I will review five relevant theoretical constructs for this dissertation: (1) epistemological beliefs, (2) knowledge-in-pieces, (3) epistemology-in-pieces, (4) the resources perspective, and (5) learning as viewed through the resources framework.

### *1. Epistemological beliefs*

There are several simultaneous and complementary lines of research that deal with the theoretical construct of epistemologies, more specifically epistemological beliefs (Belenky, Clinchy, Goldberger, & Tarule, 1986; King & Kitchener, 1994; Schommer, 1990; Magolda, 1992; Perry, 1970). These constructs are not discipline-specific. Some of these constructs define an epistemic belief, or a belief about knowledge, as a unified whole while others break down epistemologies into several dimensions; however all constructs describe the nature of epistemological development in terms of fairly stable cognitive units, or epistemological beliefs (Buehl & Alexander, 2006). Hofer defined epistemological beliefs as, "how individuals come to know, the theories and beliefs they hold about knowing, and the manner in which such epistemological premises are a part of and an influence on the cognitive processes of thinking and reasoning" (Hofer, 2000). This research focuses on the structure, source, and certainty of knowledge (Hofer & Pintrich, 1997). As stated before, in each dimension, the ontological structure is assumed to be semi-independent and fairly stable.

While this body of literature describes epistemological beliefs as fairly stable cognitive constructs, the authors also explain how these beliefs can (and do) evolve predictably over time. Such a developmental stage model is based on the writings of William Perry (1970). Perry described a stepwise transition from: (i) a dualistic understanding of knowledge, to (ii) a multiplicity stance, finally ending in (iii) a relativistic understanding of knowledge based on contingency and context (Perry, 1970). At each stage, the structure of beliefs is coherent and then as an individual becomes more knowledgeable, each set of beliefs is replaced by more sophisticated ones.

Contemporary models of epistemological beliefs are also structural and developmental in nature, but are broader than Perry's framework. They incorporate different domains and even disciplinary views.   Despite the evolution of the beliefs framework, there is still a great deal of coherence between models (Hofer, 2000).

At present, the major consensus, from this theoretical perspective, is that an individual acquires a theory of knowledge and knowing by holding a series of independent cognitive units, or beliefs. These various ‘‘epistemological beliefs’’ can aggregate into epistemological theories, made up of a series multiple beliefs (Hofer, 2000; Schommer, 1990; Schommer, Crouse, & Rhodes, 1992; Schommer, 1993). In this way, epistemological beliefs influence an individual's theories about learning and knowledge and, therefore, their learning behavior.

Most of the studies on beliefs have been conducted in the field of educational psychology, are domain general, and detail student' epistemological beliefs about the nature of science or science learning. Carrying on the traditions of Perry and his contemporaries, many of these studies investigate how individual differences in epistemological beliefs might affect comprehension and thus academic performance in college students (Hofer, 2001; Perry, 1970). These studies demonstrate how the tendency to conceive of knowledge as discrete facts is often associated with the Perry state of dualism while the tendency to conceive of knowledge as interrelated propositions, combined with changes in information processing strategies, typically marks the transition to relativism (Ryan 1984). Many of these papers also focus on building or evaluating models of conceptual change or conceptual ecologies (Duschl, 1992; Strike & Posner, 1992).

Most researchers have assumed that “epistemological beliefs” are unitary elements of stable epistemologies (Hammer & Elby, 2002). By unitary, I mean “each belief corresponds to a unit of cognitive structure, which an individual either does or does not possess” (Hammer & Elby, 2002). Viewed this way, the study of epistemological beliefs is comparable to the “conceptions” or “misconceptions” literature (Hammer & Elby, 2002). In the same way that cognitive science has understood naïve scientific knowledge to be made up primarily of “misconceptions” that differ from expert conceptions, research on student epistemologies has understood students to have “misbeliefs” (e.g. scientific knowledge is certain) that differ from expert beliefs (e.g. scientific knowledge is tentative) (Hammer & Elby, 2002). According to the misconceptions model, in order for students to develop an expert conceptual understanding, they must undergo a process of “conceptual change.” Likewise, in order to acquire a sophisticated epistemology, students must change their epistemological beliefs. While the unitary view of misconceptions and misbeliefs still predominates the literature, two complimentary lines of research challenge this view of knowledge.

### *2. Knowledge-in-pieces: an alternative to misconceptions*

With regards to the misconceptions perspective, some researchers argue that concepts are too complex and variable to be described in terms of being stably correct or incorrect (Clement, Brown, & Zietsman, 1989). diSessa furthered this view of cognition based on small, emergent units by describing "phenomenological primitives" or "p-prims" (diSessa, 1993). In his paper, diSessa defines p-prims as the smallest cognitive unit, meaning that p-prims are much smaller than a belief or a concept. P-prims are grounded in our intuitions and everyday experiences and refined through our interactions. diSessa describes how we build our understanding of the world by acquiring many tiny unconscious bits of knowledge.

### *3. Epistemology-in-pieces: an alternative to epistemological beliefs*

In the same way that diSessa argued against treating conceptions as unitary constructs, several research teams have maintained that student epistemologies are more nuanced and variable than a beliefs model would imply. The authors in this alternative camp argue that the specific cognitive elements often described as stable, conscious beliefs are really composed of many smaller, often subconscious or semiconscious units. These units come together in a given moment to build the conscious perception of a particular impression or idea, much the same way that we understand other emergent phenomenon (Hammer & Elby, 2002). An individual has a variety of units that can be called upon, and the particular activation pattern of the units is dependent on the context.

Hammer built upon diSessa's work to describe the resources perspective, which the next section explores (Hammer, 2000). This work, primarily done in undergraduate physics, has made compelling arguments that challenge both the epistemological beliefs and misconceptions perspectives.

There is little or no evidence that researchers in biology education have ever seriously taken up and explored diSessa's or Hammer's alternative conceptions models of knowledge for biology knowledge or beliefs about knowledge. While the research in in mapping student misconceptions in biology has proven useful, it is also important to expand our understanding beyond labeling the phenomenon. It appears that diSessa and Hammer's model provides a viable, alternative construct.

### *4. The resources perspective*

Resources is a theoretical construct first introduced into the literature by David Hammer in a paper entitled *Student Resources for Learning Introductory Physics* (Hammer, 2000). In his paper, Hammer describes the previous focus on classroom phenomenon and misconceptions as necessary to motivate the physics teaching community to reexamine current teaching methods and to promote curriculum development, but of limited value in furthering the understanding of student knowledge and learning (Hammer, 2000). Like p-prims, resources are small, subconscious units of thought that when activated in the right contexts serve as productive reasoning tools that students use to understand a phenomenon. In other words, students come into the classroom from their daily lives armed with myriad, cognitive "resources" for understanding what we are trying to teach them (diSessa, 1993; Hammer, 2000). The task is to help them learn when to use which ones.

In this way, a resources-based account of student knowledge and reasoning does not disregard difficulties or phenomena typically associated with misconceptions. Rather, a student difficulty represents a tendency to misapply resources, and misconceptions represent robust patterns of misapplication (Hammer, 2000). Ultimately, Hammer expands on the new construct of "student resources for learning, with an emphasis on the practical benefits to be gained for instruction" (Hammer, 2000). Since then, Hammer and collaborators have continued to refine what is meant by the term "resources" (Hammer et al., 2004; Hammer & Elby, 2003; Hammer, 2000; Louca et al., 2004; Smith & Wittmann, 2008; Wittmann, 2002).

Since Hammer (2000), a lot of research on student resources has focused on the idea of "epistemological resources" (Hammer et al., 2004; Hammer & Elby, 2003; Louca et al., 2004; Redish & Hammer, 2009). An epistemological resource is an individuals' perception of the source of their own knowledge. These ways of understanding "how they know what they know" help individuals develop their personal epistemology (Hammer & Elby, 2002; Hofer, 2002; Hofer, 2006). Elby and Hammer argue that epistemologies can be subdivided into epistemological resources, much like cognitive units can be broken down into cognitive resources. This grain-size allows for a more detailed analysis of the epistemology of students.

Louca, Elby, Hammer, and Kagey (2004) furthered clarified our understanding of student resources by looking at the various "forms" of epistemological resources. By "form," the authors meant the "grain size, stability, and context dependence of the relevant cognitive elements" (Hammer et al., 2004; Hammer & Elby, 2002). As with the previous work on the resource framework, Louca et al. view epistemologies as constructed from fine-grained cognitive elements. Resources are also context dependent — meaning that an individual will not always apply the same epistemological resources to every situation. The result is that a person can view a cognitive construct as “known” for different reasons at different times.

### *5. Using the resource framework to understand students' epstemological development*

In the epistemological belief model (Hofer, 2000; King & Kitchener, 1994; Magolda, 1992), knowledge is regarded as developmental and stable while the resource framework views knowledge as more fragmented (Hammer et al., 2004; Hammer & Elby, 2003; Hammer, 2000; Louca et al., 2004; Smith & Wittmann, 2008; Wittmann, 2002). From the resource framework perspective, individuals may concurrently possess multiple and seemingly contradictory epistemological ideas. My own interview classroom field note data and indicates that the specific contexts in which a question was asked greatly influenced student responses (Hall et al., 2011; Hall, 2010; Watkins et al., 2010). Therefore, I hesitate to treat epistemic knowledge as intact, stable units. Instead, I propose that student epistemologies are better understood through a finer grained analysis. This way, I am still able to attribute cognitive objects to an individual, but at a much finer-grained size than concepts or beliefs. Because knowledge is viewed as an emergent process, epistemological resources may be activated or not in any particular context. From a learning perspective, the difference between beliefs and resources is mainly the way success is measured.

From a beliefs perspective, the goal is to have an individual acquire the correct belief, concept, idea etc. in order to able to use it again, appropriately, later in another context (Prince, 2004). From a resources perspective, learning is not conceptualized as the acquisition or formation of a particular cognitive object, but rather as a cognitive state the learner enters in the moment by activating multiple resources (Hammer et al., 2004; Hammer & Elby, 2003). In these terms, successful learning would mean the learner entering a similar state later in a different context.

### D. Effects of the Learning Context

Beyond the stability and coherence of our thoughts, another debate has also dominated the discussion on learning and cognition in the learning sciences. This dispute has centered on whether learning is primarily the result of individual cognitive self-reorganization or the process of social enculturation. To this end, two major "camps" are identifiable in science education literature. The first camp, broadly grouped as the cognitive constructivists, views learning in terms of how an individual learner understands things. The second group, broadly defined as the socioculturalists, emphasizes how meanings and understandings grow out of social encounters. Taken at the most basic level, constructivist and sociocultural theories appear to be in direct conflict, with adherents to each claiming to be the authority on how we come to know and learn in the sciences (Steffe, 1999).

Of course, this debate is not new or restricted to educational research; cognitive psychologists are also deeply interested in ontology and epistemology of human thought and behavior. Within both the fields of psychology and education, whether social and cultural processes have primacy over individual processes, or vice versa, has been the subject of equally intense debate (Cobb, 1994). Ultimately, this dispute has led researchers to form theoretical assumptions and methodological preferences in both education and psychology. The result of which is the apparent forced choice between the two perspectives.

In this dissertation, rather than attempt to show evidence for the supremacy of one perspective over another, I contend that the two perspectives are, for the most part, complementary. In particular, I argue that learning is better viewed as a process of active individual cognition embedded within, and largely dependent upon, interaction with a rich social context. Viewed this way, the researcher's goal changes from resolving two opposing theories of learning, to exploring ways of coordinating two complementary perspectives. For this dissertation, I will limit my review to five relevant discussions: (i) a review of the cognitive constructivism literature, (ii) a review of the sociocultural literature, (iii) comparisons and contrasts between the two perspectives, (iv) a review of social constructivism, and (v) a discussion of social constructivism in practice.

### *1. Cognitive constructivism: it's all in the mind*

The first perspective, (cognitive) constructivism is the commonly accepted view that learners actively construct new knowledge out of their pre-existing ways of thinking about the world (Crotty, 1998). In essence, individuals learn by constructing "new" knowledge—recombining and modifying their understanding of prior experiences. In this way, all new knowledge must arise from seeds of old knowledge and cannot spontaneously form in the mind of the learner.

In its most radical form, constructivists assert that there is no reality except for what we create with our own minds (E. von Glasersfeld, 1992, 1996). This view is in direct opposition to objectivism, which holds that a human can come to know external reality or truth beyond one's own mind (Crotty, 1998). Jean Piaget is credited with formalizing constructivism by articulating mechanisms by which individual learners internalize knowledge (Piaget, 1999a, 1999b). Piaget first articulated two distinct processed that learners internalize knowledge — accommodation and assimilation.

When individuals assimilate, they incorporate new experiences into an already existing mental framework, or schema, without dramatically changing their preexisting cognitive framework. When assimilating correctly, the individual aligns the new experience with their internal representations of the world. If they are assimilating incorrectly, however, the individual fails to change a faulty schema—resulting in misunderstandings or misconceptions (Inhelder & Piaget, 1999; Piaget & Cook, 1952; Piaget & Inhelder, 1969; Piaget, 1999b).

In contrast, an individual must accommodate when an experience directly contradicts their internal representation of the world. Rather than incorporating the experience into an existing schema, the individual alters the schema to accommodate the experience. Thus, accommodation is the process of reframing one's mental representation of the external world to fit new experiences (Inhelder & Piaget, 1999; Piaget & Cook, 1952; Piaget & Inhelder, 1969; Piaget, 1999b).

According to the theory, our actions in the world are largely dictated by the expectation that the world operates in ways consistent with our current understanding. Anytime we encounter a situation that violates that most basic premise, we must challenge our internal representations of the world. We then accommodate this new experiential knowledge into our cognitive model of the way the world works. This is learning through accommodation (Inhelder & Piaget, 1999; Piaget & Cook, 1952; Piaget & Inhelder, 1969; Piaget, 1999b). Understandably, accommodation requires much more cognitive work than assimilation as it requires significant cognitive restructuring. Since Piaget, there have been many theoretical and empirical arguments both against and in support of these specific mechanisms for learning. Today, most modern constructivists would agree that Piaget's model is overly simplistic and cannot account for the range of ways in which we perceive and process new experiences (Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992). However, most would still agree that Piaget was a critical influence in shaping the constructivist movement.

Another early influential theorist of the cognitive constructivist perspective is Ernst von Glasersfeld (E. von Glasersfeld, 1983, 1992, 1996). He was a prominent proponent of radical constructivism, which claims that knowledge is solely a self-organized cognitive process of the human brain; meaning, our entire experience of the external world, as well as the process of constructing knowledge about it, is controlled by the executive functions of the mind (E. von Glasersfeld, 1996). Radical Constructivists would argue that all knowledge is constructed rather than discovered and that it is impossible to tell (and unnecessary to know) if and to what degree individual knowledge reflects an actual 'ontological' reality. This is not to deny an objective reality as such, but to deny that our knowledge has any direct relation to it. Both ontology and epistemology thus become irrelevant topics for investigation (E. von Glasersfeld, 1996).

While most constructivists would not take such an extreme position as von Glasersfeld or his associates, there is still a great deal of contemporary support for the ability of the cognitive perspective, albeit a more moderate version, to explain learning behavior in students. Numerous studies have documented, for example, significant conceptual differences in the understandings that students develop in instructional situations, and that these understandings are frequently very different from any understanding that would typically be regarded as true or correct in any scientific context (Boyes & Stanisstreet, 1991; Cobb, 1994; Vosniadou, 1992, 1994). These misunderstandings are well documented as robust and resistant to various interventions in multiple scientific domains. Such studies would support the misconceptions or misunderstandings perspective first advanced by Piaget.

### *2. Socioculturalism: it's all in the context*

However, the broad acceptance of Piaget's work and cognitive constructivism can be contrasted with a second theoretical framework that emphasizes the socially and culturally situated nature of learning. This second framework, sociocultural theory, is often described as a reaction to the individualistic focus of mainstream psychology and attempts to go beyond purely cognitive analyses (Brown, Collins, & Duguid, 1989; Greeno, 1998; A.H. Schoenfeld, 1987, 1988). Most sociocultural theorists would not deny the existence of an individual cognizing mind. Nevertheless, they claim that we cannot directly access or assess the internal cognitive structures. Accordingly, our claims about learning and behavior can be better made on the basis of more observable social phenomenon rather than pure conjecture about internal cognitive states.

Another major tenet of socioculturalism is that, more than anything else; the social context (i.e. environmental cues, social pressures and cultural influences) drives human behavior. Contrast that view with constructivism, which places the emphasis on the internal states of the learner and not on the effects of the contextualized learning environment. There is little doubt that we are all shaped by the context of our environment and influenced by the perception of authority in our social order; however, sociocultural theorists go further, and view learning as primarily the result of group action, not the act of an individual mind.

The work of psychologist Lev Vygotsky provided the theoretical basis for this position (Minick, 1989; Vygotsky, Hanfmann, & Vakar, 1962; Vygotsky, 1979; Vygotsky, 1978). In his work with children, Vygotsky observed that when children were tested on tasks on their own, they rarely did as well as when they worked with an adult. During these sessions, the adult was not directly teaching the child how to perform the task. Yet the engagement process itself led to more effective reasoning and better overall performance than the children working alone (Vygotsky, 1978). Vygotsky theorized that the articulation of ideas, specifically with language, was central to learning and development. The focus on the importance of socialization and scaffolding ultimately crystallized into the "zone of proximal development," one of the foundations of sociocultural learning theory (Vygotsky, 1978). As defined by Vygotsky, the zone of proximal development, or ZPD, is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978). Simply put, the ZPD is the difference in performance between what a learner can do without help and what she can do with help. Following Vygotsky, activity theorists such as Davydov, Leont'ev, and Galperin all heavily influenced socioculturalism (Engeström, 1999). Empirical support for the importance of social context comes from studies by Kelly, Carlsen, & Cunningham (1993); Lave & Wenger (1991); Lemke (2001); O'loughlin (1992); Wells (1999), among others, which all show ways in which an individual's activity is profoundly influenced by his or her participation in encompassing social practices (Kelly, Carlsen, & Cunningham, 1993; Lave & Wenger, 1991; Lemke, 2001; O'loughlin, 1992; Wells, 1999).

### *3. Comparisons and contrasts*

Sociocultural and cognitive constructive theorists both highlight the crucial role that activity plays in learning and development. Sociocultural theorists typically link activity to participation in culturally organized or contextually significant practices, whereas cognitive constructivists, in the Piagetian sense, tend to give higher precedence to individual cognitive activity (Cobb, 1994).

In this way, both Piaget and Vygotsky focus on the individual's learning in relation to society. Piaget saw the construction as taking place within the mind of an individual, who later tests this newly constructed knowledge for viability by interacting with others. For Vygotsky, it occurs in the reverse order—the learning itself takes place in a social context and is then internalized by the individual.

Sociocultural theorists then, like Vygotsky, tend to assume, *a priori*, that social and cultural influences and pressures subsume individual intentions and autonomy. In this view, it is the culture, not the individual mind that ultimately directs the individual’s thinking and doing. This perspective directly reflects Vygotsky's (1979) assertion "the social dimension of consciousness is primary in fact and time. The individual dimension of consciousness is derivative and secondary" (Vygotsky, 1979). From this, it logically follows that "thought (cognition) must not be reduced to a subjectively psychological process" (Davydov, 1988). Individual thought exists only within the context of socially constructed meanings. According to socioculturalism, the construct of individual cognition should be viewed as something essentially "on the surface"—more superficial than (and subsumed under) individual-in-social action (Vygotsky, 1978). Naturally then, sociocultural theorists consider the entire contextualized learning environment as a more appropriate unit of analysis (Minick, 1989).

From this perspective, the primary research issue of socioculturalism is that of explaining how participation in social interactions and culturally organized activities influence individual development and learning. Sociocultural theorists formulate this issue in a variety of different ways. For example, Vygotsky (1978) emphasized the importance of social interaction with more knowledgeable others in the “zone of proximal development” and the role of culturally developed sign systems as psychological tools for thinking.

Several American theorists have elaborated on constructs developed by Vygotsky and his students and speak of cognitive apprenticeship (Brown et al., 1989; Rogoff, 1990), legitimate peripheral participation (Lave & Wenger, 1991), or the negotiation of meaning (Newman, Griffin, & Cole, 1989). In contrast to the cognitive constructivist concern with building and defining individual mental models, each of these contemporary accounts locates learning in a distributed space embedded in cultural practices. As a consequence, educational implications usually focus on the kinds of social engagements that increasingly enable students to participate in the activities of the expert rather than on the cognitive processes and conceptual structures involved (Cobb, 1994).

In direct contrast to the social and distributed models, most cognitive constructivists analyze learning at the level of conceptual understanding within an individual learner. While modern constructivists would not deny the influence of context, most would argue that learning is ultimately a cognitive process and is best understood from the perspective of the individual learner. For example, von Glasersfeld characterized learning as a process of cognitive self-organization where the learner reorganizes his or her cognitive activity to eliminate “perturbations,” thereby restoring coherence between what is known and what is experienced (E. von Glasersfeld, 1989; E. von Glasersfeld, 1989). Although von Glasersfeld defines learning as a form self-organization, even he acknowledges the importance of the community in fostering such activity. In this way, he elaborates that knowledge refers to "conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language, consider viable" (E. von Glasersfeld, 1992). Further, he contends, "the most frequent source of perturbations for the developing cognitive subject is interaction with others" (E. von Glasersfeld, 1989). However, it should be noted that, the activity of the individual, not the group, is most responsible for the reorganization.

As von Glasersfeld notes, his instrumentalist approach to knowledge is generally consistent with the views of other theorists (Bernstein, 1983; Putnam, 1987; Rorty, 1978). More moderate theorists still complement von Glasersfeld's extreme psychological focus in that both view communication as a process of mutual adaptation wherein individuals negotiate meanings by continually modifying their interpretations (Bauersfeld, 1980, 1988; Newman et al., 1989). This contrasts with the sociocultural view, which focuses on the ways in which communities make meaning through language. Once again, the difference is nuanced and centers on whether the analytic lens is centers on the group or individual.

### *4. Social constructivism: merging the two*

In recent decades, constructivist theorists have expanded the individualistic focus of traditional constructivist literature to address the collaborative and social dimensions of learning. First described as “communal constructivism” (Younie & Leask, 2001), communal constructivism would later evolve into the modern notion of social constructivism (Gredler, 1997; Prawat &

Floden, 1994).

Based strongly on Vygotsky's (1978) work, social constructivism suggests that knowledge is constructed both in a social context and then appropriated by individuals (Cole, Gay, Glick, & Sharp, 1971). According to most social constructivists, the social aspect of learning, referred to as collaborative elaboration, allows the group of learners to share knowledge and individual perspectives, building collective knowledge beyond what any individual could have accomplished alone (Brown et al., 1989; Greeno, Collins, & Resnick, 1996; Greeno, 1998). This bears a resemblance to Vygotsky's vision of proximal development. Social constructivist scholars view learning as a dynamic process of individual cognitive effort situated within learning communities and contexts.

Most modern constructivist scholars would agree with the idea collaborative elaboration and emphasize that individuals make meanings through interactions with others and with the environment they live in. From this view, learning is neither a process that takes place only inside our minds, nor is it a passive development of our behaviors shaped by external forces (McMahon, 1997). From this joint perspective, knowledge is the product of both the mind and social constructions (Prawat & Floden, 1994). In his later works, even Vygotsky himself highlighted the convergence of the social and individual elements in learning. In Mind and Society, Vygotsky asserts that the most significant moment in the course of intellectual development occurs when speech and practical activity, two previously independent lines of development, converge. Through practical activity, a child constructs meaning on an intra-personal level, while speech connects this meaning with the interpersonal world shared by the child and her or his culture (Vygotsky, 1978).

In practice, social constructivists often perceive the ideal learning environment as providing the opportunities that allow learners to discover principles, concepts and facts for themselves (Ackerman, 1996; Brown et al., 1989). The primary focuses of social constructivists then become identifying what contexts, environments, and social situations provide individuals with the supports needed to learn. While this does differ from the initial mission and research ideals of socioculturalism, it is possible to see social constructivism as a bringing together of aspects of the work of Piaget with that of Vygotsky, Bruner, and other earlier socialculturalists (Bruner, 1977; Lave & Wenger, 1991; Mehan & Wood, 1975; Vygotsky, 1979; Vygotsky, 1978).

### *5. Social constructivism in practice*

Social constructivists see both the context in which learning occurs and the contexts that individual learners bring to bear in the learning environment as crucial units of analysis. Essentially the basic premise of social constructivism is this—without social influence, everyone is free to construct individual meaning of things different from what any other person will have. Logically, this would make building a cohesive society impossible. Therefore, it is important to understand the ways in which individuals learn to share their understandings of the world and inform the greater collective. As researchers and practitioners, this is an appealing concept as it furthers both perspectives while, at the same time, honoring the individual contributions of each.

Theoretically, most social constructivists focus on two aspects of the social context that largely affect the nature and extent of the learning: (i) the historical references or frameworks inherited by the learner as a member of a particular culture and (ii) the symbol systems, such as language, logic, and mathematical systems that are learned as a result of being in a particular social environment. These two aspects of the social context often directly affect how and what is learned by influencing individual preconceptions and constructions of the learning event (Gredler, 1997).

Thus, social interaction with knowledgeable members of society is an essential component for individual learning. Without the social interaction with more knowledgeable individuals, it is impossible for the learner to acquire the necessary social meanings of important symbol systems and learn how to use them. Within this general framework, there are four general overlapping perspectives that inform how we could view learning (Gredler, 1997):

- Cognitive Tools
- Idea-based social constructivism
- Pragmatic or emergent approach
- Transactional or situated cognitive perspective

First, the “cognitive tools perspective” focuses on the learning of cognitive skills and strategies (Gredler, 1997; Prawat & Floden, 1994). From this view, group cohesion, sense making, or meaning-making for the group is produced through the creation of a physical product. Analytically, the researcher’s task is to understand the social and individual meanings made through the skills employed and the meanings imposed by the group.

Second, “idea-based social constructivism” influenced by the work of Dewey, posits that ideas function as a bridge between the internal world of the mind and the external world of the social and cultural. Dewey (1916) stated that peoples’ ideas or thoughts affect the physical environment, and the affected environment in turn influences their thoughts. In this way, the individual is a conscious and active participant in the reciprocal activities that take place. The goal is to understand this complex interaction.

Third, is the “pragmatic or emergent approach,” which asserts that the implementation of social constructivism should be emergent as the need arises (Gredler, 1997). Proponents of this approach hold that knowledge, meaning, and understanding of the world can be addressed from both the view of the individual learner and the collective view (Cobb, Wood, & Yackel, 1993; Gredler, 1997).

Fourth, is the “transactional or situated cognitive perspective,” which focuses on the relationship between people and their environment. Humans are a part of the constructed environment (including social relationships); the environment is in turn one of the characteristics that constitute the individual (Bredo, 1994; Gredler, 1997). When a mind operates, its owner is interacting with the environment. Therefore, if the environment and social relationships change, then the tasks of each individual also change (Bredo, 1994; Gredler, 1997).

Active research programs based on social constructivism are numerous. For example, studies by Reznitskaya, Anderson, & Kuo (2007) and Reznitskaya et al. (2009) show a correlation between adding group discussion to the classroom and the ability of individual students to generalize and transfer their knowledge from the classroom discussion to other contexts (Reznitskaya et al., 2009; Reznitskaya, Anderson, & Kuo, 2007). The authors concluded that the improved individual learning outcomes were likely due to the students communicating ideas orally in groups. In a similar fashion, other studies argue that discussion plays a vital role in increasing students' ability to test their ideas, synthesize the ideas of others, and build a deeper understanding of what they are learning (Grossman & McDonald, 2008; Newman et al., 1989; Nystrand, 2006; Reznitskaya et al., 2009, 2007). Both large and small group discussion also afford students opportunities to exercise self-regulation, self-determination, and their desire to persevere with tasks (Corden, 2001; Matsumura, Slater, & Crosson, 2008). Additionally, group work has been shown to increase student motivation, collaborative skills, and the ability to problem-solve (Matsumura et al., 2008; Nystrand, 2006). Increasing students' opportunity to talk with one another and discuss their ideas increases their ability to: support their thinking, develop reasoning skills, and increase their learning productivity (Reznitskaya et al., 2007). High quality, interactive, discussion and discourse has been supported theoretically and demonstrated empirically to promote individual learning in certain contexts.

### *6. Discussion of the Learning Contexts*

If, as is likely true, both the cognitive and the social are key factors in the learning process, how are we to resolve the theoretical issue of whether society or the individual is foregrounded during the learning process? Even the attempt at a compromise, social constructivism, appears to fall short. Social constructivists, while acknowledging the important role of the individual mind in the meaning making process, still rely heavily on understanding and analyzing the various contextual cues and pressures exerted on the individual. Rarely do social constructivists make claims as to the cognitive structures, or nature of changes, that might occur within the mind.

While it is easier to describe the social, we must not ignore that after an event in which we learn something, the resulting learned concept or idea now resides in our own mind. The type of constant comparing, contrasting, and modifying of old with new information, as described by Piaget, von Glasersfeld and others, takes place (for better or worse) in our head. Internal cognitive structures are constantly changing as we have new experiences. Various internal learning mechanisms are constantly occurring as the individual continues to refine, reconcile, and redefine experiences and any theory of cognition, including group cognition must acknowledge these cognitive processes.

Therefore, any full theory of learning must make some attempt to understand the cognitive processes at the ontological level of the individual, not just be able to describe the social contexts that appear most fruitful for creating these useful cognitive structures. While the construction of the meaning took place with another individual, and may not have occurred without that interaction, the actual change is still at the level of the individual mind, activated by the individual’s perception and interpretation of the interaction. Whether we can accurately capture and interpret the mental models of an individual, however, is another matter entirely and is beyond the scope of this discussion.

If knowing that learning is a combination of cognitive and social processes, then we should ask whether we could coordinate these two perspectives? While the two perspectives are difficult to reconcile because of the very different ontological views on where each places the locus of learning, they do share much common theoretical ground. As researchers, I think that we must remember that groups are indeed made of individuals and that while the construction of knowledge (i.e. learning) may take place because of and during interactions with others, that learning is quite definitely taking place within the head of the individual. We must look at both aspects of learning: the individual and the social. Ultimately, ignoring the construction of meaning in the individual's mind would be as foolish as ignoring the fact that one does a great deal of one's learning with others. It would be irresponsible to look at one at the expense of the other. In this dissertation, I will be primarily using a cognitive constructivist perspective, but one that takes into account the socially situated nature of learning.

### E. Summary of the Literature Review

This literature review has shown how students' perceptions of the learning context affect how they interact in the classroom. It follows that expectations are one of the cognitive elements that potentially affect and direct students' framings and perceptions of that learning context. Curricular efforts cannot reach their potential until we understand and account for students' expectations and understandings of learning and how those expectations and understandings inform their preconceptions of the learning process.

Previous research has shown that students do not come to the classroom as blank slates (Clement et al., 1989). They come to class armed with preconceptions about what it means to learn biology and what types of things they need to do and think about in order to be successful. Unfortunately, these preconceptions are often wrong or shortsighted. These expectations often include, misinterpretations about what kinds of knowledge and learning their courses are trying to teach, about what counts as knowing and understanding in biology, and about what is appropriate for them to do to learn it. Even in contexts designed to foster appropriate expectations, students' expectations about content can hinder their learning and students' preconceptions about biology can constrain their approach to learning. As shown in the literature review, physics researchers have documented that certain ideas about physics knowledge can negatively affect student approaches to learning. Biology students are likely to be impacted in similar, yet context-specific ways.

Experience suggests that student expectations impede not just individual learners but also larger reform efforts. Yet, researchers have not focused on understanding student expectations and preconceptions of how to approach learning biology. There is little evidence about the nature of these ideas in biology or how these expectations can be altered through pedagogical and curricular interventions.

# III. Chapter 3: Developing the MBEX I: Describing Students' Classroom Expectations in Undergraduate Biology Courses

## A. Introduction

Over the past few decades, researchers in science education have become increasingly interested in theories of learning. These new understandings have shaped the way we think about curriculum reform as well as the way we approach teaching. While many theories of learning exist, one common element among these theories is the role of prior knowledge in shaping student perceptions and interactions. It is commonly accepted that students come into classrooms with prior knowledge that is incompatible with experts views of the subject; therefore, most current research programs in biology have focused on documenting students' prior conceptual knowledge, and there is a vast literature documenting students' conceptions and misconceptions in biology (AAAS, 2011; Allen & Tanner, 2005; Chi, 2005; Khodor et al., 2004; Klymkowsky & Garvin-Doxas, 2008; Michael et al., 2003; Nehm & Reilly, 2007; Skinner & Hoback, 2003; Southerland, Abrams, Cummins, & Anzelmo, 2001). However, learning in biology requires more than simply knowing (or not knowing) the correct concepts — it also requires knowing how to think and reason productively with those concepts. It means understanding what type of knowledge is appropriate, and what types of knowledge are useful to bring to novel situations. To date, this dimension of dynamic knowledge construction remains largely unexamined in the biology education literature.

Other fields, such as physics and chemistry education, have made important strides toward unpacking how curriculum can affect what students think it means to learn in a particular course and how specific curricular changes can improve student perceptions of what it means to know and learn in a given subject domain (Adams et al., 2006; Grove & Bretz, 2007). Researchers in education have identified a variety of student attitudes, perceptions, and beliefs that appear to drive student ideas about what it means to know and learn in science. In this dissertation, I show how similar cognitive constructs may also impact student behavior in biology classrooms. In this chapter, I discuss ways in which specific pedagogical interventions may help improve students' expectations in biology.

In this chapter, I describe the Maryland Biology Expectations survey (MBEX); a survey that probes student classroom expectations regarding undergraduate biology. I report on the results of pre- and post-instruction delivery of this survey in three sections of an introductory organismal biology course at a large east-coast public research university (500 total students). I report a significant variance in the student classroom expectations of both the pre-post gains within a classroom and between classrooms as a result of specific pedagogical interventions. Using a student-centered curriculum, I document positive shifts in students' ideas about the structure of biological knowledge as well as students' ideas about the value about incorporating other disciplines into undergraduate biology courses.

### *1. Modern reforms in biology education are improving treatment of content and pedagogy*

The goals of biology education are not just to teach vocabulary terms and collections of facts. Many reviews of the biological curriculum suggest that primary goals should include helping students develop: (i) deeper levels of understanding, (ii) transferable knowledge, and (iii) effective scientific reasoning skills (AAAS, 2011; AAMC-HHMI committee & AAAS, 2011; Armbruster & Patel, 2009; Derting & Ebert-May, 2010; Julia Khodor et al., 2004; Labov, Reid, & Yamamoto, 2010). For several decades now, research from the fields of science education, psychology, and cognitive science have demonstrated that the lecture-predominated format of most biology classrooms is ineffective at teaching the types of knowledge and skills shown to be most beneficial to students (AAAS, 2011; AIBS Education Office, 2010; National Research Council, 2000). Lectures are often unable to engage students in the more individualized and skill-orientated ‘apprenticeship’ of becoming a scientific thinker.

For most students, lectures do not provide the attention and interaction required to develop the (increasingly valuable) communication, reasoning, and analytic skills students need to thrive in an increasingly science and technology-driven world (National Commission on Excellence in Education, 1983; National Research Council, 2003, 2009).

In response to this challenge, some groups of university faculty have developed undergraduate biology education reforms aimed at changing the content and pedagogical structure of the curriculum. Often, one essential component to this approach to reform is student-centered (or learner-centered) pedagogy. Student-centered pedagogy approaches an individual’s learning as an active, cooperative, and social process (Shor, 1992). Rather than transmit knowledge from teacher to student, the learning process is negotiated, and authority is shared between educator and learner (Derting & Ebert-May, 2010; Shor, 1992).

For example, in Derting & Ebert-May (2010), the instructors created a learner-centered classroom by having students participate in specifically designed course modules. In these modules, the students "posed their own research questions and hypotheses, presented and critiqued peer research proposals and final research papers, collected and statistically analyzed their data, and presented their research in the form of a scientific journal article or poster" (Derting & Ebert-May, 2010). The authors evaluated the new courses and determined these new versions were indeed more learner-centered compared with the introductory biology courses in the original curriculum by using questionnaires, attitudes surveys, and conceptual indexes (Derting & Ebert-May, 2010).

Another essential element to these reformed classrooms is the incorporation of "active learning" components that use student-driven interactions in place of extensive lecturing.  For example, in science classrooms, active learning often involves either group-based learning activities or inquiry-based laboratories.  For many students, these pedagogical strategies have been shown to achieve a number of positive learning outcomes, such as increased self-directed learning behaviors, as well as improved problem-solving skills, communication, critical-thinking abilities, and enhanced conceptual understandings (Allen & Duch, 1998; Allen & Tanner, 2005; Blumberg & Michael, 1992; Derting & Ebert-May, 2010; Ebert-May et al., 1997; Goodwin & Davis, 2005; Khodor et al., 2004;

Rawson & Quinlan, 2002; Reingold, 2005; Steen, 2005). Researchers using active learning and inquiry-based pedagogical approaches have documented significant student learning gains in, for example, conceptual learning and argumentation skills (Baldwin, Ebert-May, & Burns, 1999; Blumberg & Michael, 1992; Blumenfeld et al., 1991; Ebert-May et al., 1997; Ebert-May & Hodder, 2008; Eisobu & Soyibo, 1995; Michael, 2006; Niaz et al., 2002; Springer et al., 1999).

It should be noted that learner-centered classrooms and active learning pedagogy are similar ideas with similar student outcomes, but are not necessarily the same. A learner-centered classroom requires that students take responsibility for their own learning. Active learning describes a specific category of pedagogical interventions that instructors can use to help foster a broader variety of classroom outcomes (one of which is student autonomy).

### *2. Content and pedagogy reforms are necessary but not sufficient*

Many of these biology reform initiatives are motivated by the assumption that traditional pedagogy is ineffective because students tend to develop deep, pervasive misconceptions about science, and lectures are ill-suited in addressing or correcting these misunderstandings (National Research Council, 2000). As a result, an important role of many current biology reforms is to identify and dispel these misconceptions. In the same way, the role of education research about these reforms has typically been to study the effects of these revised curricula and active-engagement pedagogies on students’ conceptions of science. While biology education researchers have documented a great number of biological misconceptions and even developed specific interventions to correct them, less effort has been devoted to describing or understanding the complex underlying interactions that are driving these potential misconceptions. Unfortunately, a detailed catalog of student difficulties in biology does not provide a comprehensive picture of the underlying cognitive processes the students use to either successfully or unsuccessfully negotiate their biology classes, as has been attempted in the physics education literature (Hammer et al., 2004; Hammer, 2000; Redish, 2009a; Redish & Hammer, 2009).

While content and pedagogical goals for curricular change in biology education are important first steps toward reform, they are not enough. Learning to think scientifically means learning to make sense of basic principles as well as knowing the correct concepts, and it means learning to reason — using both principles and concepts in new situations flexibly and productively and seeking coherence among different knowledge elements.  It is imperative that students are able to demonstrate that they can take what they have learned and make sense of those ideas in novel situations. These skills, often referred to as adaptive expertise, are a critical step toward building more sophisticated conceptual frameworks and more productive reasoning strategies (Pellegrino, 2006).

Many biology course reforms tend to emphasize and make explicit the *types of knowledge* students should know, but keep the epistemological goals about *how to think* –scientifically, critically, etc. implicit. One possible reason for this ommision is because of the common assumption that conceptual reforms automatically trigger epistemological development. Unfortunately, when the full nature of the intructor’s goals are not made explicit, students are more able (and likely) to misintepret them. For example, Hall et al. (2011) has shown that some students tend to view or assume that conceptual reforms represent “new ideas or facts to memorize” rather than opportunities to seek deeper understandings. Of course, this assumption is not unreasonable given that most prior school experiences included lots of memorization. An explicit discussion of what it means to learn for understanding and how that process differs from memorization might help provide a way for students to better understand the new goals for instruction, reframe the educational task, and redirect the nature of the activity from “memorizing” to “thinking for understanding and coherence.”

### *3. Moving beyond misconceptions*

It is commonly accepted in education research that students come to science courses with conceptions about the world that differ from scientists' (Carey, 1986, 1992; McCloskey, 1983). The core idea is that students' prior knowledge includes conceptions that are not consistent with expert understanding (Chi, 2005; Clement, Brown, & Zietsman, 1989; Klymkowsky & Garvin-Doxas, 2008). This “misconceptions” perspective asserts that students will then perceive and interpret the world through these incorrect knowledge structures. In this view, misconceptions affect, in a fundamental way, how students’ perceive and interpret what they see and hear in the classroom. From the misconceptions perspective, the goal of education and education research is to identify the misconceptions and then to design curriculum to confront, and resolve them.

The wide acceptance and application of this perspective merits some concern, in part because there remains a number of reasons to question its validity and completeness as a theory of knowledge and learning. A growing number of researchers have challenged the theoretical and empirical validity of the misconceptions perspective and have offered alternative accounts of student reasoning in a number of learning contexts (Hammer, 1996a; Smith et al., 1993).

For example, Smith et al. (1993; 1994) argued that the misconceptions perspective contradicts, rather than supports, constructivism (Cobb, 1994). According to constructivism, one cannot build something from nothing; therefore, the authors argue that students could not possibly acquire an expert view of knowledge if their own initial understandings need to be “replaced” by the expert concept. A more plausible explanation, according the Smith et al., is that students’ learn through a process of refining their existing ideas to better match those of the experts. According to Smith et al., this model of gradual refinement better matches our cognitive models of learning than the misconceptions model of replacing old “wrong” conceptions for new “correct” ones. The authors also argued that intuitive reasoning is not as consistent or stable as the misconceptions perspective implies. They argue that student reasoning is highly contextual and dependent on a number of external factors.

Smith et al. (1993; 1994) built their arguments from diSessa’s (1988; 1993) earlier work, and they contrast the misconceptions perspective with his "knowledge-in-pieces" view of intuitive knowledge (Hammer & Smith, 1996). The misconceptions perspective, diSessa argued, confuses emergent knowledge, acts of thinking in particular contexts, with stable cognitive structures (McCaskey, 2009). When students answer a question incorrectly on a concept inventory, we cannot automatically assume that they lack the appropriate knowledge structures to answer that question. Instead, a better interpretation is that the incorrect response representatives an idiosyncratic incident, one in which it did not occur to the students to use the appropriate knowledge that they had because they did not consider the knowledge relevant at that time. If asked the question again, the students may answer the question differently. There is evidence to suggest that the context in which knowledge or reasoning is activated is directly related to how well students are able to perform on specific knowledge tasks (Lising & Elby, 2005). Therefore, understanding the ontological structure of these misconceptions, and recognizing why they appear more frequently in certain students in certain contexts, is a better way to approach them than simply attempting to remove the misconceptions with instruction (Elby, 2001). In order to understand the dynamic structure of student thinking, we must become more sophisticated in our approach and attempt to help students make sense of their own thinking with respect to how they use their own knowledge and in what contexts. In this way, the students can begin to better access their own cognitive tools for reasoning in multiple contexts.

### *4. Assessments do not address all aspects of knowledge construction*

Another significant problem is that most research on misconceptions relies on only relative gains on conceptual inventories as evidence for learning. In these cases, a single score from a concept inventory, such as the Biology Concept

Inventory (BCI), or from various pre/post tests provides the operational definition of successful instruction (Klymkowsky & Garvin-Doxas, 2008). It is virtually impossible to draw a comprehensive picture of student learning from a single instrument that does not characterize the multiple dimensions that may have contributed to the measured gains. Research in physics learning has shown that student difficulties are often highly contextualized (Lising & Elby, 2005). Therefore, results from concept inventories may be misleading. Similarly, biology researchers have documented that students were unable see the possibility for hypothetical questions on the exams because they expected the exam only require singular "right" answers. This specific epistemological miscue not only led students to answer questions wrong on exams, but also prevented them from understanding how to answer questions more productively in the future (Hall et al., 2011).

In many ways, our current assessments of our pedagogical and curricular reforms are not closely linked with our models of how students actually learn. As a result, assessments tend to measure the process by which students' acquire specific skills or bits of factual knowledge as discrete, stable events (i.e. knowledge is either in the mind or is not), but that model does not carefully address the ways in which students actually come to develop more complex knowledge structures (Pellegrino, 2006). Every instructor has experienced a despondent student coming into her office right after an exam exclaiming, "Why is it that I couldn't answer a single one of the questions on the exam, but I can easily explain all of them to you now?" In this example, we have to ask ourselves, did the student magically “learn” this information between the examination room and the office? If not, what other mechanisms might have contributed to the discrepancy?

In order to deepen our understanding of the impacts of our curricular reforms, our assessments must first conceptualize learning and knowledge construction as a highly complex, context-driven phenomenon.

Despite the issues with validity, this misconceptions perspective is still widely prevalent in the biology research literature. By only identifying specific misconceptions, and not the contexts in which they occur, we limit our ability to provide a complete picture of student understanding and how they use their knowledge in multiple contexts (Hammer, 1996a, 2000; Smith et al., 1993). It is imperative that we develop more comprehensive ways to assess and examine how students perceive the specific knowledge that is presented to them and how they view the learning process in general if we are going to create successful and lasting reforms.

### *5. The role of expectations in understanding classroom participation*

One of the ways students make sense of these different or novel situations and select the appropriate cognitive assets is by drawing on their expectations — what students bring from their previous experience with similar situations and from their interpretation of cues in the current environment that tell them “what’s going on” and what is appropriate behavior in this situation (Tannen, 1993a). For my purposes, I have chosen to focus explicitly on a specific subset of students’ expectations that appear to be particularly salient for curricular reform. I refer to them as classroom expectations. Classroom expectations refer to a predictive set of ideas or assumptions students make regarding the nature of the classroom experience. While these expectations are not always completely independent of one another, previous work with students has demonstrated that students often demonstrate multiple, contradictory, or context-dependent sets of expectations (Hall et al., 2011; Watkins et al., 2010). Therefore, whenever possible, it is important to describe the nature of student expectations, and the contexts in which they occurred, with as much precision as possible.

Other disciplines have already begun to document that expectations leading to selective attention play a profound role in how individuals perceive and respond to the situations in which they find themselves. Psychology research has demonstrated that expectations cause people to ignore important cues in potentially life-threatening events; for example, pilots in a flight simulator ignored a plane parked in their path on a runway in order to read data projected on the windscreen (Most et al., 2005). Physics researchers showed that certain students understood specific concepts in certain contexts, but then failed to use that knowledge and insights in other contexts (Lising & Elby, 2005; Tuminaro & Redish 2007; Bing & Redish 2009). In these cases, the most plausible explanation was that the students had different expectations of what they were supposed to do in the learning tasks. This affected their perceptions of what types of knowledge were appropriate to bring to each task and, as a consequence, what knowledge they accessed – and did not access – in those tasks.

Not surprisingly, my own research with biology students has led to similar findings. I have consistently documented, both in interviews and classroom interactions, that a biology student's capacity to understand and perform in diverse situations depends significantly on their expectations. In essence, these expectations are built by a student's answer to the question: "What do I think is the nature of the knowledge I am learning and what is it that I have to do in order to learn it."

The way in which a student answers this question will have a lasting impact in how they interact, or perform, in the classroom. For example, one response that students might give to answer this question is that individual biological knowledge exists within a coherent framework, and it is their job as a student to understand how discrete knowledge fits within the bigger system. Another response might be that school knowledge typically is presented in the form of independent, isolated facts and, as a result, it is their job to acquire those facts as quickly and accurately as possible. These two different epistemological orientations, *or framings*, clearly lead to very different learning strategies (Bing & Redish, 2009). One of my goals as a researcher is to understand how these epistemological expectations influence a student's framing about what types of learning they are engaged in, what types of knowledge they can use, and what types of learning strategies are appropriate in order to be successful.

## B. Why I Chose to Construct My Own Expectations Survey

Ultimately, my goal is to describe the factors leading to successfully implemented pedagogical reforms. A critical step in this process is to understand how the classroom expectations of biology students shape their classroom interactions. A student does not come into the classroom as a *tabula rasa*, and instead, uses pre-existing classroom and external expectations to interpret a particular instructional situation. Expectations are measurable in a variety of ways, including online pre-post surveys. Surveys are a quick, efficient, and economical way to measure class-wide shifts in expectations over a fixed set of time. Our research group has previously demonstrated that surveys are a useful tool to measure shifts in expectations in the context of undergraduate physics courses (Redish et al., 1998). While surveys do not allow for a fine-grained analysis into the ontology, or causes driving these expectations, they can provide critical insight toward understanding the impact of course reforms on students.

Our research group has previously argued that expectations play an important role in the level of success students achieve in a specific course. Since its original publications more than a decade ago, the original Maryland Physics Expectations Survey (MPEX) has expanded to measure cognitive expectations for biology students in physics courses (MPEX2) (McCaskey, 2009; Redish et al., 1998). In addition to the original MPEX and MPEX2, other groups have developed similar instruments for measuring students attitudes and expectations — both in physics and in other science domains (Adams et al., 2006; Elby, 2001; Grove & Bretz, 2007; Halloun, 1997).

While at least one of these instruments, the Colorado Learning Attitudes about Science Survey-biology (CLASS-bio), attempts to measure students' attitudes and beliefs in the domain of biology (Adams & Perkins, 2004; Semsar et al., 2011), I still felt it necessary to develop the MBEX for several reasons. First, the CLASS-bio survey was not publicly available at the start of my investigation. Second, the CLASS-bio, which is built on the theoretical framework of the MPEX, modifies the original ontological construct of the MPEX. For example, the CLASS-bio is written to focus on the transition from novice to expert and to probe students' views on the nature of biological knowledge. One of the main goals of the CLASS-bio is to distinguish between the specific characteristics of expert attitudes and beliefs of biologists from those of introductory students. In this way, the CLASS-bio assumes attitudes and beliefs exist as stable cognitive constructs that undergo continuous progression from novice to expert.

By contrast, the authors of the MPEX do not accept that student views exist as stable constructs. Instead, they assume that students have multiple (even contradictory) ideas about a given subject. According to the "epistemology-in-pieces model" described in the MPEX, students' responses to questions on a survey are greatly impacted by what the students thinks is important in that moment (Redish et al., 1998). My understanding of student cognition more closely matches those of the authors of the MPEX than those of the CLASS-bio. Since I view student responses as not stable and highly dependent on the students' interpretation of the specific question or task, I chose to use the scoring scheme of (MPEX) rather than that of the (CLASS-bio). Additionally, I chose to focus on a specific group of expectations (classroom expectations) that appear to impact how students behave in the classroom.

Third, the CLASS-bio survey is context neutral and does not include statements that ask the student to reflect on the requirements of a specific course. I felt that classroom evaluation questions were both valuable and insightful to instructors. By epistemologically grounding the CLASS-bio in science courses more broadly and not in a particular course context, I felt that a survey of this type loses some of its appeal to practitioners. Since I view surveys primarily as instructor tools, I felt that course evaluation is an essential component of the instrument. Therefore, I consider it critical to include course-specific questions in the MBEX. Fourth, the CLASS-bio categories are empirically determined groupings of statements based on student interview responses; this is in contrast to *a priori* groupings of statements of the MPEX. I prefer to use an *a priori* cluster structure because this cluster grouping is a better match for my theoretical assumptions. I have found students to be somewhat inconsistent in their responses to what appear to be similar questions and situations. This inconsistency is not a failure in the instrument, but only one of the many challenges posed by the complex nature of human cognition. In this way, I am aware that students' self-reported perceptions may not match the way they actually function in a particular classroom setting. Empirical groupings have less flexibility to adjust for these differences between self-perception and observed actions.

Finally, and most important, none of the biology-relevant surveys appear to have been specifically developed within the context of a biology course. Rather, many of the questions were derived from the original physics templates by merely substituting “biological” words for “physical” words. In my experience, this simple substitution method does not always produce biologically authentic questions. For example, a large percentage of the questions on the CLASS-bio were taken verbatim from the original CLASS, focus on biological problem solving (e.g. “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.”) or are questions that probe for students making connections between biology classroom content to the real world (e.g. “The subject of biology has little relation to what I experience in the real world.”). In my experience, physics students struggle much more in these specific epistemic areas. First, biology students do not tend to encounter large numbers of complex biological “problems” to “work on” in their introductory sequences. Most of the topics covered in introductory biology are descriptive rather than quantitative. There is little, if any, mathematical problem solving or multiple approaches used to gain an understanding. Second, I rarely encounter biology students who claim that they have difficulty making connections between biology and the real world. In fact, students in biology very commonly assert the deep and constant real world connection to be one of the elements that set biology apart from the other sciences.

In my other work on disciplinary epistemologies, we have found that the different disciplines have unique sets of expectations and epistemologies (Watkins et al., 2010). Therefore, I chose to create a new survey specifically for understanding students’ learning expectations in the context of biology.

### C. Research Questions

Because we know so little about the distribution, role, and evolution of students’ expectations in a university biology course, many questions are as yet, unanswered. To limit the scope of this chapter, we restrict ourselves to two questions.

1. *How does the initial state of students’ epistemological expectations in university biology differ in regular enrollment versus honors-only enrollment courses?*

2. *How are the expectations of a class changed (or not) as the result of one semester of instruction in various learning environments?*

### D. The Classroom Contexts

I envision this new survey, the Maryland Biological Expectations Survey (MBEX), as a tool to look for shifts in student classroom expectations in biology courses. I intend to show that an increasingly sophisticated response pattern in the survey correlates with positive student experiences and approaches to learning as measured by other approaches like interviews and classroom observations. In order to test whether the survey correctly captures specific, relevant elements of students’ classroom expectations, I gave it to several groups of students taking three different versions of an organismal biology class.

I carried out my research in the context of three sections of BSCI 207, Organismal Biology (OrgBio). This course is the third semester of a three-semester introductory biology sequence that is required of all biology majors. It follows courses presenting the fundamental principles of cellular and molecular biology (BSCI 105) and of ecological and evolutionary biology (BSCI 106). BSCI 207 presents an overview of the diversity and functions of all organisms, with an emphasis on the unifying physical, chemical, genomic, and evolutionary principles governing life. Thus, this class has been transformed from the conventional “forced march through the phyla” often presented in OrgBio courses into a new principles-based OrgBio course emphasizing multidisciplinary perspectives.

All three of the OrgBio classes I observed for this study utilized nearly identical syllabi. While the topics covered by the classes were quite similar, the three versions employed different pedagogical strategies, ranging from a lecture-only format to a student-centered, group-based format. For the lecture-based classrooms, I have data from multiple instructors. In the case of the novel pedagogical interventions, data were collected from one section of instructors and students. A summary of the three classrooms environments is described below:

- OrgBio A (1-3)[2]
- OrgBio B
- OrgBio C

The first version, which I will refer to as OrgBio A, followed the standard lecture pedagogy model. These large classes of 150-200 typical students used 50-minute lectures presented three times a week. These lectures involved PowerPoint presentations or other visual aids that were intended to present fundamental principles and specific content needed to understand those principles and their

---

[2] I surveyed three different classroom sections of OrgBio A in our data analysis. I used the numbers 1-3 to distinguish between the three sections.

applications. Although the subject material presented in OrgBio A was reformed to match the principles-based approach used in the other versions, OrgBio A did not use any reformed pedagogical approaches, such as active-engagement pedagogies, small-group interactive environments, or out-of-class problem solving.

In addition to OrgBio A, I am also considering two reform-oriented OrgBio versions in order to assess the effects that such reformed pedagogical approaches might have on student expectations, attitudes, and conceptual understanding. OrgBio B was also designed for a large class of typical (150+) biology students. This class used two conventional lectures each week, but replaced the third lecture with group active engagement (GAE) activities involving small groups of 4 to 6 students in a separate discussion room. The active-engagement activities were specifically designed to help the students use their prior knowledge to develop revised conceptual models and to achieve a deeper understanding of the fundamental principles. Many of the reforms used in OrgBio were similar to those described in Ebert May et al. (1997) and included concept mapping, group enactments of biological phenomena, clicker questions, and computer modeling activities. OrgBio B also required the students to meet outside of class to complete weekly homework assignments.

OrgBio C was an honors-only class of 75 students, which involved a mixture of conventional teacher-presented lectures, small group activities, student-presented material, demonstrations, and enactments, which were similar to the GAE activities used in OrgBio B. Unlike OrgBio B, OrgBio C did not specifically designate lecture or GAE days, but rather attempted to integrate teacher- and student-centered activities during all three class periods in each week. It will become significant for the following data analysis that OrgBio A and OrgBio B classes were composed of a mixture of honors and regular students, whereas OrgBio C was restricted to honors students.

## E. Methods

### *1. Survey construction*

The goal of the Maryland Biology Expectations (MBEX) survey is to understand some of the incoming student expectations about learning biology and how those perceptions change over the course of a semester. This survey is presented to students as an online pre- and post-class survey. The MBEX survey also attempts to measure the students' expectations and goals for learning compared to the instructors’ goals.

I began to develop the MBEX survey in the fall of 2009. Adapting the basic framework of the MPEX survey for use in our biology classroom, I maintained the same question format but created a new, biologically relevant, question set and grouping structure. I gave undergraduate biology students a variety of statements about the nature of biology, the study of biology, and their relation to it. They rated these statements on a five-point Likert scale from strongly disagree-1 to strongly agree-5.

I chose items for the survey after conducting a detailed literature review, having discussions with biology faculty, reviewing class exams, synthesizing students’ feedback and interview statements, making classroom observations, and drawing on my research team's teaching and research experience. I then validated the initial survey items in a number of ways: discussing with other faculty and science education experts, giving the survey to a variety of ''experts'' (meaning both professional biologists and science educators), and repeatedly delivering the survey to groups of undergraduate biology students. This repeated delivery has shown that the pre values for the MBEX are stable from semester to semester over last four years. This indicates that the classes appear to be drawn from the same population. I also validated the original MBEX items by administering over 20 student validation interviews. These interviews reduced the possibility for multiple interpretations of the questions. From these interviews, I also learned a great deal about how classroom expectations become salient for students specifically in biology courses.

From this student feedback, I iteratively refined the MBEX. For example, I changed some of the wording of statements to better clarify their meaning. The final version of the survey has 32 items[3] and typically takes 20–30 minutes to complete.

I have administered this survey as a pretest and posttest in the OrgBio A course having reformed content and more traditional pedagogy, and the OrgBio B and OrgBio C classes having the same content but reformed pedagogy. These MBEX survey questions serve as an independent measure to assess how the different OrgBio versions effected students' expectations towards learning biology. The results with identical pre- and post-test questions suggest that the

---

[3] The final MBEX I question set is provided in Appendix I.

expectations of students taught in a lecture-only course (OrgBio A) slightly deteriorate (as is commonly found in introductory physics classes) or remain static after one semester of instruction, while in our revised-pedagogy courses (OrgBio B and C) we find marked improvements in several dimensions.

### *2. Overall MBEX design*

Student classroom expectations are clearly complex cognitive structures with many facets. I decided to focus on four dimensions along which I might categorize student classroom expectations toward learning biology. Two of these were adapted from the previous physics survey (MPEX) and I have added two new ones. The four clusters probed by the MBEX survey are:

*a) Facts v. Principles — Ideas about the structure of biological knowledge — whether biology needs to be considered as a connected, consistent framework or biology can be treated as unrelated facts or ‘‘pieces.’’*

*b) Independence v. Authority — Ideas about learning biology — whether it means taking responsibility for constructing own understanding or taking what is given by authorities (teacher, text) without evaluation.*

*c) Interdisciplinary Perspectives v. Silo Maintenance — Ideas about the value about incorporating other disciplines into undergraduate biology courses — Believes that knowledge processes are shared among the disciplines* *or focuses on the traditionally held conceptual boundaries in the disciplines.*

*d) Connected v. Isolated — Ideas about the purpose of education — Whether knowledge learned in the biology classroom are relevant and useful in a wide variety of real contexts or ideas learned in biology only serve limited purposes and have little relation to future endeavors.*

These survey items build on the work of several known instruments and focuses on some key issues raised in the *BIO2010* and *Vision and Change* reports, such as the importance of incorporating interdisciplinary content and encouraging meaningful classroom collaboration (AAAS, 2011; Adams et al., 2006; AIBS Education Office, 2010; Elby, 2001; Redish et al., 1998). I categorized all of the survey items *a priori* as either favorable or unfavorable based on these reports as interpreted by the research team and from the results of asking biology faculty how they would like to see their students answering on these items.

I refer to the collection of survey items designed to probe a particular dimension as a cluster. Note that there is some overlap as these dimensions are not orthogonal variables. Although I believe the constructs that I have defined as expert correspond to those expectations needed by most creative, insightful, and successful biologists, I note that they are not always predictors of success in introductory biology classes. I refer to the extreme view that agrees with that of most mature scientists as the expert or favorable view, and the view that agrees with that of most beginning students as the novice or unfavorable view. The extreme views associated with each of these variables are given in table 1.

Table 1: Dimensions of student expectations in the MBEX I

| | **Favorable** | **Unfavorable** | **MBEX items** |
|---|---|---|---|
| **Facts v. Principles** | Believes biology needs to be considered as a connected, consistent framework | Believes biology can be treated as unrelated facts or ‘‘pieces’’ | 3,6,10,11,18,20,27,28,30,31,32 |
| **Independence v. Authority** | Takes responsibility for constructing own understanding | Takes what is given by authorities (teacher, text) without evaluation | 2,4,5,13,18,21,23,27,28,29,30,31,32 |
| **Interdisciplinary Perspectives v. Silo Maintenance** | Believes that knowledge processes are shared among the disciplines | Focuses on the traditionally held conceptual divides in the disciplines | 1,8,14,15,19,22,25,26,32 |
| **Connected v. Isolated** | Believes ideas learned in the biology classroom are relevant and useful in a wide variety of real biological contexts | Believes ideas learned in biology have little relation to future endeavors. | 7,9,11,16,17 |

## F. MBEX I Analysis

In this section, I discuss the results obtained from giving the MBEX survey at the beginning and end of two semesters in three different class sections of the introductory organismal biology class, OrgBio. In each case, the three sections used nearly identical syllabi. For two of these sections, I have data from multiple instructor pairs for a total of five classroom sections. In order to eliminate the confounding factor of differential dropout rates, I only include students who completed the survey both at the beginning and at the end of the term. I refer to this data as matched. All of the student and instructor data sets have been matched pre and post in order to increase the validity of the instrument.

In the subsections of this chapter, I first discuss the implications of the whole instrument analysis, then the results from analyzing clusters. In the third section, I discuss the statistical uncertainty of the results, showing that shifts of more than *2 or 3%* on the whole instrument or *5%* on the clusters are statistically significant.

### *1. Whole instrument analysis*

#### *a) The initial state of the OrgBio A and OrgBio B classes are equivalent*

### Table 2: Analysis of whole MBEX instrument

| **Class Section** | | **Pre** | | | **Post** | | | **% Difference** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fav | Neutral | Unfav | Fav | Neutral | Unfav | Fav | Neutral | Unfav |
| OrgBio A-1 | Total | 49% | 25% | 26% | 46% | 24% | 30% | -3% | -1% | 4% |
| OrgBio A-2 | Total | 49% | 23% | 28% | 49% | 23% | 29% | -1% | 0% | 1% |
| OrgBio A-3 | Total | 51% | 24% | 24% | 45% | 25% | 29% | -6% | 1% | 5% |
| OrgBio B | Total | 51% | 25% | 25% | 54% | 23% | 23% | 3% | -2% | -2% |
| Org Bio C | Total | 56% | 18% | 25% | 58% | 22% | 20% | 2% | 3% | -5% |
| | Average | 51% | 23% | 26% | 50% | 23% | 26% | -1% | 0% | 1% |
| | ST DEV | 0.03 | 0.03 | 0.01 | 0.05 | 0.01 | 0.04 | 0.04 | 0.02 | 0.04 |

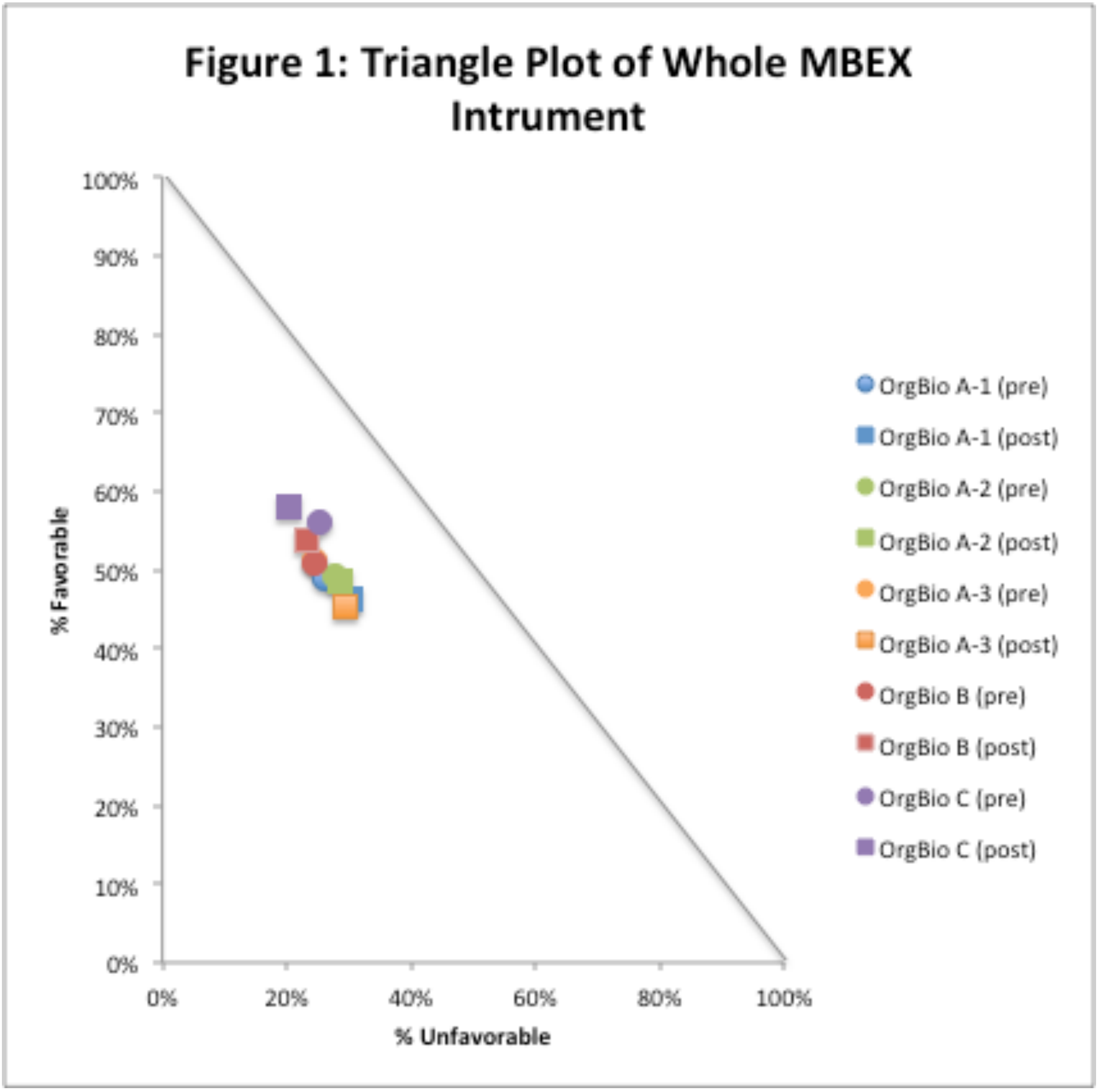


**Figure 1: Triangle plot of whole MBEX instrument**

*To display our results in a concise and easily interpretable manner, we use a Favorable-Unfavorable plot (Redish et al., 1998). In this plot, the percentage of respondents in each group answering favorably is plotted against the percentage of respondents in each group answering unfavorably. Since the fraction of students agreeing and disagreeing must add up to less than or equal to 100%, all points must lie in the triangle bounded by the corners (0,0), (0,100), (100,0). The distance from the diagonal line is a measure of the number of respondents who answered neutral or chose not to answer. The closer a point is to the upper left-hand corner of the allowed region, the better the group's agreement with the expert response.*

Table 2 and figure 1 present the summary results from the whole MBEX instrument. The pre-class results from all the sections except the honors OrgBio C classes are equivalent with respect to statistical significance. In all four classes OrgBio A (1-3) and OrgBio B students gave favorable responses on approximately half of the items and unfavorable responses on one quarter of them. This implies that the populations in these classes may be treated as equivalent on these measures.

#### *b) Traditional pedagogy results in overall deteriorations in student classroom expectations*

Table 2 and figure 1 present the summary results from the whole MBEX instrument. In all cases of traditional instruction, the results from the overall survey were quite similar. In one section (OrgBio A-2), I observed no essentially change and in two sections (OrgBio A-1, 3) I observed an increase in unfavorable responses and a decrease in favorable responses. Thus, lecture-based instruction produced an overall deterioration of overall favorable expectations, instead of the improvement that had been expected due to the increased emphasis on fundamental principles. This result, though disappointing, is entirely consistent with the previous work in introductory physics (McCaskey, 2009; Redish et al., 1998).

From this analysis, I conjecture that reforming the curricular content alone did not suffice to improve student ideas of what it means learn in a biology course. In fact, in several domains, the students' ideas seemed to become worse after one semester of instruction as we see from the analysis of the clusters discussed below.

### *c) Certain student-centered pedagogical approaches can positively impact student classroom expectations in large courses*

Table 2 and figure 1 present the summary results from the whole MBEX instrument. In the large class using a reformed, active learning-based pedagogy (OrgBio B), the instructors were able to achieve slight improvements. The initial state of the students in OrgBio B was fairly consistent with those in OrgBio A, with students explicitly supporting favorable positions 51% of the time and the undesirable positions 25% of the time. Unlike the results found in the traditional classes, the result of instruction on the overall survey was a 2% decrease in the unfavorable responses and a 3% increase in the favorable responses. This +3%/-2% favorable/unfavorable percentage change in OrgBio B is notable compared to the average -3%/+3% percentage change in the traditionally structured OrgBio A classes – an improvement shift of the B class to the A class of +6%/-5%.

These improvements were observed the throughout the MBEX and they were particularly strong in the Fact versus Principles Clusters and the Interdisciplinary Perspectives versus Silo Maintenance cluster as discussed below. From this analysis, I conjecture that restructuring the curricular content combined with specific pedagogical interventions could potentially have improved students' overall learning expectations in a large enrollment biology course.

### *d) Certain student-centered pedagogical approaches can positively impact student classroom expectations in small honors courses*

Table 2 and figure 1 present the summary results from the whole MBEX instrument. In the small honors class using a reformed, active learning-based pedagogy, instructors achieved significant (~7%) improvements in the overall MBEX instrument. The initial state of the students in OrgBio C was slightly higher than either OrgBio A (1-3) or OrgBio B, with students explicitly supporting the favorable positions 56% of the time. Yet, they reported a similar number of unfavorable positions (25% of the time). The higher score on the pretest may have been due to a number of factors, including the fact that these particular students may have had more biologically relevant experiences, such as internships. That said, their initial scores on the specific clusters were not significantly higher, indicating that they are not too different than their non-honors peers.

The results on the overall survey for OrgBio C were similar to the results found in the reform-oriented, large classroom (OrgBio B). Post-instruction the students showed a 2% increase in favorable responses and a 5% decrease in unfavorable responses. These improvements were consistent throughout the MBEX and were particularly strong in the Fact versus Principles Clusters and the Interdisciplinary Perspectives versus Silo Maintenance cluster.

From this analysis, I conjecture that restructuring the curricular content combined with pedagogical interventions could potentially have improved students' overall learning expectations, even in a small, honors biology course. In order to better understand what is happening in the classes observed, let us consider the initial state and the change of student expectations in our various clusters.

### *2. Cluster analysis*

#### *a) Reformed pedagogical approaches helped students view biology knowledge as principle-based rather than fact-driven: analysis of the facts versus principles cluster*

In this cluster, I asked students a series of questions that probed their expectations about biology learning. The 11 questions (3,6,10,11,18,20,27,28,30,31,32) associated with this cluster pose two alternative visions for how best to think about and accommodate new biological knowledge. The favorable view describes biological knowledge in terms of a dynamic web of related information. The favorable view describes biological learning in terms of building an increasingly complex knowledge base. We expect that students who hold this view tend to connect their learning to prior knowledge.

Alternatively, the unfavorable view describes biological knowledge as existing predominately in independent pieces. These "facts" can be learned in isolation and do not need to be related to other pieces in order to be helpful or meaningful. Students who agree with this naïve view tend to learn biology by memorizing large sets of isolated facts. These facts are often disconnected to other learned knowledge. For students who had high-school biology classes dominated by rote memorization and recall tasks, we might expect largely unfavorable responses on our pretest items. We would hope, however, for substantial improvement, even as the result of a single college biology course.

## Table 3: Summary of MBEX I results by cluster — all classes

| | Class | | Pre | | | Post | | | % Change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fav | Neu | Unfav | Fav | Neu | Unfav | Fav | Neu | Unfav |
| Facts v. Principles Cluster | OrgBio A-1 | Total | 49% | 25% | 26% | 49% | 24% | 27% | 0% | -1% | 0% |
| | OrgBio A-2 | Total | 51% | 25% | 24% | 53% | 23% | 24% | 2% | -2% | 0% |
| | OrgBio A-3 | Total | 50% | 25% | 26% | 48% | 25% | 27% | -2% | 1% | 2% |
| | OrgBio B | Total | 51% | 26% | 24% | 57% | 23% | 20% | 6% | -2% | -4% |
| | Org Bio C | Total | 54% | 25% | 21% | 62% | 21% | 17% | 8% | -4% | -3% |
| | | Average | 51% | 25% | 24% | 54% | 23% | 23% | 3% | -2% | -1% |
| | | ST DEV | 0.02 | 0.00 | 0.02 | 0.05 | 0.01 | 0.04 | 0.04 | 0.02 | 0.02 |
| Independence v. Authority Cluster | OrgBio A-1 | Total | 50% | 24% | 25% | 47% | 24% | 28% | -3% | 0% | 3% |
| | OrgBio A-2 | Total | 51% | 23% | 26% | 52% | 22% | 26% | 0% | 0% | 0% |
| | OrgBio A-3 | Total | 53% | 24% | 24% | 48% | 24% | 28% | -5% | 0% | 4% |
| | OrgBio B | Total | 51% | 25% | 24% | 55% | 24% | 22% | 4% | -1% | -3% |
| | Org Bio C | Total | 53% | 26% | 21% | 55% | 25% | 20% | 2% | -1% | -1% |
| | | Average | 52% | 24% | 24% | 51% | 24% | 25% | 0% | 0% | 1% |
| | | ST DEV | 0.01 | 0.01 | 0.02 | 0.04 | 0.01 | 0.04 | 0.04 | 0.01 | 0.03 |
| Interdisciplinary Perspectives v. Silo Maintenance Cluster | OrgBio A-1 | Total | 41% | 29% | 30% | 41% | 26% | 33% | 0% | -3% | 3% |
| | OrgBio A-2 | Total | 42% | 26% | 32% | 43% | 25% | 32% | 1% | -1% | 0% |
| | OrgBio A-3 | Total | 45% | 28% | 27% | 39% | 29% | 32% | -6% | 1% | 5% |
| | OrgBio B | Total | 46% | 28% | 26% | 54% | 24% | 23% | 7% | -4% | -3% |
| | Org Bio C | Total | 50% | 27% | 23% | 60% | 20% | 20% | 9% | -7% | -2% |
| | | Average | 45% | 28% | 28% | 47% | 25% | 28% | 2% | -3% | 0% |
| | | ST DEV | 0.04 | 0.01 | 0.04 | 0.09 | 0.03 | 0.06 | 0.06 | 0.03 | 0.03 |
| Connected v. Isolated Cluster | OrgBio A-1 | Total | 58% | 21% | 21% | 53% | 19% | 28% | -5% | -1% | 6% |
| | OrgBio A-2 | Total | 56% | 21% | 23% | 53% | 20% | 27% | -3% | -1% | 4% |
| | OrgBio A-3 | Total | 63% | 19% | 18% | 52% | 23% | 25% | -11% | 4% | 7% |
| | OrgBio B | Total | 61% | 20% | 19% | 55% | 22% | 23% | -6% | 2% | 4% |
| | Org Bio C | Total | 65% | 20% | 15% | 60% | 20% | 20% | -5% | 1% | 5% |
| | | Average | 61% | 20% | 19% | 55% | 21% | 24% | -6% | 1% | 5% |
| | | ST DEV | 0.04 | 0.01 | 0.03 | 0.04 | 0.01 | 0.03 | 0.03 | 0.02 | 0.02 |

## Table 4: Results for MBEX I for the Facts versus Principles Cluster — results for *select questions* by class

| | **Class** | | **Pre** | | **Post** | | **% Difference** | |
|---|---|---|---|---|---|---|---|---|
| | | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| Facts v. Principles Cluster | **OrgBio A 1** | 18 | 31% | 40% | 26% | 44% | -4% | 4% |
| | | 32 | 59% | 26% | 59% | 24% | 0% | -2% |
| | **ST DEV** | | 0.20 | 0.10 | 0.23 | 0.14 | 0.03 | 0.04 |
| | **AVG** | | 45% | 33% | 42% | 34% | -2% | 1% |
| | **OrgBio A 2** | 18 | 33% | 47% | 35% | 42% | 2% | -5% |
| | | 32 | 62% | 23% | 68% | 18% | 5% | -4% |
| | **ST DEV** | | 0.21 | 0.17 | 0.23 | 0.17 | 0.03 | 0.00 |
| | **AVG** | | 48% | 35% | 51% | 30% | 4% | -5% |
| | **OrgBio A 3** | 18 | 32% | 36% | 30% | 45% | -2% | 8% |
| | | 32 | 62% | 25% | 59% | 21% | -3% | -4% |
| | **ST DEV** | | 0.21 | 0.08 | 0.21 | 0.17 | 0.00 | 0.09 |
| | **AVG** | | 47% | 30% | 44% | 33% | -2% | 2% |
| | **OrgBio B** | 18 | 27% | 42% | 41% | 32% | 14% | -10% |
| | | 32 | 64% | 20% | 83% | 6% | 20% | -15% |
| | **ST DEV** | | 0.26 | 0.15 | 0.30 | 0.19 | 0.04 | 0.03 |
| | **AVG** | | 45% | 31% | 62% | 19% | 17% | -12% |
| | **OrgBio C** | 18 | 41% | 35% | 56% | 20% | 15% | -16% |
| | | 32 | 62% | 18% | 82% | 7% | 20% | -11% |
| | **ST DEV** | | 0.15 | 0.12 | 0.18 | 0.09 | 0.03 | 0.03 |
| | **AVG** | | 52% | 27% | 69% | 13% | 17% | -13% |

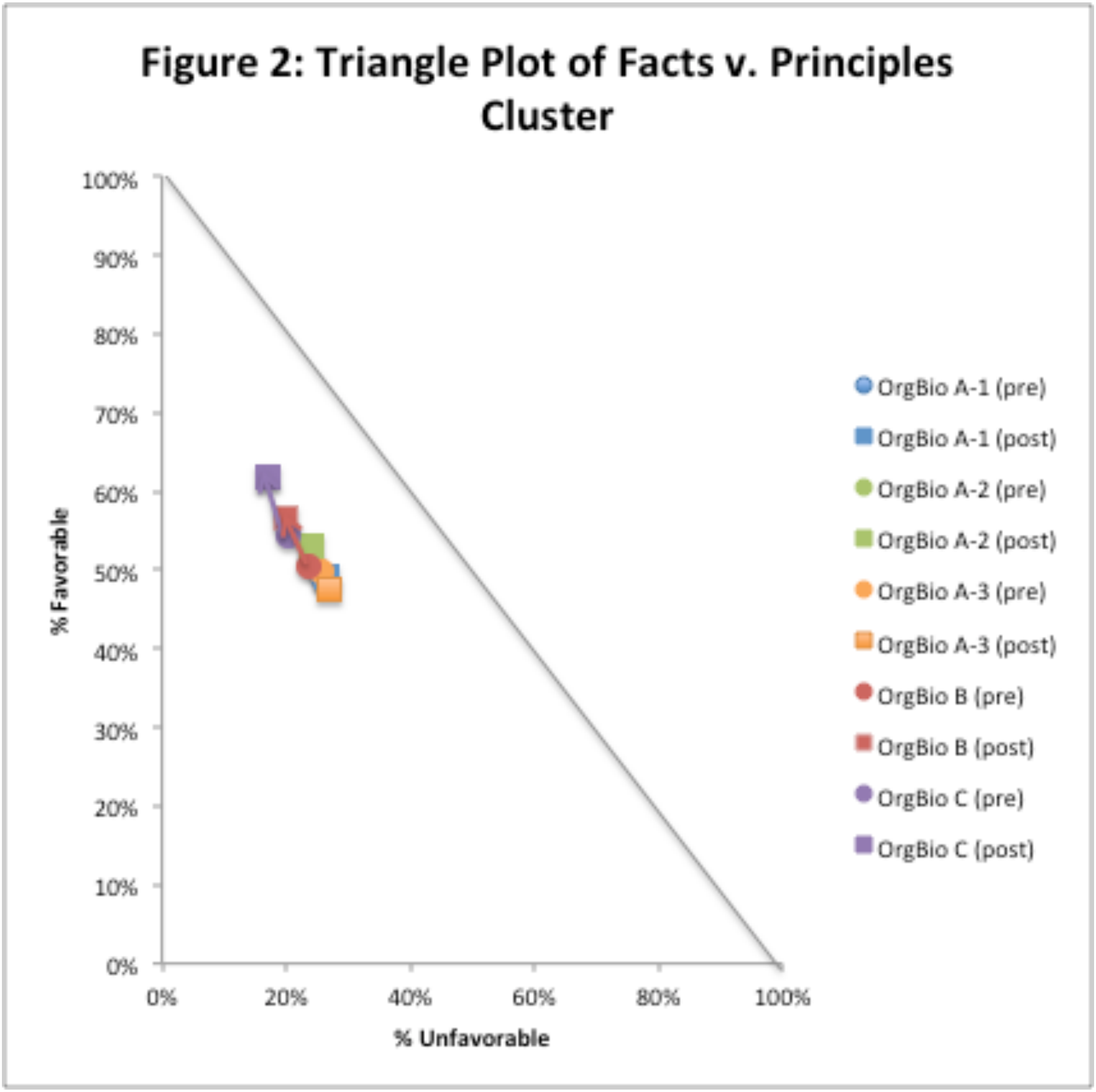


**Figure 2: Triangle plot of the Facts v. Principles Cluster**

Results and totals from select questions are presented in Table 3 and 4. The results are shown graphically in figure 2. The full results of this cluster are presented in Appendix II. In the pretest, incoming students in both the traditional (OrgBio A) and reformed (OrgBio B) sections of the large classes reported the favorable view 49%-51% of the time while 24%-26% of students reported the unfavorable view. Students in OrgBio C agreed with the items in this cluster 54% of the time and disagreed 21% of the time. After one semester of instruction, students in both OrgBio B and C reported gains in their favorable responses and modest drops in their unfavorable response percentage while sections of OrgBio A (1-3) reported either no change or slight deteriorations in this cluster. Within this cluster, results on questions 18 and 32 are particularly interesting:

> Q# 18 Learning biology is mostly a matter of acquiring the factual knowledge presented in class and/or in the textbook.
>
> Q# 32 Biology and physics are:
>
> A. Related to each other by common principles.
>
> B. Are separate and independent of each other.

On question 18, the students in all three sections of OrgBio A-C had very low or mixed responses in the pretest. In the validation interviews, many students reported that broad principles might play a role in upper division courses, but not in the introductory classes. Students felt that introductory courses were mostly about basic knowledge acquisition and not view introductory courses as a place to make sense of that knowledge. Lectures and the textbook were often the primary sources of their information. In our interviews, one student, Patrick went so far as to say “the most effective teachers will teach straight from the book and it's the responsibility of the student to go back and fill in the blank, basically.” He elaborated, “they [the good instructors] just have to. They go in sequence, they go in chapter, they go in order in the way that the material is presented, or in their most logical way for it to be presented. If you go back to the book, you can see where they're pulling the information from.” Patrick statements are reflective of a lot of students I interviewed, but these ideas often come at the expense of the types of creative thinking skills most educators want to see in students.

OrgBio B-C saw a favorable shifting on this specific question during both semesters. By contrast, OrgBio A (1-3) all saw unfavorable shifting in question 18. This particular item is important because it directly correlates to the *Vision and Change* “Core Concepts” for biology literacy (AAAS, 2011). The “Core Concepts” emphasize a complex systems-based approach to understanding “fundamental biological concepts,” rather than an exemplar or case-based approach. An expectation that biological literacy equates to memorizing straight from the text is not usually correlated with a principle, systems-based approach to learning biology. It appears that the reformed biology classes were better able to shift that expectation.

On question 32, all three OrgBio A sections reported fairly high numbers of favorable responses in the pretest. By favorable, I mean that the average favorable response rate was above 50%. In the posttest, OrgBio B-C reported large gains on this question, (+20%/-15%) and (+20%/-11%) respectively while OrgBioA-1 reported no change (+0%/-2%), OrgBio A-2 reported modest gains

(+5%/-4%), and OrgBio A-3 reported mixed results (-3%/-4%).

The difference between the answers in these two questions highlights the clear discrepancy between what types of stances students tend to take toward the sciences in general (i.e. that the sciences are related by broad ideals) and the types of expectations students report toward classroom assessments (i.e. exams tend to assess discrete bits of isolated facts). The core competencies demand that students not only recognize that the scientific disciplines are related by similar ways of approaching knowledge, but also be able to apply what they are learning in various ways. For example, the newly developed lists of competencies require that students be able to apply their biology knowledge to “disciplinary concepts outside biology” or “social and historical dimensions of biological practice.” Question 32 indicates that students have a grasp on the former, that the disciplines share common principles, but question 18 indicates that those ideas may not always translate into classroom behaviors, especially in traditional lecture style classrooms.

### *b) Pedagogical interventions did not result in significant improvements in students ownership of the learning process: analysis of the independence versus authority cluster*

One characteristic of a dualistic thinker, as reported by Perry, is the view that knowledge comes from an authoritative source, such as an instructor or a text, and it is the responsibility of that authority to transfer this knowledge to the learner (Perry, 1970).

By contrast, more experienced students recognize that acquiring and understanding knowledge is a participatory process. Hammer first classified these two opposing views as ‘‘by authority’’ and ‘‘independent’’(Hammer, 1994). MBEX Survey items (2,4,5,13,18,21,23,27,28,29,30,31,32) probe students’ views along this dimension. On this cluster, students’ initial views were favorable in a range from 50% to 53% and unfavorable in a range of 21% to 26%.

## Table 5: Results for MBEX I for the Independence versus Authority Cluster — results for *select questions* by class

| | **Class** | **Question** | **Pre** | | **Post** | | **% Difference** | |
|---|---|---|---|---|---|---|---|---|
| | | | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| Independence v. Authority Cluster | **OrgBio A 1** | 5 | 38% | 36% | 32% | 40% | -5% | 4% |
| | | 21 | 39% | 34% | 23% | 49% | -16% | 16% |
| | | 27 | 13% | 50% | 16% | 48% | 2% | -2% |
| | **ST DEV** | | 0.14 | 0.09 | 0.08 | 0.05 | 0.09 | 0.09 |
| | **AVG** | | 30% | 40% | 23% | 46% | -6% | 6% |
| | **OrgBio A 2** | 5 | 38% | 39% | 33% | 47% | -5% | 8% |
| | | 21 | 40% | 35% | 32% | 39% | -9% | 5% |
| | | 27 | 16% | 42% | 19% | 41% | 3% | -1% |
| | **ST DEV** | | 0.14 | 0.16 | 0.19 | 0.14 | 0.05 | 0.05 |
| | **AVG** | | 31% | 39% | 28% | 43% | -3% | 4% |
| | **OrgBio A 3** | 5 | 50% | 30% | 30% | 50% | -20% | 21% |
| | | 21 | 35% | 30% | 26% | 48% | -8% | 18% |
| | | 27 | 16% | 43% | 12% | 56% | -4% | 13% |
| | **ST DEV** | | 0.17 | 0.08 | 0.10 | 0.04 | 0.08 | 0.04 |
| | **AVG** | | 34% | 34% | 23% | 51% | -11% | 17% |
| | **OrgBio B** | 5 | 38% | 34% | 45% | 38% | 7% | 4% |
| | | 21 | 28% | 43% | 26% | 43% | -2% | 0% |
| | | 27 | 17% | 43% | 15% | 37% | -2% | -6% |
| | **ST DEV** | | 0.11 | 0.05 | 0.15 | 0.03 | 0.05 | 0.05 |
| | **AVG** | | 27% | 40% | 29% | 39% | 1% | -1% |
| | **OrgBio C** | 5 | 41% | 34% | 27% | 35% | -14% | 1% |
| | | 21 | 51% | 30% | 41% | 27% | -10% | -3% |
| | | 27 | 13% | 30% | 28% | 27% | 15% | -4% |
| | **ST DEV** | | 0.20 | 0.02 | 0.08 | 0.05 | 0.16 | 0.03 |
| | **AVG** | | 35% | 31% | 32% | 30% | -3% | -2% |

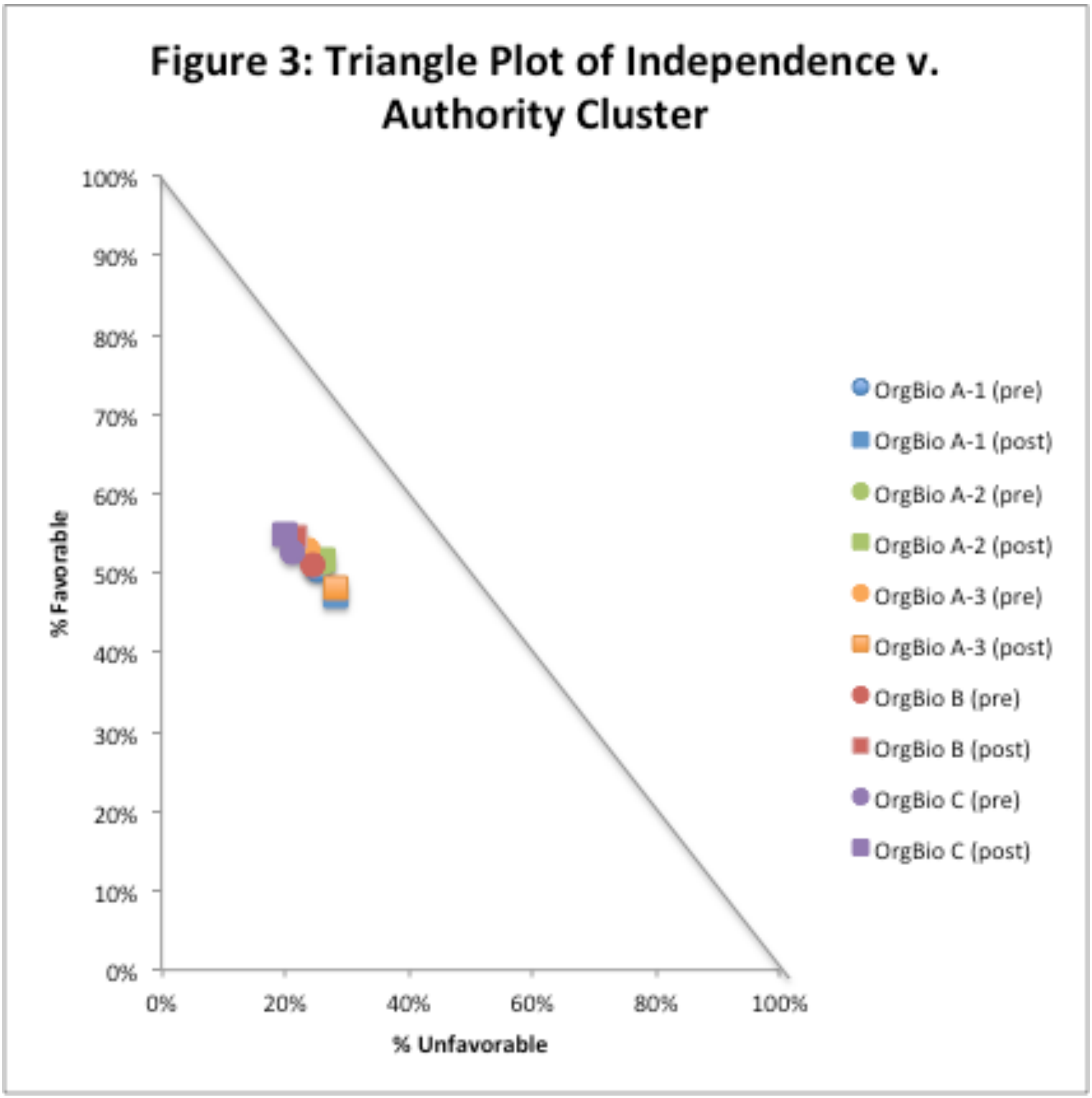


**Figure 3: Triangle plot of Independence v. Authority Cluster**

Results and totals from select questions are presented in Table 3 and 5. The results are shown graphically in figure 3. The full results of this cluster are presented in Appendix III.

While no group showed large improvements in this cluster, OrgBio B did see a 4% gain in favorable responses and a small 3% decline in unfavorable responses. In contrast to OrgBio B, OrgBio A-3 saw a 5% decline in favorable responses and a 4% increase in unfavorable responses. All other groups showed essentially no significant change across the cluster as a result of instruction. Despite the lack of movement across the cluster, survey items 5, 21, and 27 are particularly illuminating and show the largest gaps between the expectations of students and current education reforms initiatives:

> Q#5 If biology professors gave really clear lectures, then most good students could learn the material without having to spend a lot of time thinking outside of class.
>
> Q#21 I find that I often forget the material I've learned for a biology test soon after the exam.
>
> Q#27 I expect my exam performance in biology courses to reflect how well I can:
>
> A. Recall course materials the way they are presented in class.
>
> B. Apply course materials in situations not discussed in class.

This sub-cluster of items, and item 5 in particular appears to confirm that most students in university biology enter with at least some characteristics of Perry’s “binary learners,” agreeing that learning biology is simply a matter of passively receiving information in contrast to constructing one's own understanding (Perry, 1970). I anticipated that a university education would have helped students develop a more sophisticated view of their own learning, and one semester of a conceptually sophisticated university biology curriculum would have moved students in the direction of more independence. Unfortunately, this does not appear to have been the case.

In the benchmark item 5, only OrgBio B reported any significant improvement on this question. The other classes showed declines, with some classes reporting large unfavorable shifts. From this, I conjecture that all of the classrooms, even the reformed classroom, could be doing more to encourage students to take more responsibility for their learning.

On question 21, OrgBio A (1-3) all reported declines on this question. OrgBio B reported essentially no significant change and OrgBio C reported declines. This question is interesting because information retention and transfer are two high priority goals of many education reforms. Question 21 indicates that even the reformed courses described could be doing more to improve students' learning experience.

Finally, question 27 specifically addresses students' expectations about course assessment. On this question, sections OrgBio A-1, OrgBio A-2 and OrgBio B showed essentially no change on this question while the honors version OrgBio C reported large gains. Only OrgBio A-3 showed declines. Since both OrgBio B and C were given similar exams written by the same instructor, this question indicated that the honors students might have different, more sophisticated expectations or approaches regarding exams than the average student.

### *c) Reformed pedagogical approaches helped students see the value of incorporating interdisciplinary perspectives into the biology curriculum: analysis of the Interdisciplinary perspectives v. Silo maintenance cluster*

In this cluster, we asked students a series of questions that probed their expectations about interdisciplinary learning. The nine questions (1,8,14,15,19,22,25,26,32) associated with this cluster probe ideas about the value about incorporating both concepts and methods traditionally associated with other disciplines into undergraduate biology courses. The favorable view reflects the assumption that knowledge processes are shared among the disciplines. The unfavorable view focuses on the traditionally held conceptual divides within the disciplines. This cluster explicitly addresses many of the core concepts addressed in *Vision and Change* and *Scientific Foundations for Future Physicians* (AAAS, 2011; AAMC-HHMI committee, 2009).

## Table 6: Results for MBEX I for the Interdisciplinary Perspectives versus Silo Maintenance Cluster — results for *select questions* by class

| Interdisciplinary Perspectives v. Silo Maintenance | **Class** | | **Pre** | | **Post** | | **% Difference** | |
|---|---|---|---|---|---|---|---|---|
| | | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| | **OrgBio A 1** | 1 | 41% | 38% | 38% | 40% | -4% | 2% |
| | | 8 | 39% | 30% | 27% | 40% | -12% | 10% |
| | | 15 | 19% | 44% | 27% | 45% | 8% | 1% |
| | | 25 | 63% | 7% | 56% | 15% | -8% | 8% |
| | | 26 | 43% | 18% | 37% | 23% | -6% | 5% |
| | **ST DEV** | | 0.16 | 0.15 | 0.12 | 0.13 | 0.07 | 0.04 |
| | **AVG** | | 41% | 27% | 37% | 33% | -4% | 5% |
| | **OrgBio A 2** | 1 | 43% | 38% | 47% | 32% | 4% | -6% |
| | | 8 | 27% | 43% | 40% | 41% | 13% | -3% |
| | | 15 | 32% | 45% | 23% | 48% | -8% | 3% |
| | | 25 | 54% | 8% | 55% | 13% | 1% | 5% |
| | | 26 | 49% | 21% | 45% | 19% | -4% | -2% |
| | **ST DEV** | | 0.11 | 0.16 | 0.12 | 0.15 | 0.08 | 0.04 |
| | **AVG** | | 41% | 31% | 42% | 31% | 1% | -1% |
| | **OrgBio A 3** | 1 | 40% | 28% | 43% | 30% | 3% | 2% |
| | | 8 | 36% | 33% | 26% | 36% | -10% | 4% |
| | | 15 | 28% | 44% | 17% | 54% | -11% | 10% |
| | | 25 | 66% | 7% | 52% | 21% | -14% | 13% |
| | | 26 | 49% | 11% | 45% | 20% | -3% | 9% |
| | **ST DEV** | | 0.15 | 0.15 | 0.15 | 0.14 | 0.07 | 0.05 |
| | **AVG** | | 44% | 25% | 37% | 32% | -7% | 8% |
| | **OrgBio B** | 1 | 39% | 34% | 56% | 19% | 17% | -15% |
| | | 8 | 31% | 31% | 48% | 24% | 17% | -7% |
| | | 15 | 33% | 39% | 25% | 44% | -8% | 5% |
| | | 25 | 71% | 5% | 69% | 6% | -3% | 1% |
| | | 26 | 54% | 16% | 66% | 12% | 12% | -4% |
| | **ST DEV** | | 0.17 | 0.14 | 0.17 | 0.15 | 0.11 | 0.07 |
| | **AVG** | | 46% | 25% | 53% | 21% | 7% | -4% |
| | **OrgBio C** | 1 | 56% | 25% | 66% | 21% | 10% | -4% |
| | | 8 | 39% | 24% | 55% | 24% | 15% | 0% |
| | | 15 | 25% | 42% | 31% | 39% | 6% | -3% |
| | | 25 | 70% | 7% | 73% | 6% | 3% | -1% |
| | | 26 | 48% | 14% | 76% | 8% | 28% | -6% |
| | **ST DEV** | | 0.17 | 0.13 | 0.18 | 0.14 | 0.10 | 0.02 |
| | **AVG** | | 48% | 23% | 60% | 20% | 12% | -3% |

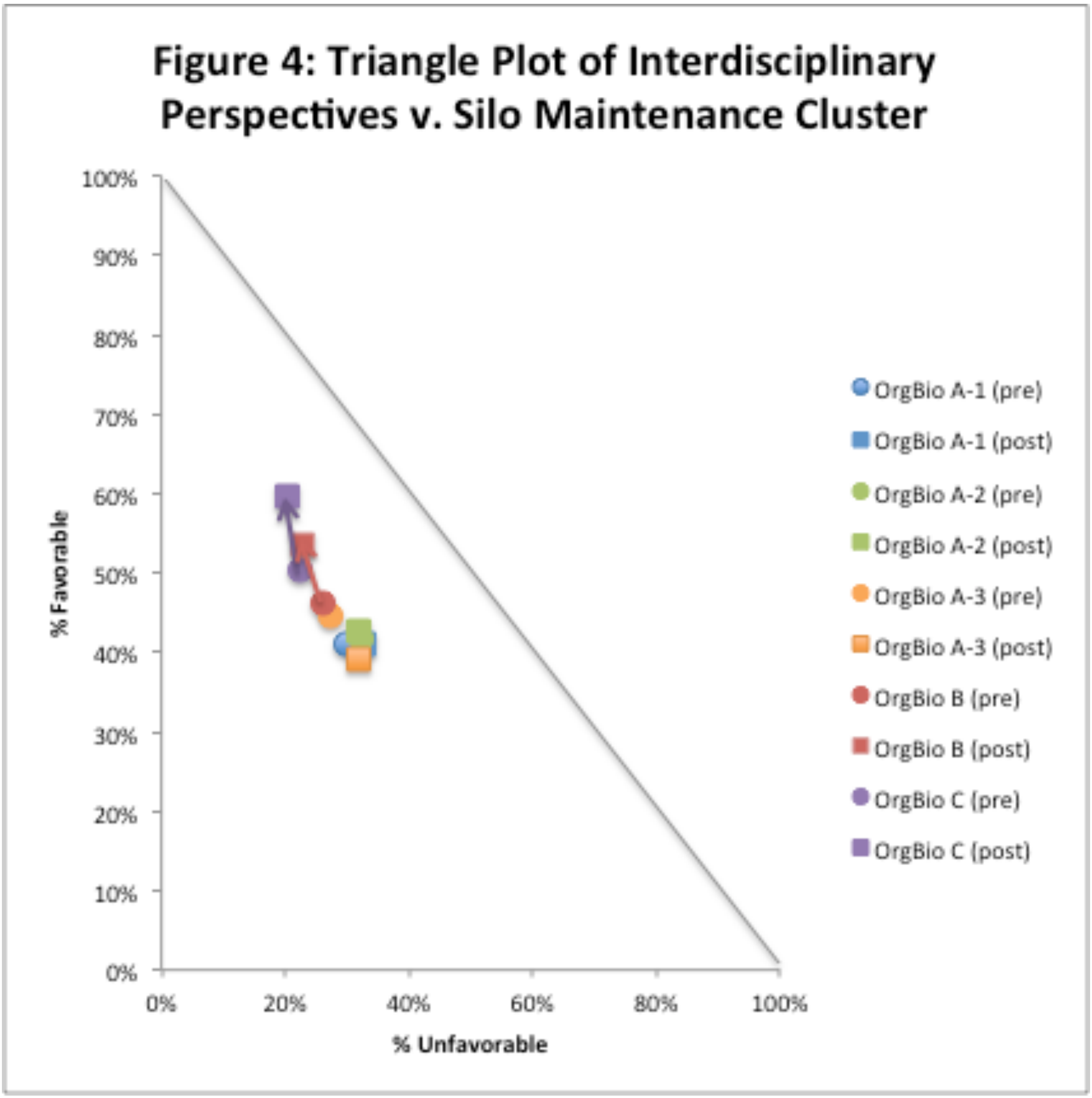


**Figure 4: Triangle plot of Interdisciplinary Perspectives v. Silo Maintenance Cluster**

Results and totals from select questions are presented in Table 3 and 6. The results are shown graphically in figure 4. The full results of this cluster are presented in Appendix IV.

The MBEX data indicate that biology students had mixed views about incorporating concepts from other disciplines into biology courses. In the pretest, the initial views of students in were only favorable between 41% and 46% of the time. The honors group (OrgBio C), did slightly better, and was in agreement as to what responses were desirable on the elements of this cluster 50% of the time. In this cluster, overall improvements were seen in the two reformed classes. (OrgBio B-C).

Within this cluster, some of the lowest initial pretest scores, and/or the largest (downward) shifts in the traditional courses were observed in questions 8, 15, and 25. On the pretest, students in largely agreed with the first two items and disagreed with the third:

> Q#8 Using mathematics to explain biological phenomena is more confusing than helpful to students.
>
> Q#15 I don't need to be good at math to be good at biology.
>
> Q#25 the benefits of learning to be proficient using math and physics in biology are worth the extra effort.

My goal with these questions was to probe whether students saw the potential significance of mathematics in understanding certain biological systems. In the post-test, OrgBio A-1 saw declines in items 8 and 25; OrgBio A-2 saw declines in items 15 and 25 and OrgBio A-3 saw declines in all three items. By Contrast, OrgBio B and saw significant gains with question 8 (+17%/-7%) and OrgBio C saw gains on all three items.

Question 8 explicitly probes students' views on the value of using or incorporating mathematics into the biology curriculum. The results on this item indicate that the specific curricular strategies used in the reformed classrooms may have helped students see the value and utility of using mathematics to explain biological phenomenon.

While items 15 and 25 are similar, they are not identical. Agreeing with item 15 indicates a potential lack of experience with math in general, complex problems, or quantitative modeling. A more experienced student could accept 15 but still reject 25 because they have had exposure with relevant biophysical concepts such as cell signaling or thermodynamics; however while clearly biologically relevant, those experiences were not necessarily essential to understanding all types of biological phenomenon.

In addition to these three questions, OrgBio B and C saw the large positive shifts in other questions in the cluster, such as items 1 and 26:

> Q#1 Biology courses should focus on biological subjects and should not present much chemistry and/or physics.
>
> Q#26 Physics is relatively unimportant for understanding most biological processes.

In the posttest, students in OrgBio B-C saw significant gains with question 1, (+17%/-15%) and (+10%/-4%), respectively, and question 26, (+12%/-4%) and (+28%/-6%) respectively, indicating that they saw the math and physics concepts as potentially relevant to biology. Ultimately, the difference in question profiles between OrgBio A (1-3) and OrgBio B-C indicates that the different sections of the course could really be sending different messages about the utility of math and physics in undergraduate biology courses. Those messages do appear to have influenced the students in reformed courses, but not those in traditional courses.

All of these items reflect key ideas presented in *Vision and Change*. For example, Questions 1, 8, 15, 25, and 26 mirror a key concept presented in *Vision in Change*. Core concept #4 emphasizes, "[e]nergy and matter [as] concepts fundamental to biology that build upon an understanding acquired through the integrated study of chemistry and physics." Core concept #5 emphasizes "[m]athematical and computational tools and theories grounded in the physical sciences [that] enable biologists to elucidate patterns and construct predictive models that inform our understanding of biological processes" (AAAS, 2011).

Once again, I would hope that a university education would help students understand and appreciate the connections between the sciences. Unfortunately, this does not appear to have been the case in OrgBio A, despite the effort to include physical concepts and principles in the lectures.

#### *d) Even reformed curricula do not improve students' view of the relevance of the biology they are learning: analysis of the Disassociated versus Connected cluster*

The five items I have included as the Connected v. Isolated cluster (items 7,9,11,16,17) do not just probe whether the students believe that biology knowledge applies to the real world. Rather, the items probe whether the students feel that what they are learning in their biology classes apply only to specific, isolated educational settings or knowledge can be applied more broadly in a wide variety of real contexts. In my interviews, most students had strong views about the link between biology and the real world. They felt that this connection was one of the reasons that students were drawn to study biology. At the same time, many students also felt that some of their courses did not reflect this deep connection. They felt that their courses rewarded memorization and that ideas from one course isolated to that course and were not transferred from one class to the next. That said, they still reported that they were learning to become more analytic as a result of their science education. Overall, students reported the most sophisticated views in this cluster.

**Table 7: Results for MBEX I for the Connected versus Isolated Cluster — results for *select questions* by class**

| | Class | Question | Pre | | Post | | % Difference | |
|---|---|---|---|---|---|---|---|---|
| | | | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| Connected v. Isolated Cluster | **OrgBio A 1** | 9 | 64% | 12% | 50% | 26% | -14% | 14% |
| | | 17 | 76% | 5% | 76% | 18% | 0% | 12% |
| | **ST DEV** | | 0.09 | 0.05 | 0.18 | 0.06 | 0.10 | 0.01 |
| | **AVG** | | 70% | 9% | 63% | 22% | -7% | 13% |
| | **OrgBio A 2** | 9 | 57% | 16% | 54% | 22% | -3% | 6% |
| | | 17 | 73% | 8% | 65% | 14% | -8% | 6% |
| | **ST DEV** | | 0.12 | 0.05 | 0.08 | 0.05 | 0.04 | 0.00 |
| | **AVG** | | 65% | 12% | 59% | 18% | -5% | 6% |
| | **OrgBio A 3** | 9 | 69% | 8% | 45% | 27% | -24% | 19% |
| | | 17 | 83% | 7% | 55% | 21% | -27% | 14% |
| | **ST DEV** | | 0.10 | 0.01 | 0.07 | 0.05 | 0.03 | 0.03 |
| | **AVG** | | 76% | 7% | 50% | 24% | -25% | 16% |
| | **OrgBio B** | 9 | 66% | 9% | 48% | 17% | -18% | 8% |
| | | 17 | 79% | 6% | 64% | 14% | -15% | 9% |
| | **ST DEV** | | 0.09 | 0.02 | 0.11 | 0.02 | 0.02 | 0.01 |
| | **AVG** | | 72% | 7% | 56% | 15% | -16% | 8% |
| | **OrgBio C** | 9 | 77% | 3% | 54% | 17% | -23% | 14% |
| | | 17 | 86% | 0% | 76% | 6% | -10% | 6% |
| | **ST DEV** | | 0.06 | 0.02 | 0.16 | 0.08 | 0.09 | 0.06 |
| | **AVG** | | 81% | 1% | 65% | 11% | -17% | 10% |

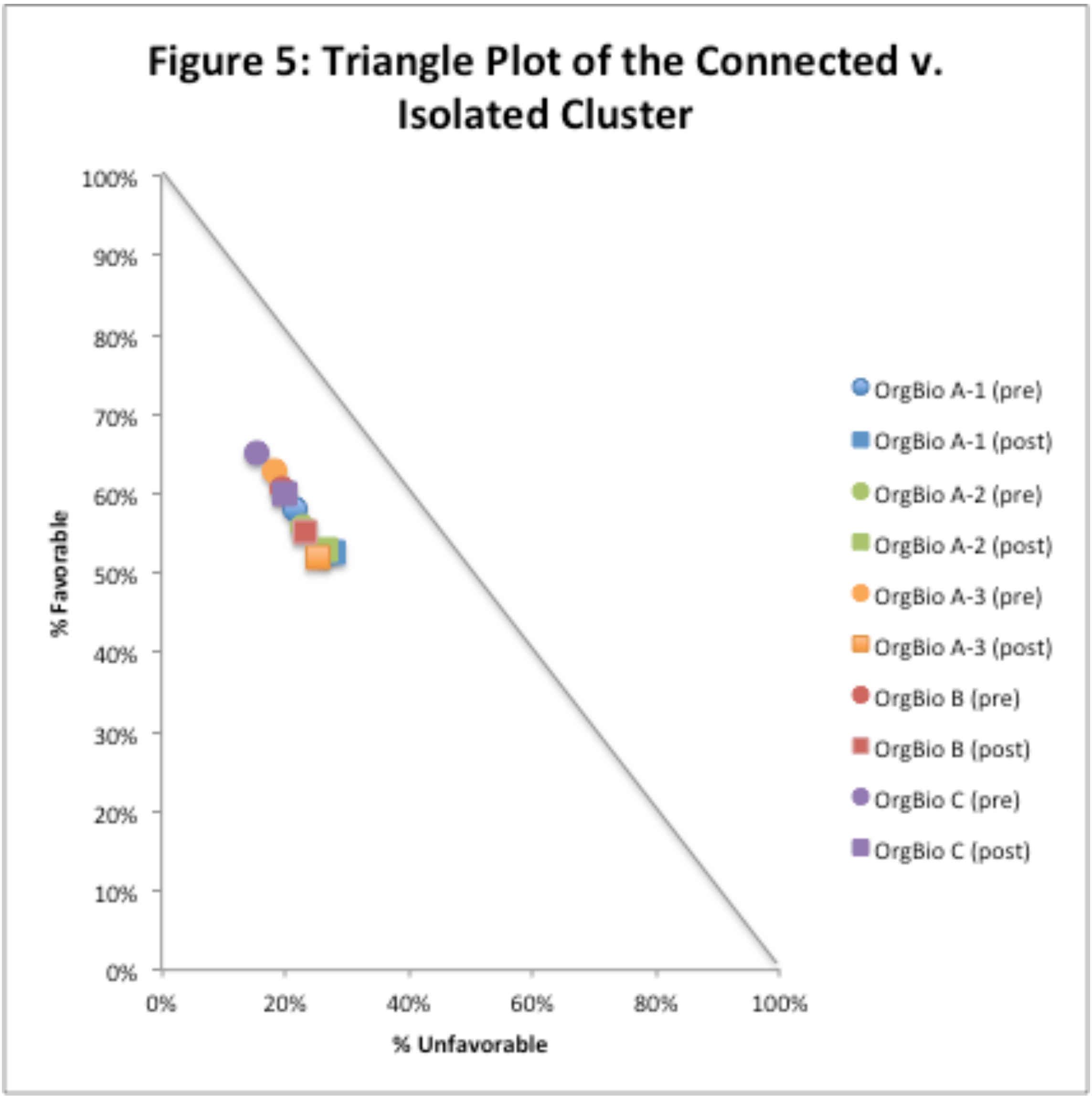


**Figure 5: Triangle plot of the Connected v. Isolated Cluster**

Results and totals from select questions are presented in Table 3 and 7. The results are shown graphically in figure 5. The full results of this cluster are presented in Appendix V.

In the pretest, 56-65% of the incoming students in both the traditional and reformed sections reported the favorable view while 15-23% reported the unfavorable view. However, all five sections saw declines in this cluster. OrgBioA-3 saw the largest (11%) drops in the number of favorable responses for this cluster. The other four sections of OrgBio saw more moderate declines across the cluster, ranging from 3-6%. Across all sections, questions 9 and 17 saw the most dramatic declines.

> Q#9 the knowledge that I acquired in this biology class is directly applicable to important issues currently facing the world.
>
> Q#17 this biology class gives me knowledge and skills to think critically about biological topics in current events.

These questions were very similar and probed whether students felt that the knowledge they were learning in class could apply to situations in the future or in their daily lives. All five student cohorts responded that the material learned in biology most introductory classes were not highly applicable — either in the future or in understanding the world around them. This finding is concerning for a number of reasons. The goal of education is twofold: the first goal is to provide the knowledge a student needs in order to be a success and the second goal is to provide productive ways of thinking and reasoning with that knowledge. If students are only attending to the first goal, they may not develop the critical thinking skills that are critical to success, both as a student and in the future.

### G. Statistical Significance

In this paper, my research questions involve comparisons of groups—students at the beginning and end of one semester of undergraduate biology. In order to compare these groups, I am comparing their averaged responses (agree versus neutral versus disagree). In order for me to understand whether two responses are significantly different, I have to have some model of the random variable in my sample. There are a number of factors that make a standard statistical analysis problematical.

The kind of data that I am analyzing may be thought of as sampling a large equivalent population. If there were a very large number of possible students to probe, my measurement could be seen as selecting a sub-sample from the larger population. I want to know the statistical probability that my result gives the true value for the larger population. If I get a high result, I might, after all, have accidentally selected a biased share of the larger population, accidentally choosing more high scorers. The p-value of a standard analysis gives the probability that the result would have been obtained by a random fluctuation[4].

Standard statistical analysis assumes that an underlying variable is being measured that has a true value that is affected by random noise. If this noise is the sum of a large number of uncorrelated factors, the result is a normal distribution. There are a number of factors that mitigate against the expectation that the results

---

[4] Note that a p value stating $P<0.05$ implies that one in twenty of such experiments really show no effect but are just randomly obtained.

will be distributed normally.

My interviews, intuitions, and many discussions in the cognitive literature suggest that an expectation is a highly complex object. This is consistent with many theoretical frameworks of psychology and education (Hammer & Elby, 2003; Louca et al., 2004; Tversky & Kahneman, 1981). Tversky & Kahneman (1981) suggests that the probability of attained a particular recalled result is associated with the "ease of constructing a story." This can be affected by context, by recent experiences, etc. As noted above, in my validation interviews (both for this survey and the previous MPEX survey) some students gave clear evidence in interviews of being in two, seemingly, contradictory states, depending on which of a set of anecdotes they recall at the moment (Hall et al., 2011). What this implies is that the random variable I should be averaging is itself a probability distribution, rather than a set of well-defined values[5]. Since detailed models of student learning do not yet exist, I estimate my significances by using a simpler model.

Also note there are some problems because of the structure and constraints on the numbers. Although the data – sets of triples of percentages of (favorable, neutral, unfavorable) responses – are numerical continuous values, they are constrained to sum to 1. This means each sample lies within a triangle so there may not be room for a "normal" distribution to spread freely. Estimating P <

---

[5] This is more in line with the sort of behavior seen in quantum mechanics, where the random variable is the phase of a wave function whose square gives the probability, rather than some classical value with added noise. This tangles the noise in a way that depends on the details of the quantum system. We do not have sufficiently robust models of student thinking to be able to create appropriate models.

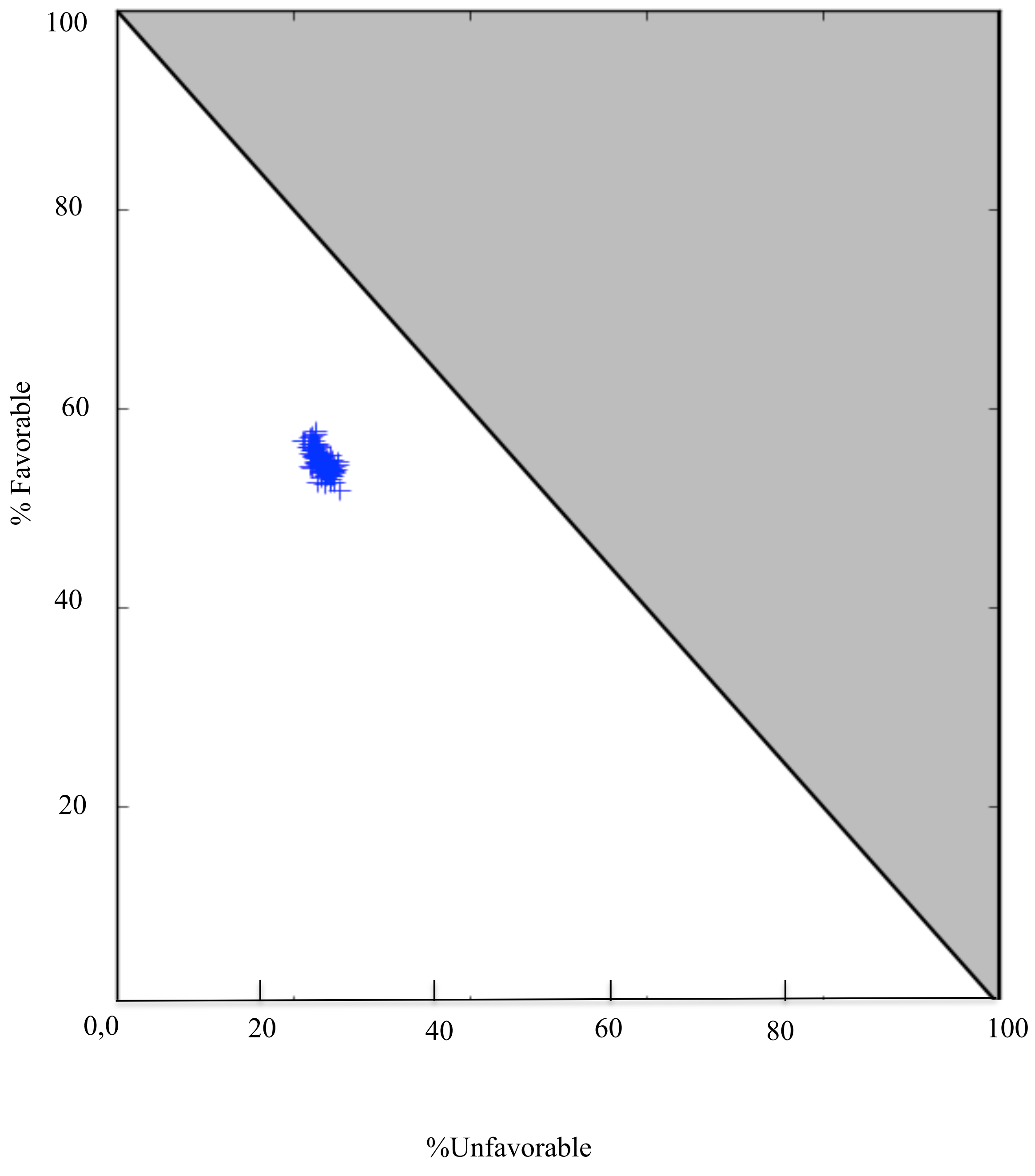
0.05% by considering a 2σ range is meaningless if adding 2σ takes you outside the allowed region. In addition, the three variables are not sequential. “Neutral” should not be conceived of as an intermediate state between “favorable” and “unfavorable.” In this case, the neutral position may refer to a host of states, including, but not limited to, “I am unsure,” “I have no strong viewpoint,” and “I agree equally with both statements presented.” These problems, while tractable using sophisticated statistical techniques, these seem inappropriate to apply when the model of the underlying random variable is uncertain. As a result, I let the data speak for itself.

Recall the fundamental goal of a statistical analysis: to see whether a shift observed in an experiment could have been obtained by random selection from a larger population. As a result, we have done a trial analysis[6], taking the MBEX results from a pre-instruction combined set of two classes that we deemed equivalent. This yielded a “population set” of M = 211. We took the average of these results and considered them the “true” results for the population. We then selected 100 subsets of N = 100 students at random and took their averages. The spread of the results yields an indication of the distribution. The distribution for the total results and the histogram of the favorable values are shown in figures 6 and 7. A similar analysis in figured 8-11 shows that the clusters have a bit more of a spread.

---

[6] This analysis was conducted using Matlab by Noah Sennet.

Figure 6: Distribution of the total MBEX results



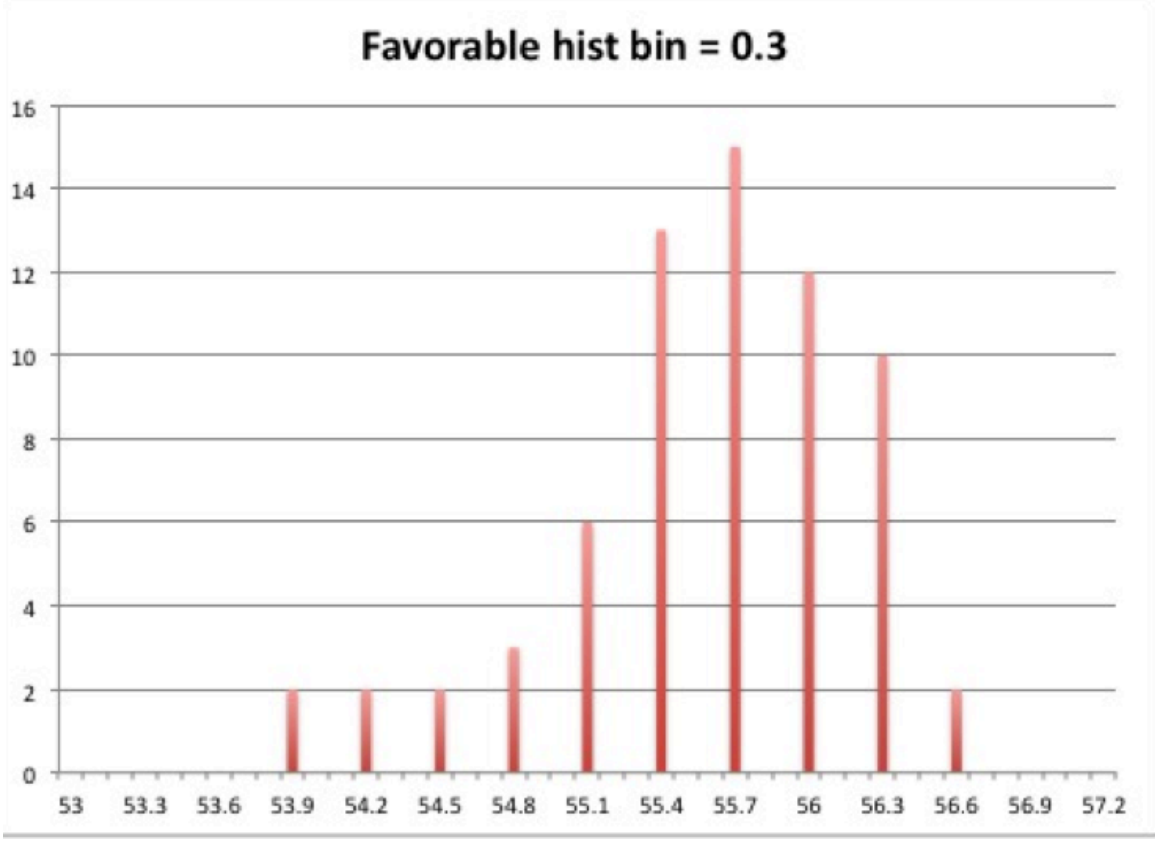


**Figure 7: Histogram of the MBEX analysis**

**Figure 8: Distribution of the Facts v. Principles Cluster**

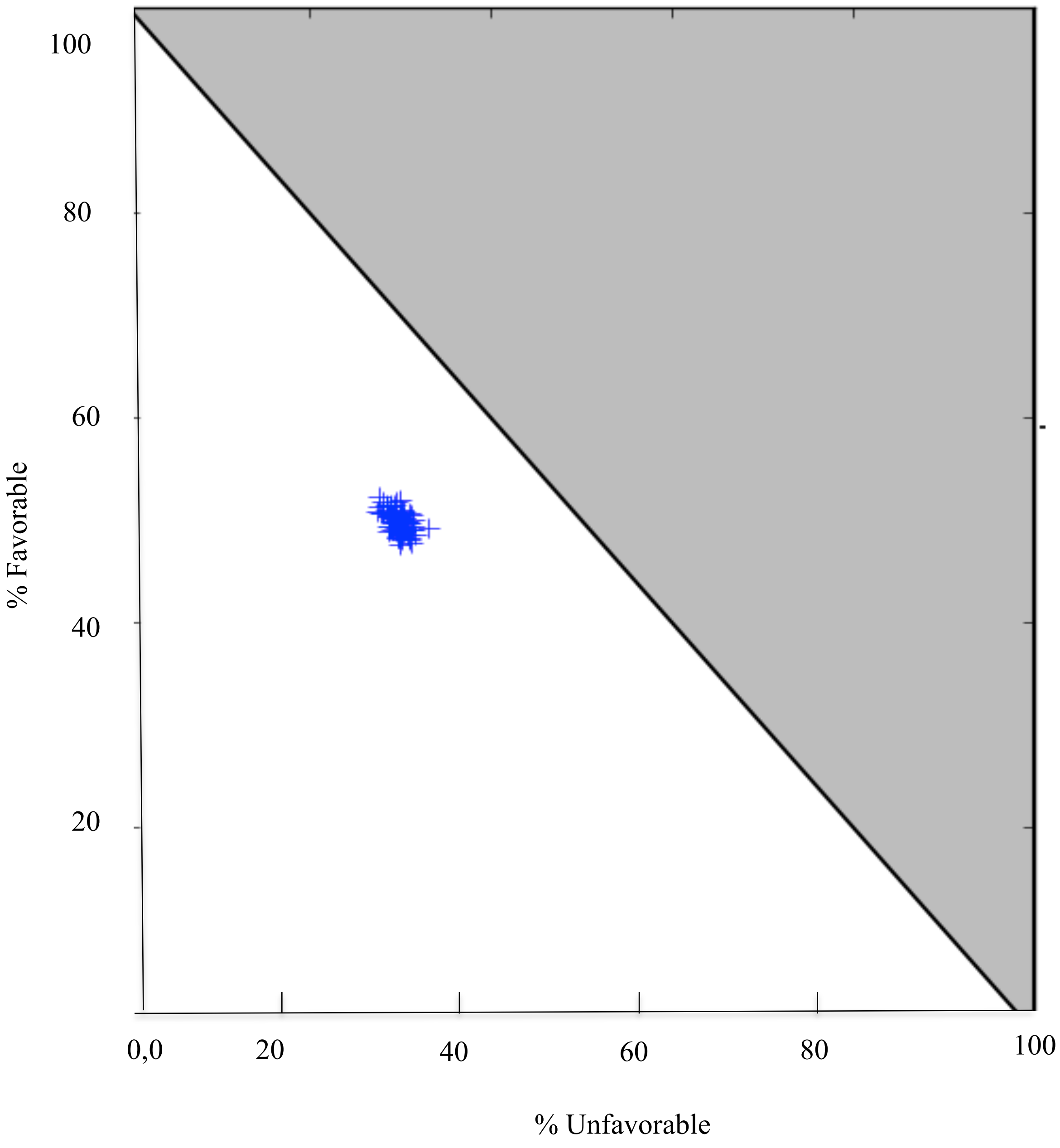


**Figure 9: Distribution of the Independence v. Authority Cluster**

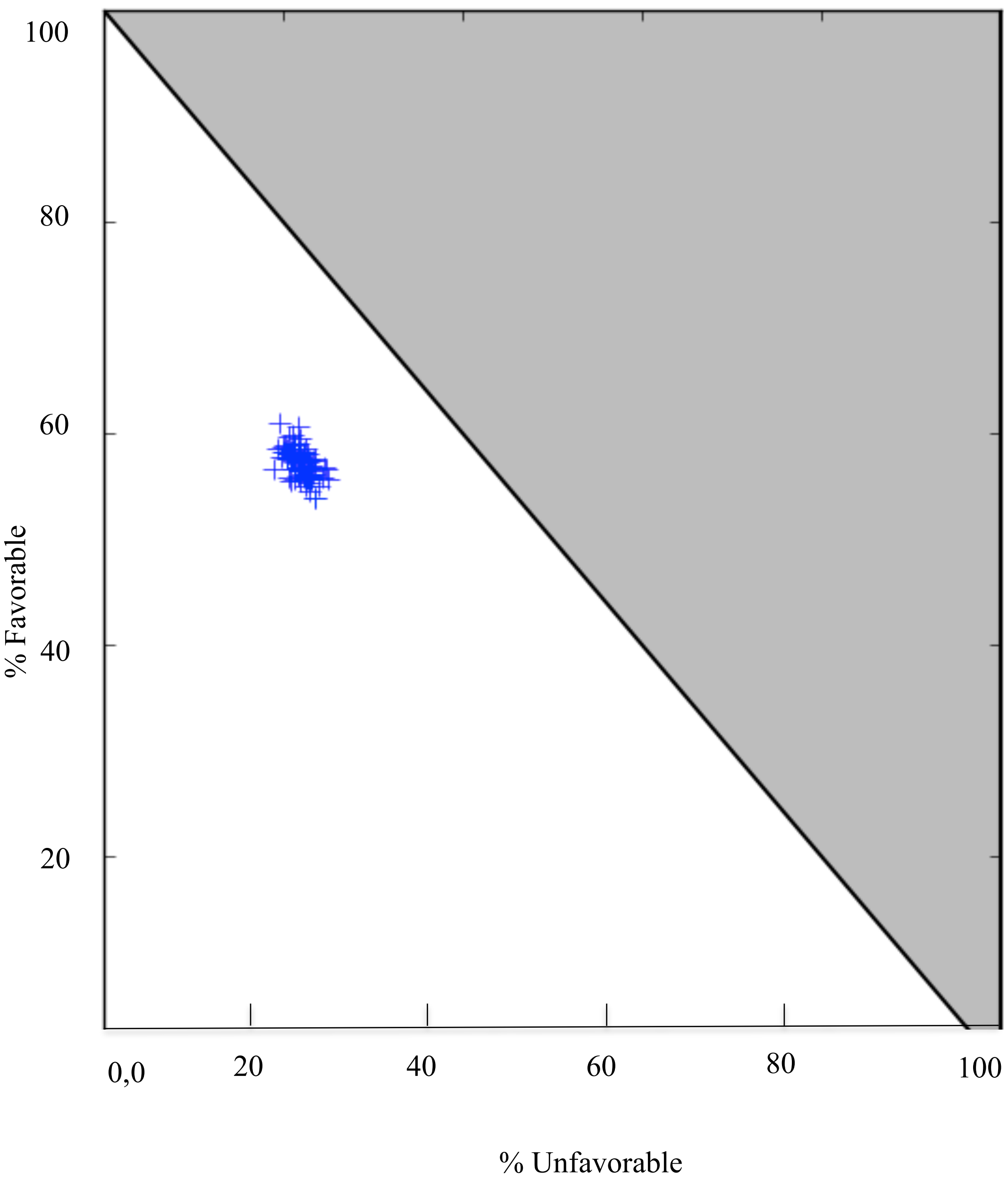


**Figure 10: Distribution of the Interdisciplinary Perspectives v. Silo Maintenance Cluster**

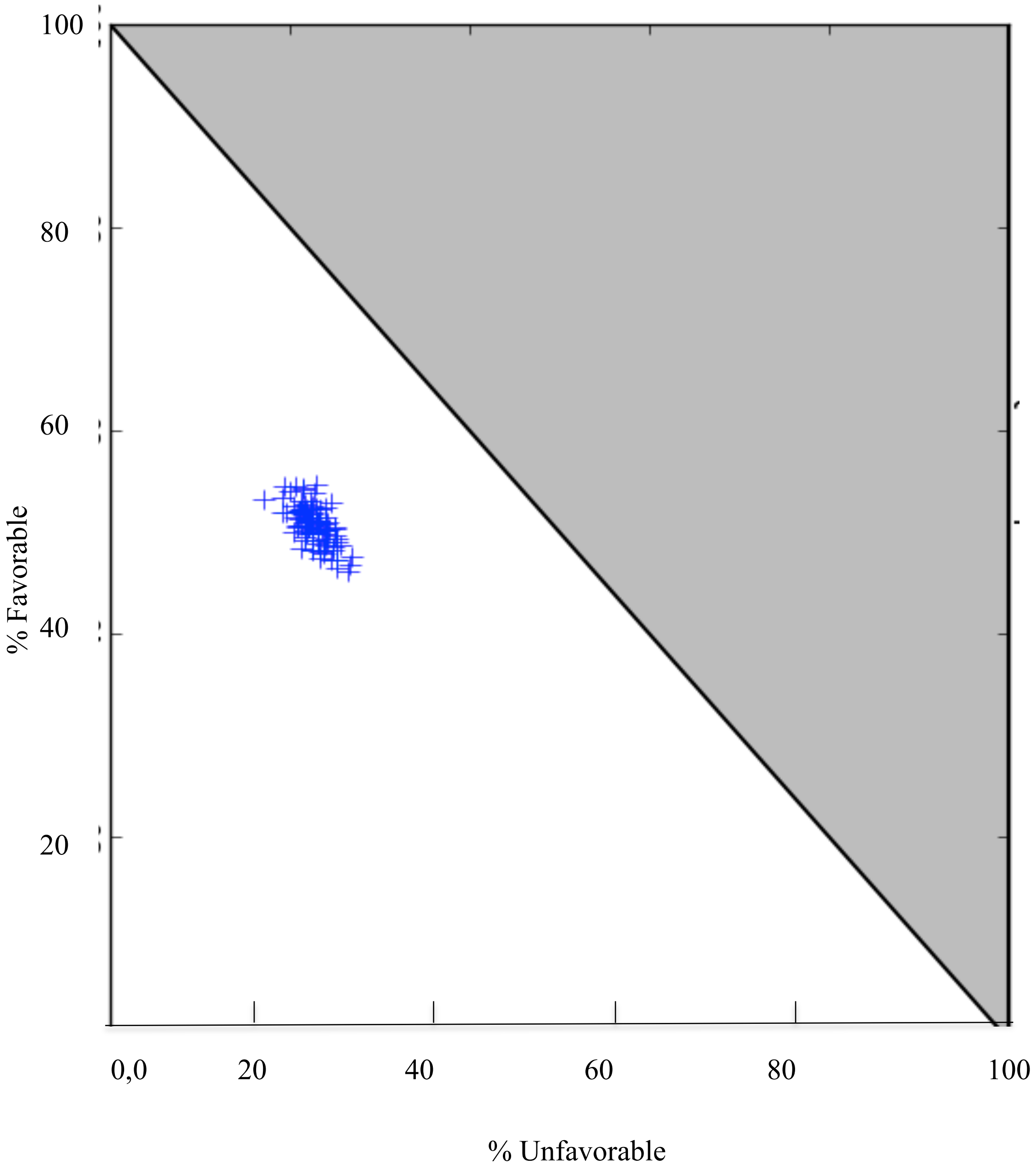
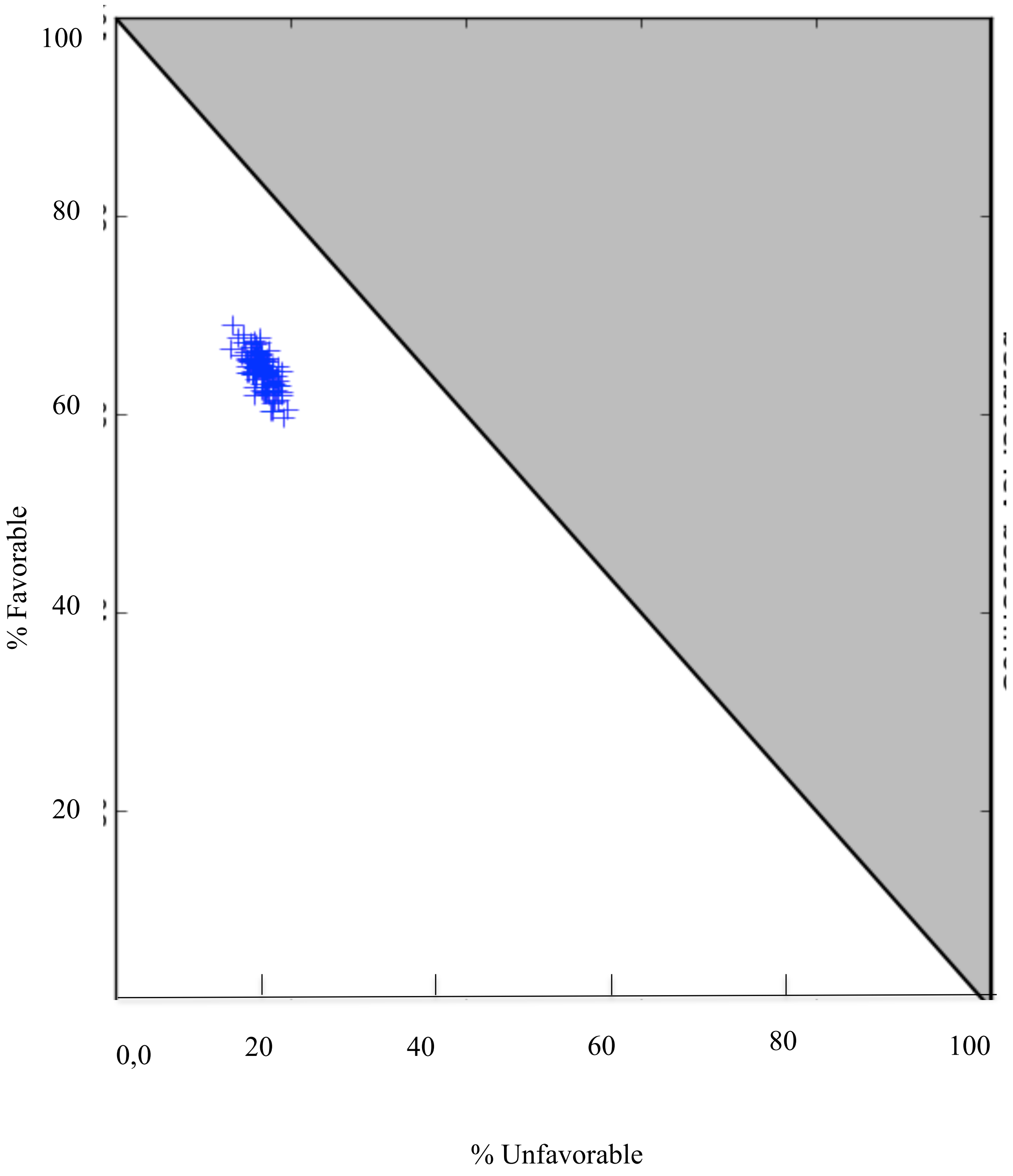


**Figure 11: Distribution of the Connected v. Isolated Cluster**



Figures 8-11 show the distributions for each cluster of the MBEX. At this stage, I feel comfortable with an expectation that a statistically significant result (probability of selection < 5%) is obtained by the values ±2 percentage points for the overall score and ±5 percentage points for sub-clusters. A larger scale study with an exploration of the character of the distribution of these results is planned.

## H. Discussion: Lessons Learned from OrgBio

### *1. Curricular changes alone proved insufficient at improving students' expectations about what it means to learn in biology*

These findings are consistent with the previous work done in physics education (McCaskey, 2009; Redish et al., 1998). While the specific expectations were different, the patterns were similar. Simply telling students to think about biology in terms of a coherent framework and describing the ways in which principles from other disciplines can inform their knowledge in biology did little, if anything, to actually change students perceptions about learning in biology. Students in the lecture-only versions of OrgBio reported either no improvements or declines in their overall classroom expectations as a result of instruction after one semester. This result was consistent with multiple instructors over multiple semesters. The classroom reforms were the most successful in shifting student expectations when they not only talked about biology in these news ways, but also allowed students the opportunity to use these ideas productively in the classroom. In this way, students' were able to take more productive ownership of these ideas and incorporate them into their own ways of thinking about learning in biology.

It important to note that these gains did not always appear for students to extend beyond the classroom context. While almost every biology student reported that they learn about the “real world” or about realistic contexts when they studied biological phenomenon, our survey results indicated that most students did not feel that the specific types of knowledge that they learned in courses helped them better understand current events. This apparent discrepancy between responses points to potential misalignments between what “realistic” means in a classroom and what types of knowledge and skills these students actually expect to use in the world. Students may believe that biology (as a discipline) is related to the real world, but they may also believe that the primary purpose of a biology education is to master specific factual material that serves little or no real world purpose. This can cause problems that are both serious and surprising to faculty. The students who spend all of their time and energy trying to do well in biology classes to achieve specific grades, without ever really understanding the information, poses unique challenges to biology instructors. On the surface, these students appear to be just fine. They are performing well on exams and advancing through their course schedules; however, they may also have significant gaps in their conceptual understanding. These gaps between epistemology (ways of knowing) and performance expectations (what types of knowledge is rewarded) may eventually affect their behavior or may hinder their ability to make broader connections in more applied biological contexts. However, if the student believes that the only way to do well in the class is to deeply understand the principles, then their short-term interests and long-term goals are more aligned. Biology instructors want students to make strong connections between the specifics of what they learn in the classroom, but they want to emphasize the future relevance of knowledge beyond the classroom or medical school admissions test because one of the goals of a university science education is to developed more systematic, logical, and analytic thinkers.

### *2. Students' classroom expectations are malleable and could be responsive to specific pedagogical interventions*

One of our most encouraging findings from the MBEX was that students' expectations do not appear so highly robust and appear to be susceptible to change. This means that instructors have the ability to impact students' ideas about what it means to learn biology in one semester. Of course this impact can be positive or negative, depending on the instruction. We have been able to demonstrate that specifically designed pedagogical interventions can reliably improve students' expectations about what it means to learn in biology, as well as what types of knowledge "count" as biological knowledge. These findings are more evidence that attending to student perceptions of the learning process is a critical element of building a successful reform curriculum.

### *3. Students' classroom expectations can improve as a result of specific classroom instruction regardless of their incoming level of achievement*

Going into this project, one of the researchers' concerns was that certain populations of students would be more resistant to curricular reform than others. They conjectured that highly successful students might be more resistant to new ways of thinking and learning because they were already academic successful.

Changing the structure of the classroom might have been perceived as a threat to their continued success. However, our MBEX results indicate that students' of multiple academic backgrounds showed improvements as a result of pedagogical supports. While the difference between the honors versus general student populations was notable at the beginning of the semester, with the honors students reporting scores significantly higher than general enrollment sections, student in both sections of the course showed comparable gains after one semester of instruction. From this data, we surmise that student-centered pedagogical reforms could be one way to help general enrollment students "catch up" to their honors peers in terms of helping them to develop the thinking and reasoning skills to learn how to learn more effectively.

### I. Chapter 3 Summary

While our two pedagogically reformed sections of OrgBio (B-C) both showed consistent improvements on the MBEX, those improvements were not evenly distributed. The largest gains were seen in the Interdisciplinary Perspectives versus Silo Maintenance Cluster, followed by the Facts versus Principles Cluster. These findings make sense given that the instructors for these sections specifically emphasized the importance of building conceptual frameworks and incorporating ideas from other disciplines into the curriculum. Admittedly, ideas about building long-term knowledge frameworks or taking individual responsibility for learning, while discussed, did not appear to be the main goals for the instructors of OrgBio B or OrgBio C. It makes sense that students cannot attend to messages that are not being brought up and reinforced. If we are committed to helping students see the value of building their own cohesive knowledge frameworks and seeing beyond learning isolated facts, then we have to include those skills explicitly into our instruction. Ultimately, the MBEX provides a starting place for discussion. Rather than focus on what specific facts students can or cannot recall, it allows instructors a way to evaluate the impact of curriculum on students' ideas about what it means to learn and know in the classroom. Knowing what type of reasoning is appropriate and what skills to use in a specific context represents a different type of knowledge sophistication. This type of knowledge, epistemological knowledge, appears to be just as valuable as content acquisition to students as they learn how to think and reason like disciplinary experts.

# IV. Chapter 4: Developing the MBEX II: Understanding Interdisciplinarity in Students Classroom Expectations

## A. Introduction

### *1. National reform initiatives in biology education represent a unified call for more disciplinary integration in undergraduate biology by incorporating more meaningful chemistry, mathematics and physics into introductory biology courses*

In order to bring undergraduate biology courses into the 21st century, a rising chorus of biology educators, researchers, and instructors urge major changes in the teaching of undergraduate biology (AAAS, 2011; AAMC-HHMI committee, 2009; National Research Council, 2003). Such changes are necessary because, in recent years, modern biology has undergone significant transformations. For example, biologists now use emerging technologies and interdisciplinary collaborations to create new areas of biological research pioneering new approaches. The products of these innovations have greatly enhanced our understanding of biological systems. At the same time, our society has become more technologically sophisticated and while our traditional pedagogical approaches were especially well suited to the transmission of conceptual and systematic knowledge, we are now less reliant on human cognition for these simple recall tasks. Because of these trends in both research and technology, the ways in which we now discover, understand, and learn about biology must also adapt and change.

In response to these new realities, biology educators must consider new ways to educate students in the life sciences. Traditional undergraduate teaching approaches no longer seem appropriate. As a result, multiple stakeholders have taken on the task of remodeling undergraduate biology education. For example, in 2003, the National Institutes of Health (NIH) and the Howard Hughes Medical Institute (HHMI) issued *BIO2010: Transforming Undergraduate Education for Future Research Biologists*. The authors of *BIO2010* made several key recommendations for improving undergraduate education — one recommendation was to incorporate more interdisciplinary curriculum into the classroom in order to help students better collaborate with their scientific peers in other disciplines as well as to help them design more interdisciplinary projects of their own.

Another report, called *Vision and Change in Undergraduate Biology* was issued by the National Science Foundation (NSF) — in partnership with the Howard Hughes Medical Institute (HHMI), the National Institutes of Health (NIH) and the American Association for the Advancement of Science (AAAS). This initiative, one of the largest to date condensed a decade of conversations and reports and calls for change into explicit approaches to curricular reform.

Finally, in 2009, the AAMC-HHMI *Scientific Foundation for Future Physicians* voiced concerns that premedical course requirements may no longer accurately reflect the essential competencies every entering medical student must have in order to be successful in the future. One goal of this project was to provide greater flexibility in the premedical curriculum that would permit undergraduate institutions to develop more interdisciplinary and integrative science courses as recommended in the *BIO2010* report. Taken together, *BIO2010, Vision and Change, and Scientific Foundations for Future Physicians* can be interpreted as a unified call for more interdisciplinary integration in undergraduate biology. All three recommend the incorporation of more meaningful chemistry, mathematics and physics into introductory biology courses. Additionally, all three reports focused on implementation strategies, moving away from a lecture-based teaching model toward a more student-centered, active learning environment. Despite concerns over the efficacy of specific implementation strategies, more and more institutions have embraced the learning objectives described in these and similar reports. As a result, many biology classrooms have now integrated interdisciplinary content into the curriculum (Bialek & Botstein, 2004; Clay, Fox, Grünbaum, & Jumars, 2008; O'Connell, 2008; Skinner & Hoback, 2003).

### *2. The Interdisciplinary Expectation Cluster (IEC) of the Maryland Biology Expectations Survey (MBEX) goes beyond single discipline performance indicators to probe students' understanding of interdisciplinary learning*

In response to these newly created reformed classrooms, both at our university and those across the country, I recognized the immediate need for alternate forms of measurement that go beyond the basic (single discipline) performance indicators of student attitudes towards learning. For example, assessment tools must now gauge both the professionally oriented perceptions of the disciplines (i.e. what experts "count" as knowing or learning in a discipline) as well as the related expectations and perceptions for participants in such programs (i.e. what students believe “counts” as knowing or learning in specific learning contexts).

To that end, I have expanded and refined the original Maryland Biology Expectations Survey (MBEX)[7] to better probe students along the dimensions of interdisciplinary learning. To accomplish this, I have restructured the Interdisciplinary perspectives versus Silo Maintenance Cluster of the MBEX I to create the MBEX II[8]. I now refer to this expanded cluster of questions as the Interdisciplinary Expectations Cluster (IEC). The direct comparison of the two surveys and a comprehensive list of changes made in the original MBEX are provided in Appendix VII. Note that there is some significant overlap in the two surveys as only one cluster has undergone significant modifications. However, some of the original questions in other clusters have been dropped or have been moved to new positions in the survey in order to improve the clarity of the instrument. In both cases (the MBEX I and the MBEX II), I derived the specific statements representing both the favorable and unfavorable views through repeated interviews with both students and faculty.

Like the original MBEX I survey, the newly revised MBEX II survey is a 32-item Likert-scale (agree–disagree) survey that probes student classroom expectations regarding undergraduate biology.  The IEC was developed specifically to probe students’ ideas about what “counts” as biological learning and what types of reasoning are valuable to biology learning across multiple learning contexts, not just biology classrooms.

---

[7] The final MBEX I question set is provided in Appendix I.

[8] The final MBEX II question set is provided in Appendix VI.

## B. Expectations, Resources and Epistemological framing: Understanding the role of expectations in the classroom

Before I discuss the impact of students' interdisciplinary perspectives in various courses, I must first discuss the way in which we are conceiving of student expectations. In this chapter, I describe student classroom expectations primarily as a process of dynamic perception. To help understand this multifaceted system, I describe the phenomenon in terms of resources and epistemological framing. My understanding of these constructs, along with the terms themselves, comes largely from the works of diSessa, Hammer, and Tannen (diSessa, 1993; Hammer et al., 2004; Hammer, 1996a; Tannen, 1993b).

Students enter the classroom with a myriad of prior experiences with school and schooling. These prior experiences help form both their *expectations* of what types of experiences they predict will occur in future learning situations as well as selectively cue students to select the various *resources* or ways that students will reason about and make sense of the actual learning situations. In turn, these two constructs help determine and shape a student's *framing* of a particular situation. This understanding of resources and epistemological framing, combined with our own understanding of classroom expectations, provides a language to help us both conceptualize and describe the complex classroom experience.

In my work with biology students, I have documented the effect of both classroom expectations and epistemological framing on student approaches to learning in pedagogically reformed courses (Hall et al., 2011; Watkins et al., 2010). Based on my experience in biology classrooms, I hypothesize that students' expectations about the nature of the knowledge they are learning will strongly affect what resources become activated and, consequently, how students approach learning across classroom contexts (Hammer et al., 2004). In addition, I have further evidence to suggest that students have discipline-specific classroom expectations about what it means to "know" and "learn" in the context of their various science courses. As a result, in order to understand the barriers to teaching scientific reasoning and critical thinking skills, we will need to know how biology student learning expectations differently manifest in various course contexts.

### C. Review of Our Previous Work With Student Classroom Expectations in Biology

In my previous work, I showed that students do not come into the classroom as *tabula rasae*. Instead, they draw on a host of prior experiences with school and schooling to help formulate their expectations and impressions about present and learning experiences (Hall et al., 2011; Watkins et al., 2010). These classroom expectations help guide students and affect what they attend to and what they ignore from the metaphorical "fire hose" of information presented during a typical undergraduate course. They also affect which activities students select as important (or trivial) in constructing their own knowledge base and in building their own understanding of the course material. My prior work with classroom expectations has also documented that the impact of these expectations could be particularly strong when students find themselves facing familiar subject material in novel contexts. From my studies in biology classrooms, I had hypothesized that similar groups of students taking different science classes might report dissimilar ideas about the value of incorporating interdisciplinary content (Hall et al., 2011; Watkins et al., 2010). I conjectured that these disparate views might be due to the labile nature of these expectations.

To investigate these assumptions, I expanded the administrative range of my original MBEX I survey to allow its delivery in a variety of both traditional and reformed biology and physics courses. I report on the results of pre- and post-instruction delivery of this survey to 200 students taking a range of both traditional and reformed introductory courses in both physics and biology in order to characterize the context dependence of student attitudes toward interdisciplinary perspectives at a large east-coast public research university. I report a significant variance in the student expectations, both pre and post, as a result of specific classroom and contextual cues.

### D. Research Questions

I surmise that present classroom expectations are largely the result of past experience with school and schooling; therefore, I investigated these discipline-specific student classroom expectations in a variety of learning contexts, including both traditional and reformed biology and physics courses. It was important to administer the survey in multiple classes in order to describe the nature of these classroom expectations in multiple contexts. That said, the role, distribution, and nature of these expectations is still not well understood; therefore, in this chapter, I limit myself to two research questions:

*1. How can we characterize student ideas regarding interdisciplinary approaches in their sciences classes?*

*2. What is the context dependence of student expectations toward interdisciplinary perspectives?*

## E. The Research Cohorts: The student cohorts and the expert cohorts

### *1. The student cohorts*

I carried out my research in the context of three sections of BSCI 207, Organismal Biology (OrgBio) and two sections of Introductory Physics for the Life Sciences — Phys121 and 122.

#### *a) Organismal Biology (OrgBio)*

Organismal Biology (OrgBio) is the third semester of a three-semester introductory biology sequence that is required of all biology majors. It follows courses presenting the fundamental principles of cellular and molecular biology (BSCI 105) and of ecological and evolutionary biology (BSCI 106). BSCI 207 presents an overview of the diversity and functions of all organisms, with an emphasis on the unifying physical, chemical, genomic, and evolutionary principles governing life. Thus, this class has been transformed from the conventional "forced march through the phyla" often presented in OrgBio courses into a new principles-based OrgBio course emphasizing multidisciplinary perspectives.

All three of the OrgBio classes I observed for this study utilized nearly identical syllabi. While the topics covered by the classes were quite similar, the three versions employed different pedagogical strategies, ranging from a lecture-only format to a student-centered, group-based format. For the lecture-based classroom, I have data from one instructor pair[9]. In the case of the novel pedagogical interventions, data were collected from multiple sections of instructors and students. A summary of our three classrooms environments is described below:

- OrgBio A
- OrgBio B
- OrgBio C (1-2)[10]

The first version, which I will refer to as OrgBio A, followed the standard lecture pedagogy model. This large class of 150-200 typical students used 50-minute lectures presented three times a week. These lectures involved PowerPoint presentations or other visual aids that were intended to present fundamental principles and specific content needed to understand those principles and their applications. Although the subject material presented in OrgBio A was reformed to match the principles-based approach used in the other versions, OrgBio A did not use any reformed pedagogical approaches, such as active-engagement pedagogies, small-group interactive environments, or out-of-class problem solving.

In addition to OrgBio A, I considered two reform-oriented OrgBio

---

[9] OrgBio is typically taught by a pair of instructors

[10] I surveyed two different classroom sections of OrgBio C in my data analysis. I used the numbers 1-2 to distinguish between the two sections.

versions in order to assess the effects that such reformed pedagogical approaches might have on student expectations, attitudes, and conceptual understanding. OrgBio B was also designed for a large class of typically (150+) biology students. This class used two conventional lectures each week, but replaced the third lecture with group active engagement (GAE) activities involving small groups of 4 to 6 students in a separate discussion room. The active-engagement activities were specifically designed to help the students use their prior knowledge to develop revised conceptual models and to achieve a deeper understanding of the fundamental principles. OrgBio B also required the students to meet outside of class to complete weekly homework assignments.

OrgBio C (1-2) were honors-only classes of 75 students, which involved a mixture of conventional teacher-presented lectures, small group activities, student-presented material, demonstrations, and enactments, which were similar to the GAE activities used in OrgBio B. Unlike OrgBio B, these classes did not specifically designate lecture or GAE days, but rather attempted to integrate teacher- and student-centered activities during all three class periods in each week. It will become significant for the following data analysis that OrgBio A and OrgBio B class were composed of a mixture of honors and regular students, whereas OrgBio C (1-2) was restricted to a special group of honors students who are in a program designed to emphasize the connections between the sciences[11].

### *b) The Physics Classrooms*

Like introductory biology, most traditional introductory physics courses

---

[11] http://www.ils.umd.edu

are taught in large (100+) student lectures. They are also comprised mostly of oral presentations, meant to present large amounts information efficiently. Most of these introductory courses follow the format of three hours of lecture, two hours of laboratory, and one hour of discussion/recitation per week. Many introductory physics courses also cover similar content areas, including: mechanics, heat, sound, electricity, magnetism, optics, and modern physics. These topics are specifically chosen to satisfy the minimum requirement of medical and dental schools.

In this study, I carried out my research in two algebra-based physics courses, physics 121 and 122, which are specifically oriented towards life sciences majors. A summary of the two classrooms is described below:

- Phys121 (1-2)[12]
- Phys122

The Phys 121-122 classes I surveyed were taught in the context of the reforms described in (Redish & Hammer, 2009). The classes were taught as large lectures (N~150) with some clicker questions; recitations were done using Maryland Open Source Tutorials (Elby et al., 2007); laboratories were Scientific Community Labs (Gresser, 2006; Lippmann, 2003); and homework problems were often selected from Thinking Problems in Physics (Redish, 2003). While there was an emphasis on conceptual thinking, the instructors did not make a particular effort to develop metacognition or epistemological skills.

---

[12] I surveyed two different classroom sections of Phys 121 for the data analysis. I used the numbers 1-2 to distinguish between the two sections.

### 2. *The expert cohorts*

In addition to the student cohorts, I administered the MBEX II to two expert cohorts. The expert cohort can be divided into two groups. A summary of our two groups is described below:

- Biology Faculty (BF)
- Science Educators (SE)

The first group, biology faculty (BF) was composed of introductory biology teaching faculty at the university (N=17). These instructors taught a variety of introductory classes and represented several different departments. Many have had considerable experience in teaching, and all had taught an undergraduate course within the last 12 months.

The participants in my science educators (SE) group were either implementing an interactive engagement model of teaching in their classroom at the time of this investigation or were affiliated with science education research at the university (N=10).

I asked the two groups to respond with the answer they would prefer their students to give. I expected these two groups to show an increasing level of agreement with answers I preferred.

## F. Methods

### 1. *Survey construction: the original MBEX I survey*

I developed our original version of the MBEX I in the fall of 2009. To establish relevant and reliable questions, I gave undergraduate biology students a variety of statements about the nature of biology, the study of biology, and their relation to it. They rated these statements on a five-point Likert scale from strongly disagree-1 to strongly agree-5. I finalized the items for the survey after conducting a detailed literature review, having discussions with biology faculty, reviewing class exams, synthesizing students' feedback and interview statements, making classroom observations, and drawing on my research teams' teaching and research experience. For the student interviews, I asked the students to describe, to the best of their ability, what "learning" means in biology and what approaches they used to understand the material in their courses. I also asked them to describe what types of activities, such as study habits, they typically engaged in. I then validated the items in a number of ways: discussing with other faculty and science education experts, administering student validation interviews[13], giving the survey to a variety of ''experts'' (meaning both working scientists and science educators), and repeatedly delivering the survey to groups of students. I refined and implemented the MBEX I survey by testing over the last four years. The final version of the MBEX I is given in Appendix I.

### *2. MBEX II survey validation*

#### *a) Interview data*

I validated this survey by conducting 25 individual interviews with students taking the biology courses mentioned above, as well as 10 designated validation interviews. Additionally, I have administered this survey as a pretest and posttest in both OrgBio as well as our Phys 121-2 over two semesters.

---

[13] For the validation interviews, I specifically asked students to read and interpret the questions on the MBEX. I did this to reduce the ambiguity of the questions and ensure that each question is written as clearly as possible.

#### *b) Comparison with expert cohorts*

We also validated the survey by giving the survey to two groups "experts." We then compared our a priori grouping of the IEC cluster with the responses of the two disciplinary experts.

### *3. Summary of previous MBEX I results*

The MBEX I was originally designed to be an independent measure to assess the effects of specific pedagogical techniques on students' expectations towards learning biology (See the discussion section of the MBEX I in Chapter 3 for a more comprehensive review). This work indicates that scores from students taught in lecture-only courses slightly deteriorate or remain static after one semester of instruction, while in revised-pedagogy courses I find marked improvements in several domains, specifically in the Facts versus Principles Cluster and the Interdisciplinary Perspectives versus Silo Maintenance Cluster. These results were found consistently over several semesters and in multiple classes, and the results mirror previous results from the Maryland Physics Expectations Survey, or MPEX — that more traditional instruction correlates with stagnating or declining expectations (Redish et al., 1998). For this chapter, I focus on and expanded the Interdisciplinary Perspectives versus Silo Maintenance Cluster to better characterize students' ideas about what "interdisciplinary" means and what types of knowledge are valuable for them as biologists.

### *4. Creating the IEC cluster of the MBEX II*

For the creation of the IEC cluster, I engaged in a very similar development and validation process to the original MBEX I. Using the methods above; I conducted a literature review, discussed the issues with biology faculty, synthesized students' feedback and interview statements, and made classroom observations. Then I administered the MBEX II survey as a pretest and posttest in both the traditional and revised Organismal Biology courses (OrgBio A-C) and in the first two introductory physics courses for life sciences (Physics 121-2) during the fall 2011 semester and spring 2012 semesters.

## G. Clustering the MBEX II

### *1. The original MBEX clusters*

In the original MBEX survey, I focused on four dimensions in order to categorize student perceptions toward undergraduate biology. The four original dimensions probed by the MBEX were:

*a) Facts v. Principles — ideas about the structure and content of biology knowledge — as a collection of isolated pieces (or facts) or as a coherent system;*

*b) Independence v. Authority — ideas about learning biology — whether it means receiving information or involves an active process of reconstructing one's own understanding; measure the degree to which students take personal responsibility for learning;*

*c) Interdisciplinary Perspectives v. Silo Maintenance — beliefs about the role of physics, chemistry, and mathematics in learning biology; and*

*d) Connection v. Isolated — beliefs about the connection between biology and future relevance — whether classroom biology is related to experiences outside the classroom or future roles as biologists and whether it is useful to think about biology content in this way.*

For the revised MBEX II survey, I decided to keep the four clusters, but focus on expanding and better defining the boundaries of the third.

**Table 8: Dimensions of student expectations in the MBEX II**

| | Favorable | Unfavorable | MBEX items |
|---|---|---|---|
| **Facts v. Principles** | Believes biology needs to be considered as a connected, consistent framework | Believes biology can be treated as unrelated facts or ‘‘pieces’’ | 1,3,7,19,28,29,30,31,32 |
| **Independence v. Authority** | Takes responsibility for constructing own understanding | Takes what is given by authorities (teacher, text) without evaluation | 1,4,6,21,28,29,30,31 |
| **IEC Cluster** | Believes that knowledge processes are shared among the disciplines | Focuses on the traditionally held conceptual divides in the disciplines | 2,5,9,13,14,16,17,20,22,23,24 |

| | | | |
|---|---|---|---|
| **Physics sub-cluster** | | | 2,5,13,16,20,23 |
| **Math sub-cluster** | | | 9,14,17,22 |
| **Chemistry sub-cluster** | | | 24 |
| **Connected v. Isolated** | Believes ideas learned in the biology classroom are relevant and useful in a wide variety of real biological contexts | Believes ideas learned in biology have little relation to future endeavors. | 8,11,12,15.18 |

## Table 9: Illustrative student comments for each cluster of the MBEX II

| | **Favorable Examples Taken From Student Comments** | **Unfavorable Examples Taken From Student Data** |
|---|---|---|
| **Facts v. Principles** | Q1-One should be able to integrate facts in a broader context and understand them. Knowledge should be stored in one's long-term memory instead of short-term. | Q1-It (biology) mostly consists of memorizing processes. |
| | Q1-It is crucial to also be able to integrate and connect the facts presented. | Q1-So far, (AP) Biology has proven to be a class of memorizing and regurgitating back all that you remember. Biology has not demanded more brainpower than this, and I keep waiting to be asked to problem solve or to come to my own conclusions about the material. |
| | Q1-Learning anything involves understanding relationships between individual topics, not only memorizing them. | |

| | | |
|---|---|---|
| **Independence v. Authority** | Q4-You will fail without an understanding of the course topic; it was a prerequisite for the prerequisites. | Q4-I suppose if you have some prior knowledge of biology it's possible. So you may not fully understand the course topic, but know enough basic knowledge to get a C or better. |
| | Q6-Learning becomes more effective when students think and find information on their own. | Q4-Students can get help on the homework, which are a major portion of the overall grade, and get a passing grade without getting good grades on the tests. |
| | Q6-Learning the material well in class prepares you for efficient studying outside of class. | Q6-AP Bio was like that; the teacher explained the material really well and I barely had to open my textbook. |

| | | |
|---|---|---|
| **IEC Cluster** | Q9-When biology incorporates math, biology makes so much more sense. In AP Biology we applied math in the Hardy-Weinberg equilibrium and statistics (Chi-square) and that for me, gave me a deeper understanding of Biology as mathematical patterns. | Q26-No I hate physics. I hope I never need it in my career. |
| | Q26-I will use the principles by making sure that the biology I learn can be explained by physics; i.e. countercurrent flow increasing oxygen intake. | Q26-No, physics is confusing. |
| | Q27-In Bioengineering, Physics is critical. I need to not only observe how Biology functions, but how I can manipulate it to function in ways that are predictable and useful. Physics is that component that will help me achieve that control. | Q26-No, because those principles do not have to do with the field I want to go into, which is more biological. I don't think the two mix much. |

| | | |
|---|---|---|
| | Q27-A great researcher needs to be able to combine many aspects of science beyond their own. Even though I am a Biochemistry major, I know I will need to use Physics to understand my subject down to the molecular level. | |
| **Connected v. Isolated** | Q1-Talking about the concepts of biology and how they apply to situations and the world around us is extremely important. | Q8-I think a lot of time is spent on evolutionary processes for reasons that were never explained to me |
| | Q8-Evolutionary processes help us understand many of the mechanisms in human biology. | Q12-One of my peeves with biology- I usually just care about human anatomy and physiology. Everything else seems extraneous (unless you're working with cross-species genetics) |
| | Q8-Human biology is strongly a result of past evolutionary experiences. | Q15-Sorry, but that's (med school) my main priority. |
| | Q18-It helps in understanding the huge technological advances that are going on in society. | |

Examples of the extreme views associated with each of these variables are given in Table 8. We refer to the interpretation that agrees with that of most sophisticated disciplinary experts as the “favorable” view, and the view that agrees with that of most introductory or incoming students as the novice or “unfavorable” view. Specific profiles of each view, as represented by student comments, are given in Table 9.

## H. IEC Analysis

### *1. Whole IEC cluster analysis*

#### *a) The initial state of our two expert cohorts are equivalent*

## Table 10: Summary results of the IEC Cluster

| | | IEC Cluster | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Class | | **Pre** | | | **Post** | | | **% Change** | | |
| | | Fav | Neu | Unfav | Fav | Neu | Unfav | Fav | Neu | Unfav |
| BF | Total | 81% | 14% | 5% | | | | | | |
| BE | Total | 82% | 5% | 13% | | | | | | |
| | **AVG** | 81% | 10% | 9% | | | | | | |
| | **ST DEV** | 0.01 | 0.07 | 0.06 | | | | | | |
| OrgBio A | Total | 45% | 29% | 26% | 51% | 25% | 24% | 6% | -4% | -2% |
| OrgBio B | Total | 51% | 28% | 21% | 61% | 24% | 15% | 10% | -5% | -6% |
| | **AVG** | 48% | 28% | 24% | 56% | 24% | 20% | 8% | -4% | -4% |
| | **ST DEV** | 0.04 | 0.00 | 0.04 | 0.07 | 0.01 | 0.06 | 0.03 | 0.01 | 0.03 |
| OrgBio C-1 | Total | 71% | 20% | 9% | 80% | 11% | 9% | 9% | -8% | 0% |
| OrgBio C-2 | Interdisciplinary: Total | 67% | 20% | 14% | 76% | 14% | 9% | 10% | -5% | -5% |
| | **AVG** | 69% | 20% | 11% | 78% | 13% | 9% | 9% | -7% | -3% |
| | **ST DEV** | 0.03 | 0.00 | 0.03 | 0.03 | 0.02 | 0.00 | 0.01 | 0.02 | 0.03 |
| Phys 121-1 | Total | 56% | 29% | 15% | 46% | 31% | 23% | -10% | 2% | 8% |
| Phys 121-2 | Total | | | | 46% | 31% | 23% | | | |
| Phys 122 | Total | 45% | 29% | 25% | 44% | 25% | 30% | -1% | -4% | 5% |
| | **AVG** | 51% | 29% | 20% | 46% | 29% | 25% | -5% | -1% | 6% |
| | **ST DEV** | 0.08 | 0.01 | 0.07 | 0.01 | 0.03 | 0.04 | 0.06 | 0.04 | 0.02 |

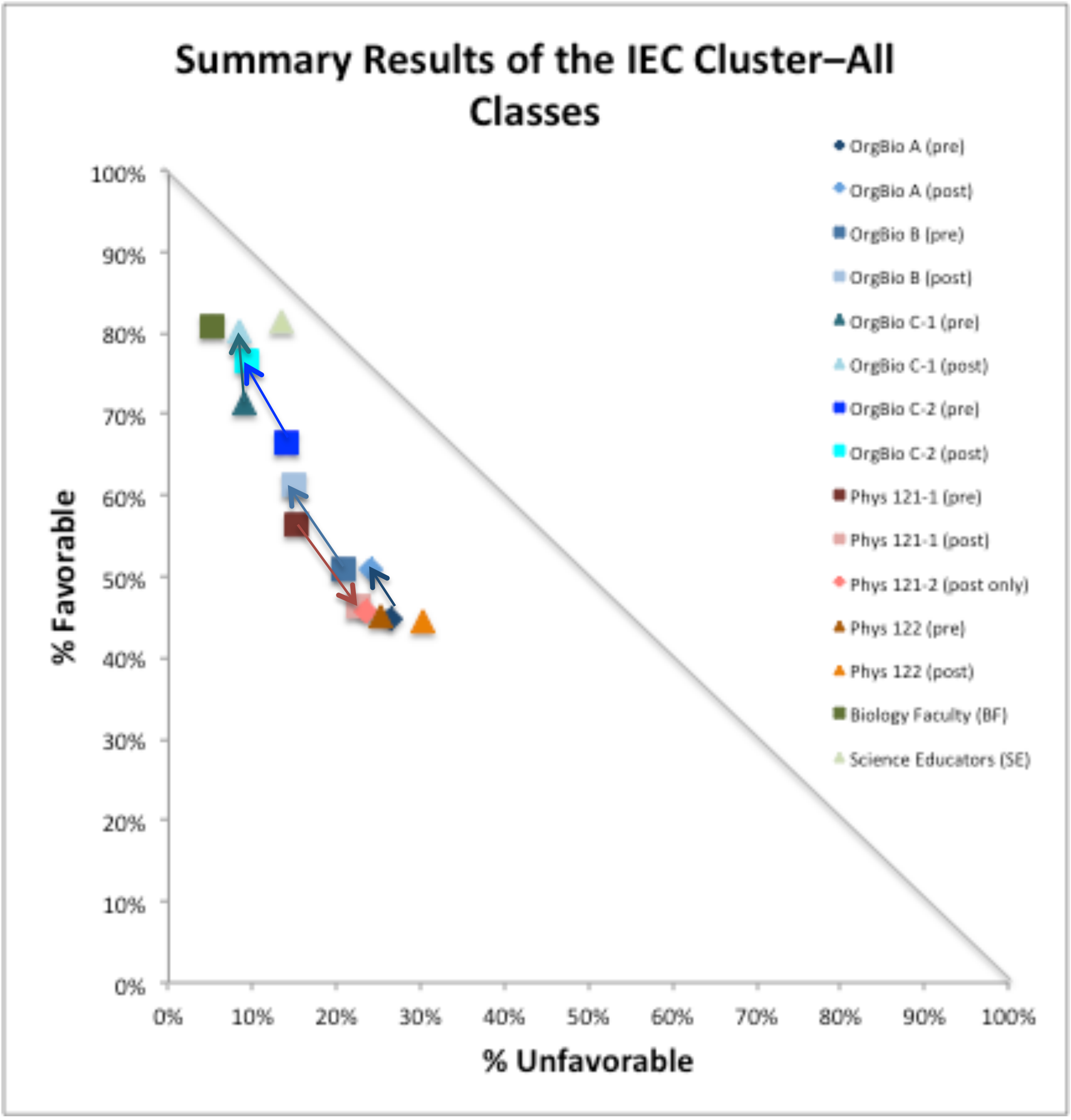


**Figure 12: Summary results of the IEC Cluster — all classes**

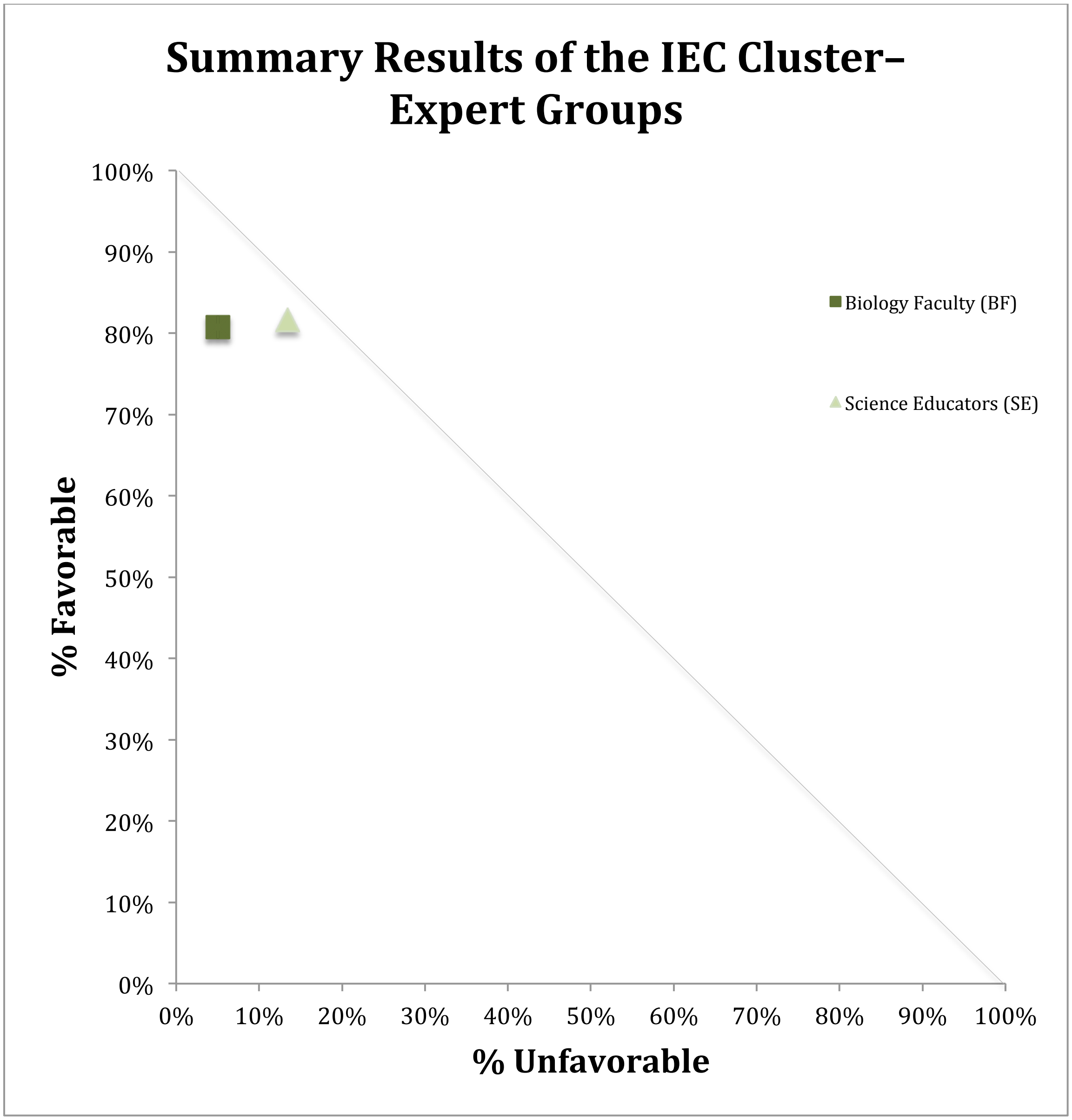


**Figure 13: Summary results of the IEC Cluster — expert groups only**

Table 10 and figure 12 present the summary results from the IEC cluster of the MBEX II. Figure 13 presents the results for the expert groups only. The whole IEC initial results indicate that the biology faculty group (BF) is equivalent to the Science Educator (SE) group to within our statistical significance. The two expert groups gave favorable responses on 81% and 82% of items respectively and unfavorable responses on 5% and 13% of the items. This implies that the populations may be treated as equivalent on these measures.

### *b) The initial state of the OrgBio A and OrgBio B classes are not quiet equivalent; however, they are still most likely equivalent populations*

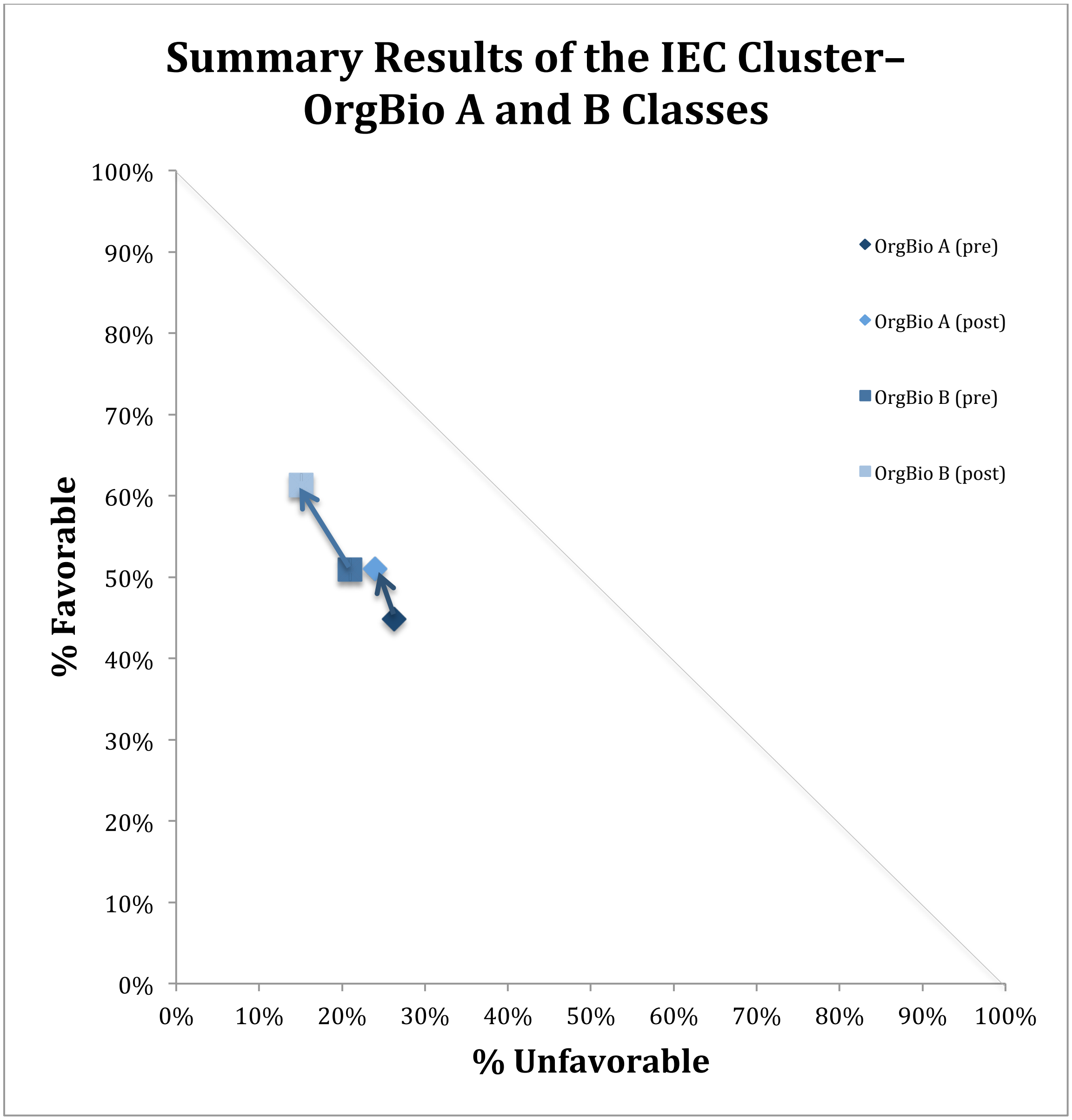


**Figure 14: Summary results of the IEC Cluster — groups OrgBio A and B only**

Table 10 and figure 12 present the summary results from the IEC cluster of the MBEX II. Figure 14 presents the results for the groups OrgBio A and B only. The whole IEC initial results in sections OrgBio A and B are not quite equivalent (~1%) beyond our statistical significance. While the two populations are nearly identical in terms of student demographics, the instructors in OrgBio B employed explicit pedagogical techniques to encourage students to think in terms of interdisciplinary integration. Since the MBEX II survey was always given during the first two weeks of the semesters, it is very likely the slightly elevated pre-scores observed in OrgBio B may be due to instructor effects[14]. In the pretest of the two classes surveyed, students gave favorable responses on 45-51% of the items and unfavorable responses on 21-26% of them. Since these two populations draw from identical populations of students, this implies that the populations in these classes are still the same. As a result, I will be treating them as equivalent on these measures despite the slight discrepancy on the pretest measures.

### *c) The initial state of the OrgBio C-1 and OrgBio C-2 classes are equivalent*

---

[14] The instructors in this class mentioned explicitly and early the importance of physics and math

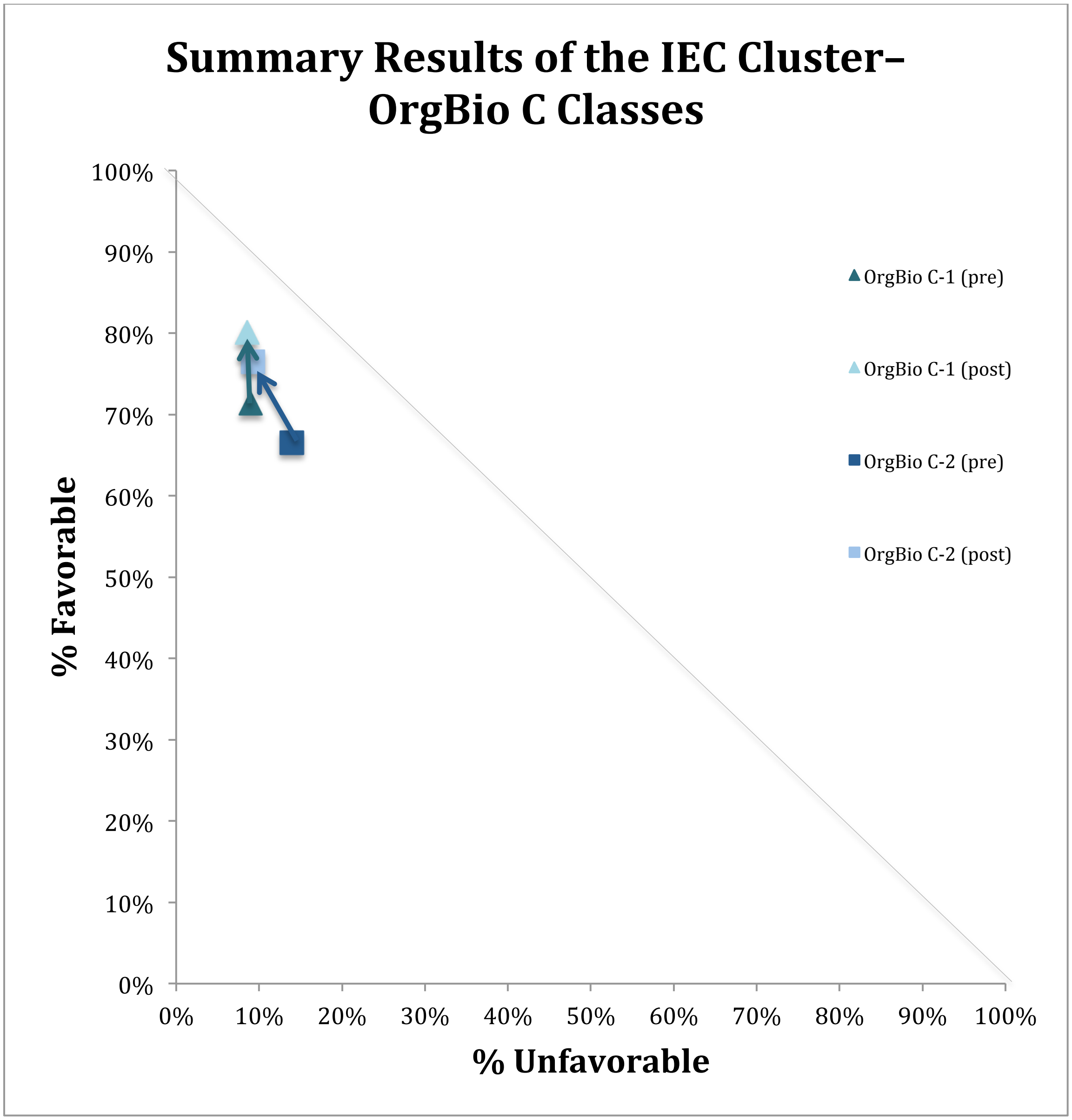


**Figure 15: Summary results of the IEC Cluster — groups OrgBio C-1 and C-2 only**

Table 10 and figure 12 present the summary results from the IEC cluster of the MBEX II. Figure 15 presents the results for the groups OrgBio C-1 and C-2 only. The whole IEC initial results in sections OrgBio C-1 and C-2 are equivalent to within our statistical significance. In the pretest of our two classes surveyed, students gave favorable responses on 67-71% of the items and unfavorable responses on 9-14% of the items. This implies that the populations in these classes may be treated as equivalent on these measures. OrgBio C scored above our statistical significance for the non-honors classes (OrgBio A and B) and below the statistical significance for our expert cohorts. This implies that the honors cohorts have incoming ideas on the IEC cluster that fall somewhere in-between novice and expert. Redish and Bing have referred to this particular pattern of student expectations as "Journeymen"–not quite expert, yet not still novices (Bing, 2008).

### *d) The initial state of the Phys 121 and Phys 122 classes are not equivalent: Students in Phys 122 reported lower incoming expectations than students in Phys 121*

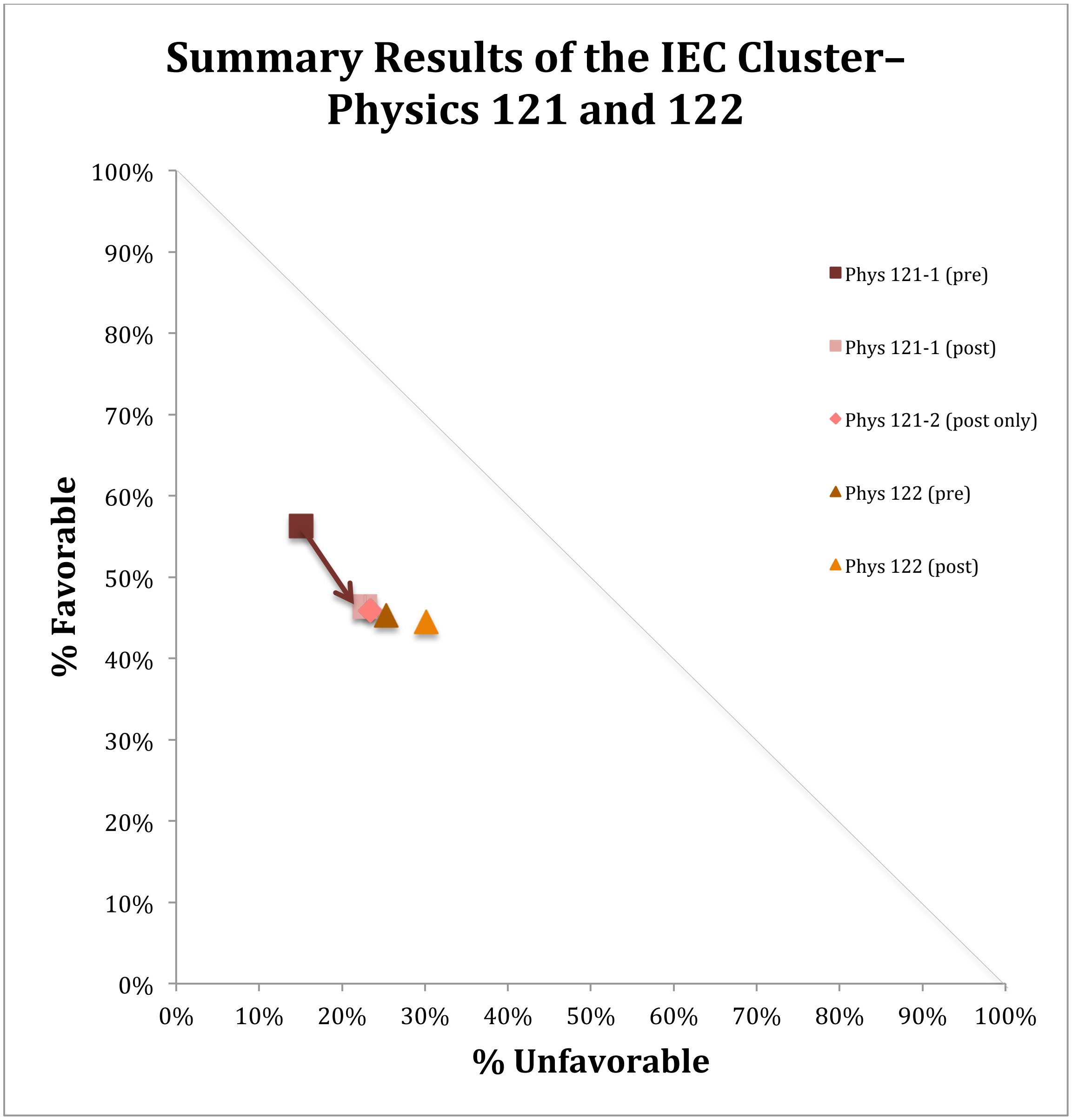


Figure 16: Summary results of the IEC Cluster — Physics 121-122 classes only

Table 10 and figure 12 present the summary results from the IEC cluster of the MBEX II. Figure 16 presents the results for the Physics 121 and 122 classes. We found the differences of the students' responses from these two courses to be statistically significant. This result makes even more sense when you compare the posttest scores of Phys 121 to the pre scores of Phys 122 shown on table 10. In this way, the initial expectations we saw in Phys 122 represented a continuation of the final expectations from the Phys 121 course, indicating that students' attitudes about the value of incorporating concepts from physics, mathematics, and chemistry deteriorated over the course of one semester of Phys 121 and those deteriorations persisted into Phys 122.

#### *e) All biology courses saw gains in overall student classroom expectations*

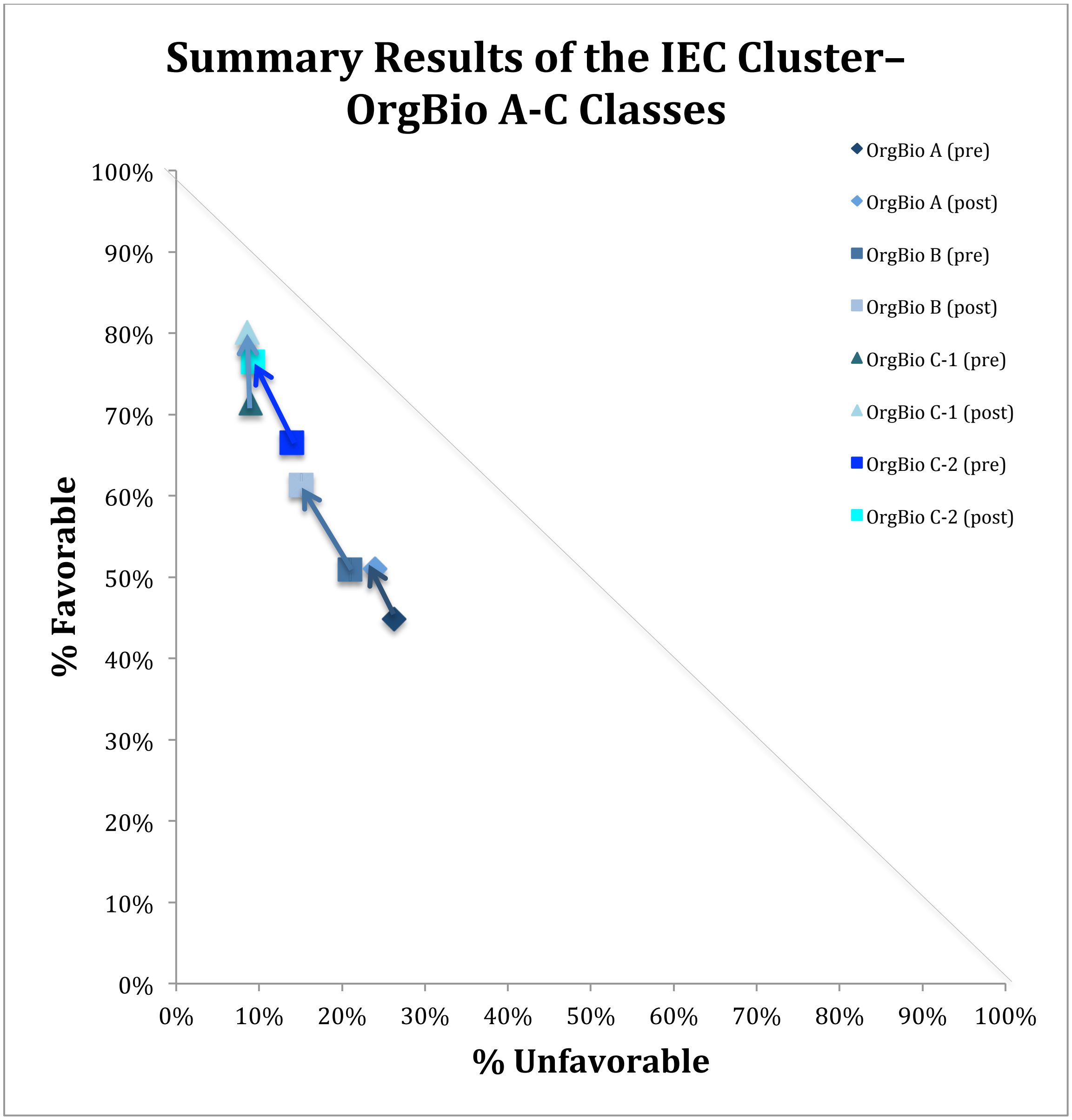


**Figure 17: Summary results of the IEC Cluster — OrgBio A-C classes only**

Table 10 and figure 12 present the summary posttest results from the IEC cluster of the MBEX II. Figure 17 presents the results for the OrgBio classes A-C only. All biology courses saw statistically significant improvements. I observed an increase in favorable responses and a decrease in unfavorable responses: OrgBio A (6%/-2%), OrgBio B (10%/-6%), OrgBio C-1 (9%/0), OrgBio C-2 (10%/-5%). Thus, biology instruction produced an average improvement in favorable student responses and a decrease in unfavorable student responses; however, the gains observed were slightly higher in courses using reformed pedagogical approaches.

From this analysis, I surmise that restructuring the curricular content did help biology student see the value of incorporating math, physics, and/or chemistry into a biology class, but not as much as when those reforms were coupled with pedagogical reforms.

#### *f) All physics courses saw deterioration in overall student classroom expectations*

Table 10 and figure 12 present the summary results from the IEC cluster of the MBEX II. Figure 16 presents the results for the Physics 121 and 122 classes. In all cases of physics instruction, the result on the IEC cluster of the MBEX II survey was the exact opposite of what we observed in the biology classes. All physics courses saw deteriorations across the cluster: Phys 121-1 (-10%/8%), Phys 121-2 (no comparison data), Phys 122 (-1%/5%). Thus, the first semester of physics instruction produced an average deterioration (rather than an improvement) in favorable student expectations and an increase in unfavorable student expectations. The second semester of physics instruction did not result in further decline; however, it also did not facilitate improvement.

From this analysis, I conjecture that the physics lectures we surveyed did not provide enough scaffolding to improve students' ideas about interdisciplinary education. This makes sense given that neither of these courses was specifically designed to help biology students make connections between the physics they were learning and their prior biology knowledge. This is unfortunate since the data indicates that the biology students may not be making these connections spontaneously. In order to understand how the students' expectations changed over the courses of the semester, we examined the student responses for the specific disciplinary sub-clusters IEC (discussed below).

### *2. IEC sub-cluster results*

#### *a) The Biology courses we surveyed were more successful than the physics courses we surveyed at demonstrating the value of using physics to evaluate or explain biological phenomenon — Results for the physics sub-cluster of the IEC.*

##### *(1) Results for the biology classes (physics sub-cluster only)*

## Table 11: The physics sub-cluster of the IEC

| | | Physics Sub-cluster | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Class | | **Pre** | | | **Post** | | | **% Change** | | |
| | Question | Fav | Neu | Unfav | Fav | Neu | Unfav | Fav | Neu | Unfav |
| BF | Total | 75% | 18% | 7% | | | | | | |
| BE | Total | 76% | 8% | 16% | | | | | | |
| | **AVG** | 76% | 13% | 12% | | | | | | |
| | **ST DEV** | 0.01 | 0.07 | 0.06 | | | | | | |
| OrgBio A | Total | 34% | 36% | 29% | 45% | 31% | 24% | 11% | -6% | -5% |
| OrgBio B | Total | 43% | 36% | 21% | 61% | 25% | 14% | 18% | -11% | -6% |
| | **AVG** | 39% | 36% | 25% | 53% | 28% | 19% | 15% | -9% | -6% |
| | **ST DEV** | 0.06 | 0.00 | 0.06 | 0.11 | 0.04 | 0.07 | 0.05 | 0.04 | 0.01 |
| OrgBio C-1 | Total | 69% | 24% | 8% | 81% | 9% | 11% | 12% | -15% | 3% |
| OrgBio C-2 | Total | 61% | 25% | 14% | 74% | 18% | 8% | 13% | -7% | -6% |
| | **AVG** | 65% | 24% | 11% | 77% | 13% | 9% | 13% | -11% | -2% |
| | **ST DEV** | 0.05 | 0.00 | 0.05 | 0.05 | 0.06 | 0.02 | 0.01 | 0.06 | 0.07 |
| PHY 121-1 | Total | 55% | 32% | 13% | 44% | 32% | 24% | -11% | 0% | 11% |
| PHYS 121-2 | Total | | | | 45% | 32% | 24% | | | |
| PHYS 122 | Total | 40% | 29% | 30% | 38% | 27% | 35% | -2% | -3% | 4% |
| | **AVG** | 48% | 31% | 22% | 41% | 29% | 29% | -7% | -1% | 8% |
| | **ST DEV** | 0.11 | 0.02 | 0.13 | 0.04 | 0.04 | 0.08 | 0.07 | 0.02 | 0.05 |

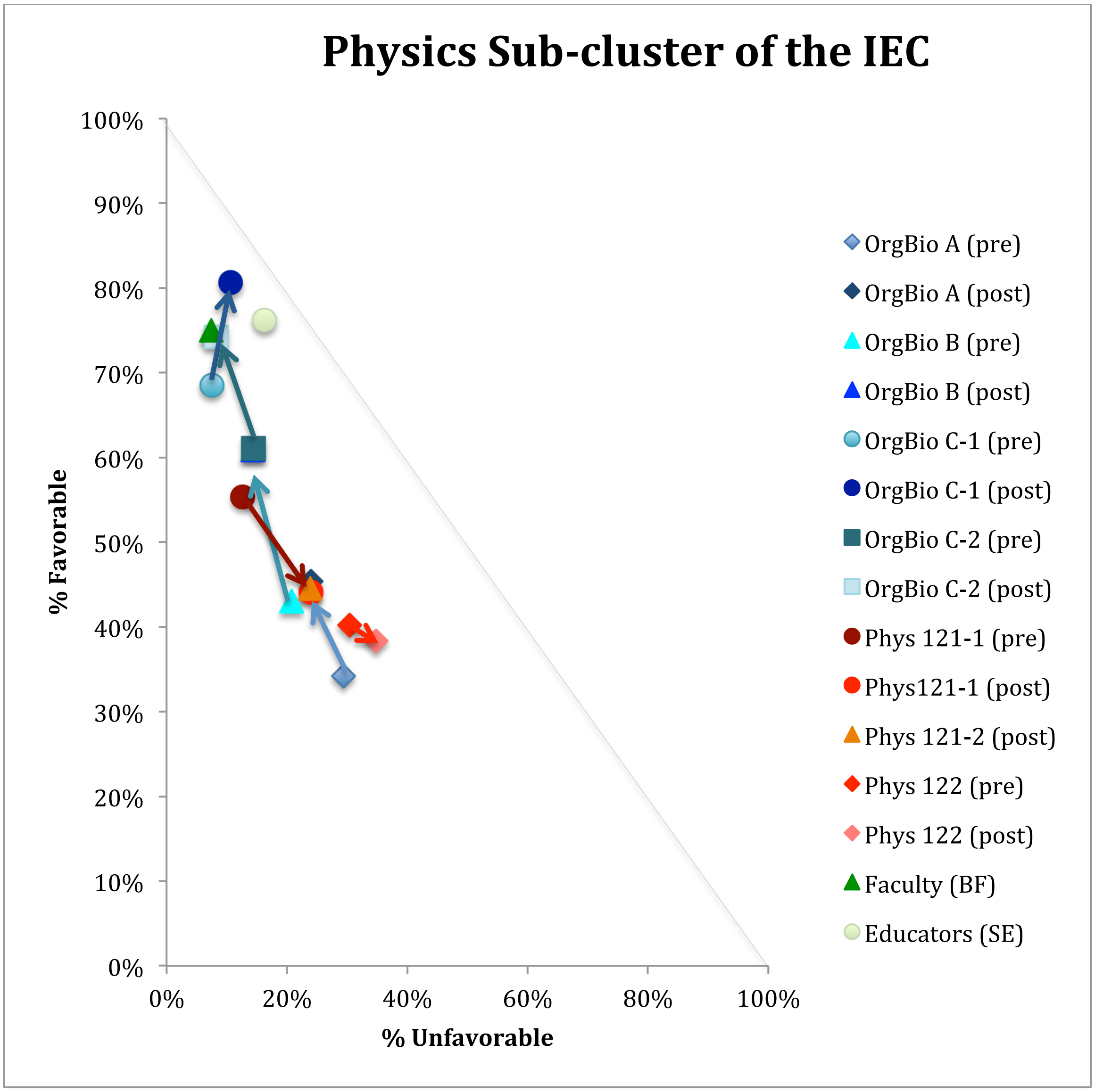


**Figure 18: The physics sub-cluster of the IEC — all classes**

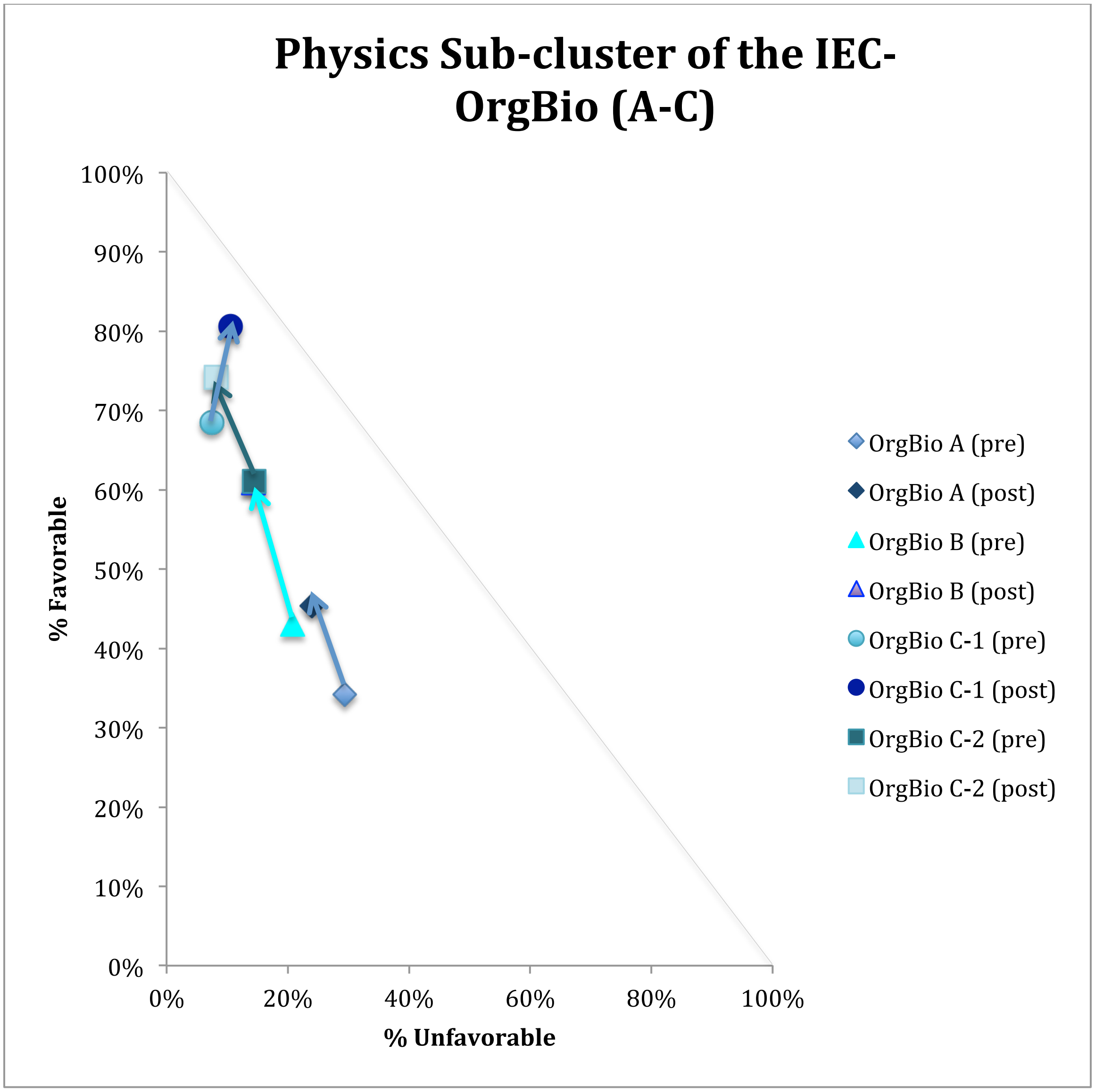


**Figure 19: The physics sub-cluster of the IEC — OrgBio A-C classes only**

Table 11 and figure 18 present the summary results from the physics sub-cluster of the IEC in the MBEX II. Figure 19 presents the results for the biology classes only (OrgBio A-C). I observed an increase in favorable responses and a decrease in unfavorable responses in classes of OrgBio A, B and C 1-2: OrgBio A (11%/-5%), OrgBio B (18%/-6%), OrgBio C-1 (12%/3%), OrgBio C-2 (13%/-6%). Thus, biology instruction produced a very large improvement in the expectations about using physics in biology courses.

A closer analysis of the physics sub-cluster of the IEC revealed that the unexpected gains appear to be due to two related factors. Non-honors sections of biology students reported very low (average 39% favorable) incoming expectations about the utility/value of using physics in biology. After one semester of instruction, all groups saw large gains across this sub-cluster. One hypothesis for the shift was that many students initially reported low physics scores because many had not yet taken physics in college (or possibly even high school). It was logical then that the low pretest scores might have been due to the students' lack of experience with physics. My interviews and the students' comments on this survey support this hypothesis. For example, 40 students[15] in one semester responded to question #13: "Ideas I learned in physics are rarely useful in biology." Of the 40 students who wrote comments to this question, 17 of the respondents stated that they had never taken a physics course before, and 8 of the respondents explicitly stated that they had never before seen any obvious connections between physics and biology in any of their classes. Only 6 of the respondents reported that had any previous experience with physics (including high school). Three students responded with positive comments on this question, and the rest were neutral. From these

---

[15] Data taken from the MBEX spring 2013.

statements, it makes sense that any explicit activities that help to define what physics is or how physics might be useful to biology should produce improvements in this domain. All three sections of OrgBio included topics such as muscle movements, diffusion, and kinetics. The inclusion of those topics may have helped students better identify, think about, and reason with physical concepts.

From this analysis, I infer that, in this instance, restructuring the curricular content did help biology student see the value of incorporating physics into a biology class.

#### *(2) Results for the Physics classes (physics sub-cluster only)*

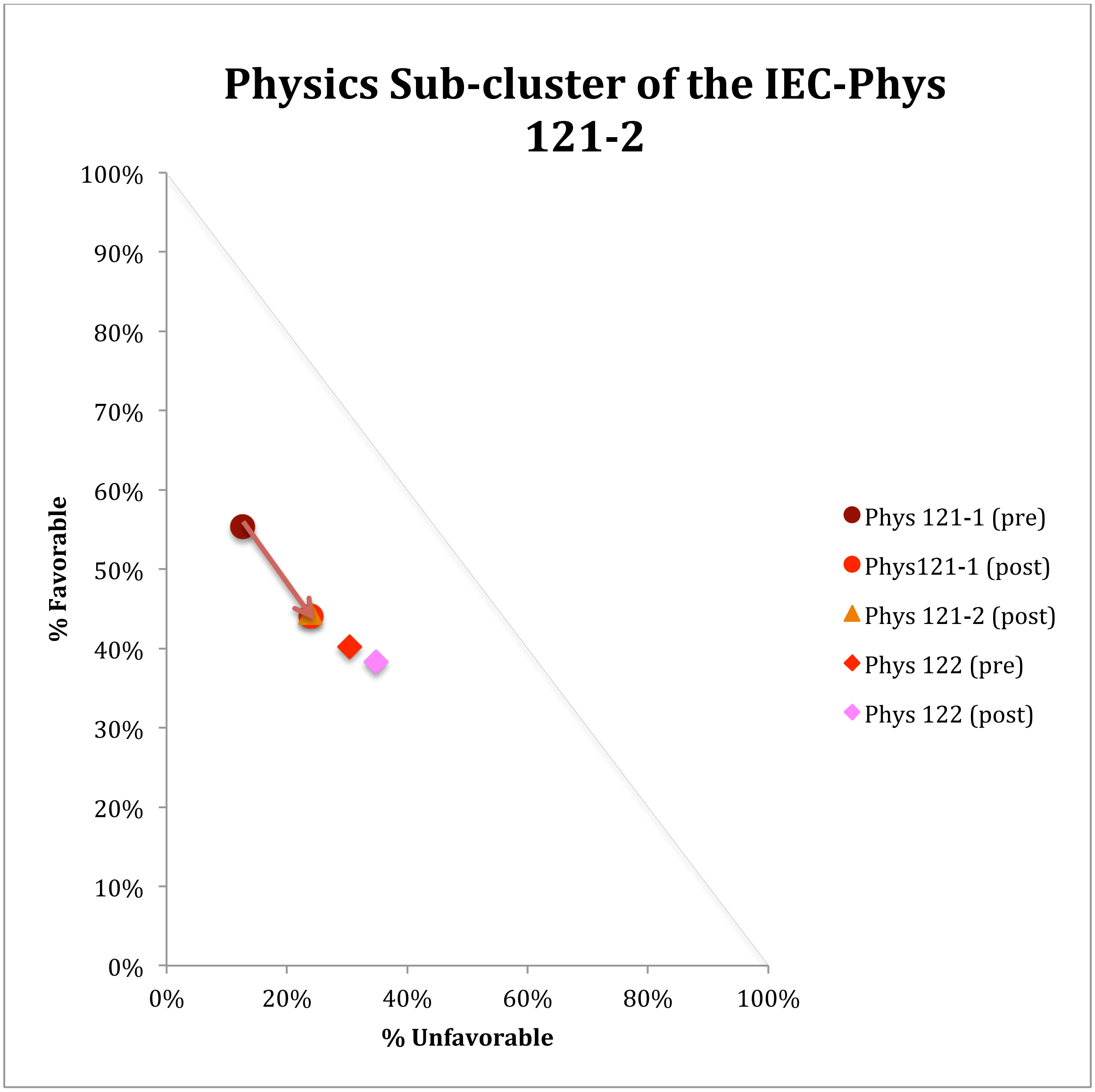


**Figure 20: The physics sub-cluster of the IEC — Physics 121-122 classes only**

Table 11 and figure 18 present the summary results from the physics sub-cluster of the IEC in the MBEX II. Figure 20 presents the results for the Physics 121-122 classes only.

In this sub-cluster, the pretest scores of the physics 121 classes were significantly higher than those reported in OrgBio A-B. This result could be due to a number or factors. First, it is reasonable to assume that the students taking Physics 121 are older (mostly juniors) than those taking OrgBio A or B (mostly freshman and sophomores), have had experiences with upper division courses or working in laboratories, and have taken OrgBio in previous semesters. That said, in contrast to the gains that I observed in biology, all physics courses reported declines in this cluster: Phys 121-1 (-11%/11%), Phys 121-2 (no comparison data), Phys 122 (-2%/4%). In addition, physics students still scored lower on the physics subscales than the math subscales, potentially indicating that they believed physics to be less helpful (or relevant) than math in understanding biology concepts. However, unlike results found in the biology courses, it appeared that one semester of physics did little to change that view.

A survey of one semester of student comments[16] from question #20, “Ideas I learned in biology are rarely useful in physics[17],” indicated that students had mixed views about this question. Of the of the 12 students who responded in the posttest — four responded negatively (e.g. “Biology does not help [me] in physics”), three responded positively (e.g. “all the disciplines were related”), two responded neutrally (e.g. “certain biology (like anatomy) might be helpful”), and three students responded that they were not biology majors and were unsure. This analysis suggests that many students see that

---

[16] Data taken from the MPEX fall 2012.

[17] This is the same as question #13 stated above, only the words “biology” and “physics” have been reversed.

scientific ideas could be related, at least in certain contexts. One student reported, “biology is hard to use in physics when it is not in biological settings.” It seems introductory physics classes we surveyed could do more to reinforce the messages being fostered in OrgBio and help biology students apply the information they already know from their biology classes to physics concepts and vice versa. This is especially important given the national emphasis on helping all biology students apply more meaningful mathematics, chemistry, and physics in all of their biology classes (AAMC-HHMI committee & AAAS, 2011; AAMC-HHMI committee, 2009).

From this analysis, I surmise that even some more experienced biology students might have prior experiences using physics, while other students remain confused about what it means “to do” physics as biology students, but both groups appear to question the relevance of physics to their understanding of biology. After one semester of physics instruction, the students we surveyed were even less sure of the connection between biology and physics. After two semesters, students’ views continue to decline as they continue to take physics.

### *b) The Biology courses we surveyed were more successful than the physics courses we surveyed at demonstrating the value of incorporating mathematics to evaluate or explain biological phenomena — Results for the math sub-cluster of the IEC.*

#### *(1) Results for the Biology classes (math sub-cluster only)*

## Table 12: The math sub-cluster of the IEC

| | | Math Sub-cluster | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Class | | **Pre** | | | **Post** | | | **% Change** | | |
| | | Fav | Neu | Unfav | Fav | Neu | Unfav | Fav | Neu | Unfav |
| BF | Total | 87% | 10% | 3% | | | | | | |
| BE | Total | 85% | 3% | 13% | | | | | | |
| | **AVG** | 86% | 6% | 8% | | | | | | |
| | **ST DEV** | 0.02 | 0.05 | 0.07 | | | | | | |
| OrgBio A | Total | 48% | 24% | 28% | 49% | 22% | 29% | 1% | -3% | 1% |
| OrgBio B | Total | 52% | 22% | 26% | 56% | 25% | 19% | 4% | 3% | -8% |
| | **AVG** | 50% | 23% | 27% | 53% | 23% | 24% | 3% | 0% | -3% |
| | **ST DEV** | 0.03 | 0.02 | 0.01 | 0.05 | 0.03 | 0.07 | 0.02 | 0.04 | 0.06 |
| OrgBio C-1 | Total | 68% | 18% | 13% | 75% | 17% | 8% | 7% | -1% | -6% |
| OrgBio C-2 | Total | 67% | 17% | 16% | 74% | 13% | 13% | 7% | -4% | -3% |
| | **AVG** | 68% | 18% | 15% | 75% | 15% | 10% | 7% | -3% | -4% |
| | **ST DEV** | 0.01 | 0.01 | 0.02 | 0.01 | 0.03 | 0.04 | 0.00 | 0.02 | 0.02 |
| Phys 121-1 | Total | 58% | 23% | 19% | 50% | 29% | 21% | -8% | 6% | 2% |
| Phys 121-2 | Total | | | | 46% | 31% | 23% | | | |
| Phys 122 | Total | 53% | 29% | 18% | 54% | 23% | 23% | 1% | -6% | 5% |
| | **AVG** | 55% | 26% | 18% | 52% | 26% | 22% | -4% | 0% | 4% |
| | **ST DEV** | 0.03 | 0.04 | 0.01 | 0.03 | 0.04 | 0.02 | 0.06 | 0.09 | 0.02 |

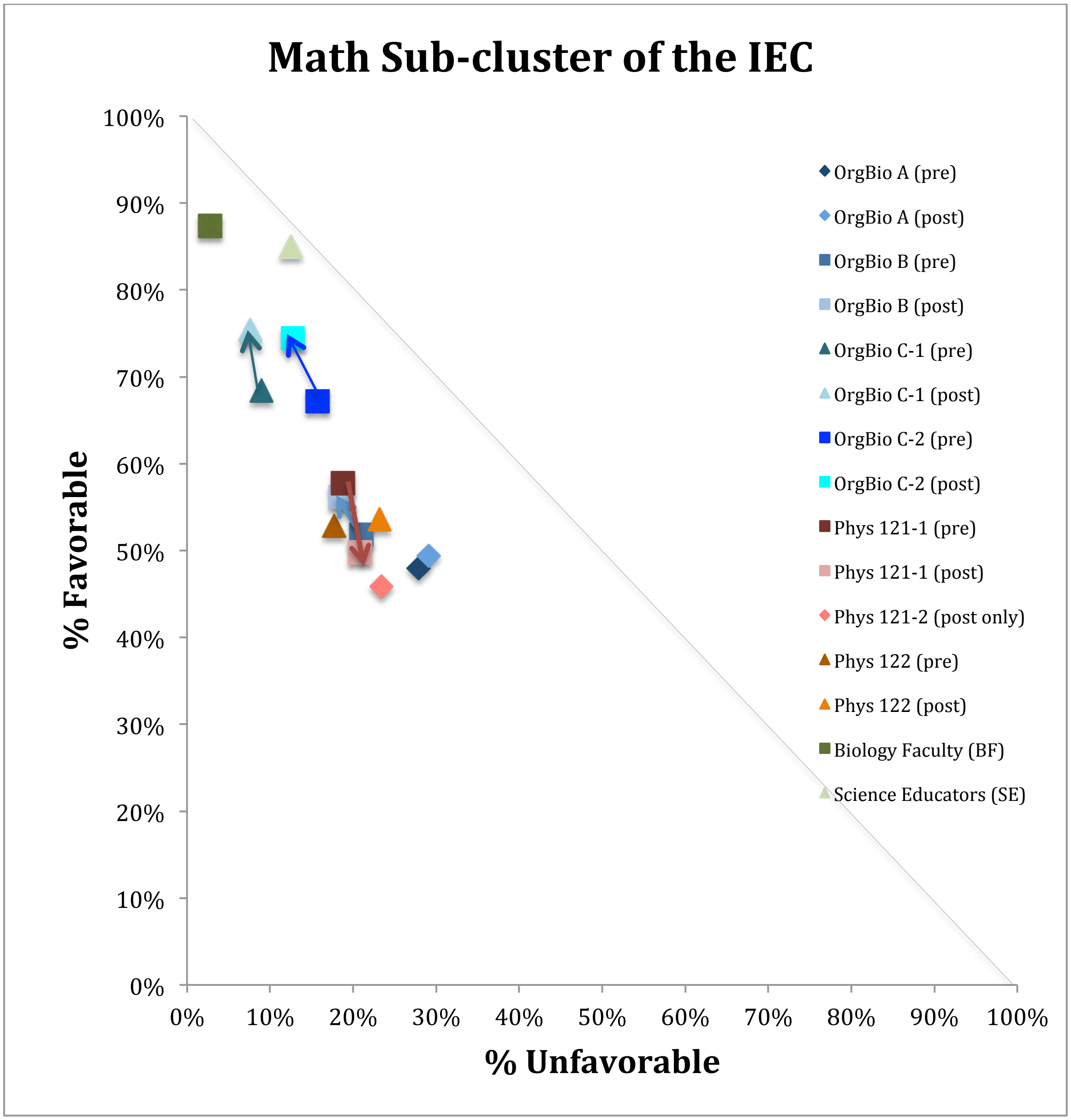


**Figure 21: The math sub-cluster of the IEC — all classes**

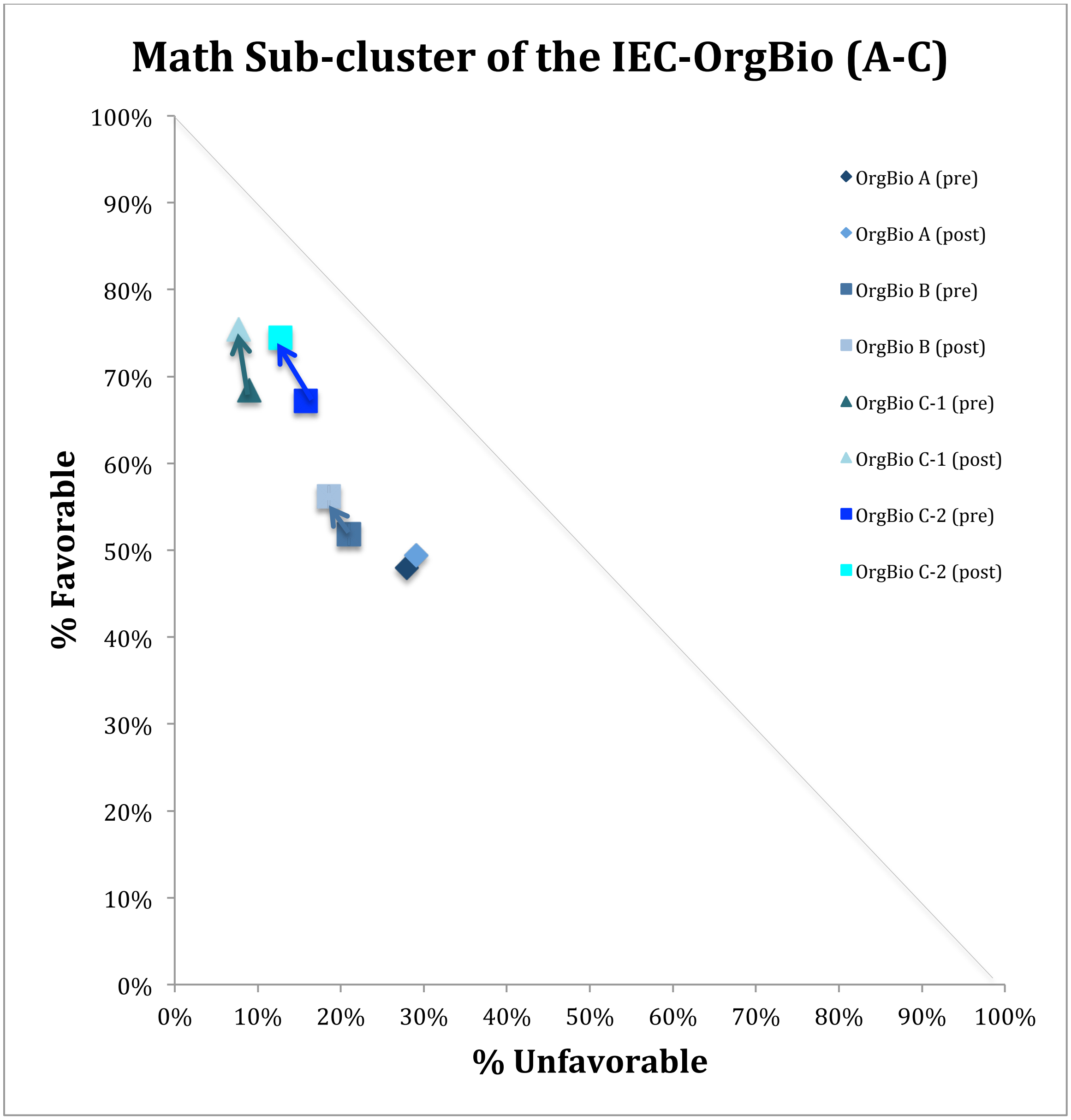


**Figure 22: The math sub-cluster of the IEC — OrgBio A-C classes only**

Table 12 and figure 21 present the summary results from the math sub-cluster of the IEC in the MBEX II. Figure 22 presents the results for OrgBio A-C only. Students in the reformed courses (OrgBio B and C) report moderate gains across the cluster while the traditional (lecture) section, OrgBio A reported no significant change: OrgBio A (1%/1%), OrgBio B (4%/-8%), OrgBio C-1 (7%/-6%), OrgBio C-2 (7%/-3%). In the pretest, all three biology student cohorts reported significantly higher initially expectations compared to the physics sub-cluster (average 50% favorable). Once again, the student comments provide insights to explain why the students appear to have specific ideas about the utility of math in understanding concepts in biology. In one semester, twenty students in the pretest[18] commented on question #17: "Ideas I learned in math are rarely useful in biology[19]." Only one student reported that they did not see any connection between math skills and biology. Most students (9) stated that math or at least "basic math" could be useful or necessary to be successful at biology. A smaller number of students (7) claimed that math was generally helpful, or very helpful, for understanding biology, and three students were neutral. Not only does it appear that students have a better initial understanding of what mathematics is, some (4) also gave specific examples (population genetics, statistics) of how they expected mathematics to relate to biology.

### *(2) Results for the Physics classes (math sub-cluster only)*

---

[18] Data taken from the MBEX spring 2013

[19] This is the same as question #13 stated above, with the word "math" substituted for the words "physics."

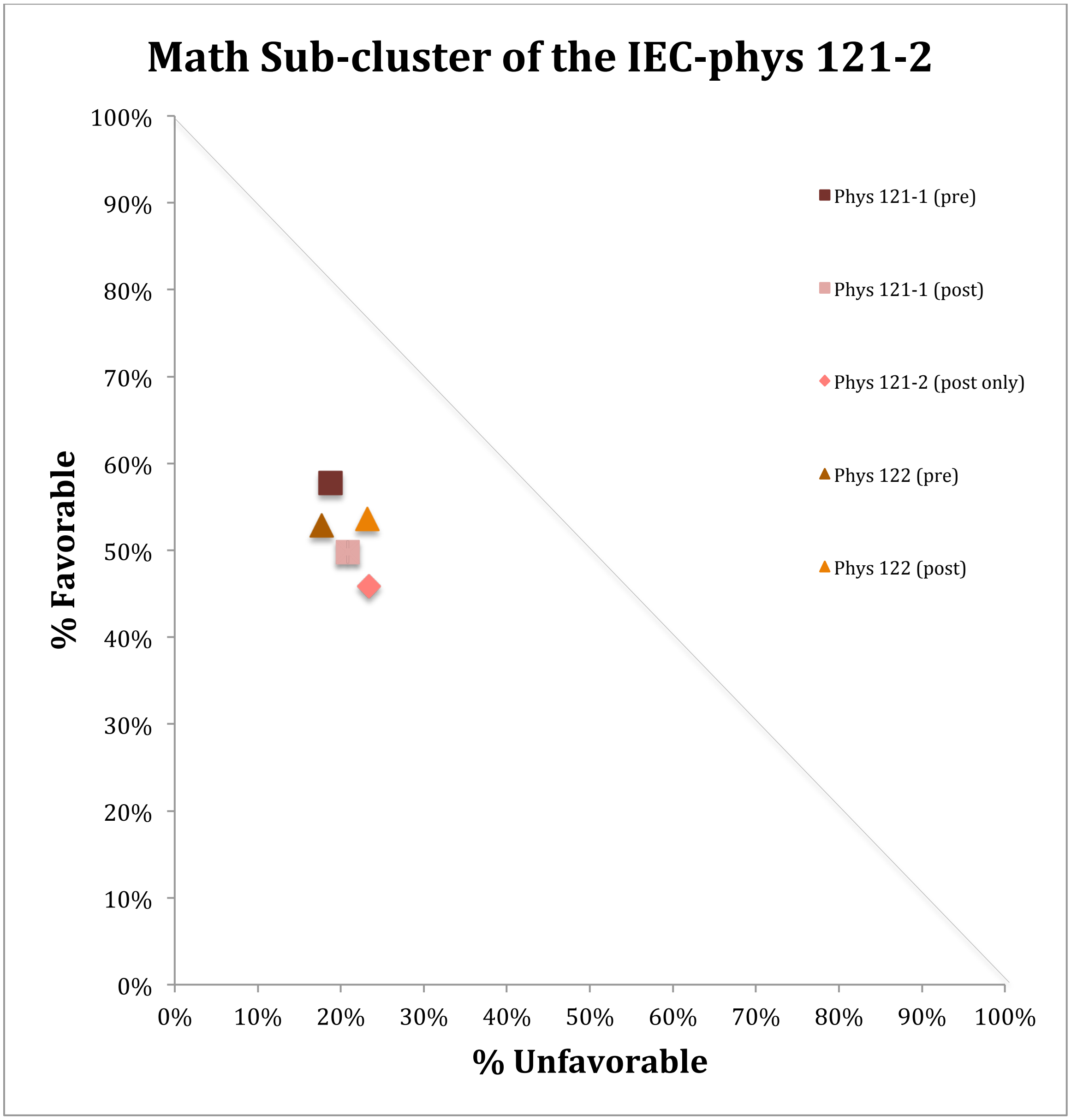


**Figure 23: The math sub-cluster of the IEC — Physics 121 and 122 classes only**

Table 12 and figure 21 present the summary results from the math sub-cluster of the IEC in the MBEX II. Figure 23 presents the results for physics 121 and 122. Students in all sections of the introductory physics courses reported declines in this cluster: Phys 121-1 (-8%/2), Phys 121-2 (no comparison), Phys 122 (1%/5%). It appears that students began with the expectation that mathematics might be helpful for biology; yet one semester of instruction did not appear to improve this perspective. In fact, students' expectations appear to decline over the course of a semester. While Phys 121 and 122 are not specifically math courses, most people can logically see the connection between equation use, physics, and mathematics. I surmise that the type of equations and mathematics that students use to solve introductory physics problems does little to help them make connections in their biology classes.

The students' comments on the survey posttest support this hypothesis. For example, 13 students[20] responded to question #17: "Ideas I learned in math are rarely useful in biology." Of the 13 students who wrote comments to this question, four of our respondents stated that they "hardly ever find a connection" between math and biology and two of our respondents saw only a limited connection and that relevance depended on "which types math" students were asked to use. In contrast, three students commented that they saw obvious connections between math and biology. For these students, the most common connection was still highly generalized and replied with comments such as, "all subjects tie together" or "all are related." Finally, one student responded that there must be a connection because calculus is a medical school requirement and two students were unsure. From these statements, it appears that while Phys 121 and 122 might have

---

[20] This Data was taken from the MPEX fall 2012.

changed the course content and pedagogy to better suit the incoming abilities of biology students, the courses could be doing more to help students see the relevance of physics and math to their biology knowledge and help them make meaningful connections between the disciplines.

### I. Statistical Significance

In this chapter, my research questions involve comparisons of groups—students at the beginning and end of one semester of either undergraduate biology or physics. In order to compare these groups, I am comparing their averaged responses (agree versus neutral versus disagree). In order for us to understand whether two responses are significantly different, we have to have some model of the random variable in our sample. My interviews, intuitions, and many discussions in the cognitive literature suggest that an expectation is a highly complex object. As noted above, some students gave clear evidence in interviews of being in two, seemingly, contradictory states at the same time. What this implies is that the random variable we should be averaging is itself a probability, rather than a set of well-defined values. Since detailed models of student learning do not yet exist, I estimate significances by using a simpler Bayesian model (For a more detail review, see the discussion of statistical significance described in chapter 3). In keeping with this model, I assert that shifts of 5% on the clusters or sub-clusters are statistically significant for populations of this size.

## J. Chapter 4 Summary

### *1. Students report initial mixed or ambivalent ideas regarding interdisciplinary approaches in their sciences classes*

Our initial analysis of the IEC indicated that introductory students from both biology and physics courses reported mixed views about the value of incorporating interdisciplinary content into their respective courses. By mixed, I mean that students favorably answered roughly 50% of the time. Students from both groups raised similar issues, including the lack of prior experience with physics and the need for only basic math skills when studying biology. From the pretest, I assume that most high school or traditional introductory science courses do not explicitly help students build connections between the shared ideas and concepts among the disciplines. While the deficits of the traditional pedagogies have already been documented in the biology reform literature, this data shows that the way we teach even pedagogically reformed classrooms can differentially impact how students perceive the future value of interdisciplinary course content. Students are coming into their biology classes not expecting to have to use ideas from their other science courses; therefore, any reforms aimed at incorporating interdisciplinary content must first address these assumptions.

### *2. Students appear to have distinct, discipline-specific expectations about the utility of incorporating concepts from other disciplines into undergraduate courses*

From an analysis of the two sub-clusters, it appears that the biology students had lower overall pretest scores than the physics students, which can be explained by the age and experience advantage of the physics students. However, both biology and physics cohorts reported mathematics to be more valuable than physics in understanding biology. The continued discrepancy between math and physics in both student cohorts could be explained in a number of ways. For the OrgBio students, their low physics scores relative to the math scores could have been due to their limited prior exposure to physics. Few of the OrgBio students reported any prior conceptions of what it means to do physics at all, and even less provided evidence of how physics could be used to understand biology. The physics students may have had more exposure to physics concepts through upper division courses or laboratory experiences, but that exposure may not have emphasized the connections between physics and biology.

In contrast to their views on physics, most of the students (from both OrgBio and Phys 121-2) who commented on the survey could provide at least one or two examples (statistics, genetics, etc.) of when mathematics could be useful to learning biology. The difference in level of exposure between the two disciplines appeared to affect the specific sub-clusters scores in the MBEX II. In order for interdisciplinary reforms to be most effective, biology students must first understand what types of math or physics are useful in a biological context and what ideas and concepts from these disciplines can be used to understand biological phenomenon.

### *3. Students responded better to our interdisciplinary survey questions measures when those concepts were explicitly forgrounded in the classroom*

In both sub-clusters of the IEC, students in the biology courses responded more favorably in the posttest than the students taking the survey in physics. Even though both OrgBio B-C and Phys 121-122 had similar student populations (mostly life science majors) and employed similar pedagogical strategies, such as clickers and in-class problem solving, the MBEX results suggests that those strategies only led to significant epistemological gains in the reformed biology classes. While the specific reasons for these discrepancies appear to differ slightly for each sub-cluster, the overall results are the same. At this time, I do not have the evidence to make claims about the mechanisms, such as instructor implementation strategies, which led to these inconsistencies, but this finding is worthy of further investigation.

While both the biology and physics courses were reformed to meet the needs of life science majors, only the biology courses we surveyed specifically attempted to foster interdisciplinary appreciation as one of those needs. It is important to show that while the epistemological gains from the OrgBio classes appeared to carry (in the form of pretest scores) into the physics classes, they then declined. If we do indeed value the idea that concepts and approaches are shared among the disciplines, and we want students to be able to take up those ideas and make sense of them in the classroom, this data indicates that we should also be sending those messages explicitly in all science courses.

### *4. Some disciplinary experts reported ideas that contradicted biology reform efforts*

While the expert groups reported a high level of agreement with our *a priori* clustering of the MBEX II, there was still some significant level (~20%) of disagreement. Interestingly, we found the experts disagreed with some statements that were explicitly derived from the language used by the national reform reports, such and *Vision and Change* and *Scientific Foundations for Future Physicians* (AAAS, 2011; AAMC-HHMI committee, 2009). Since the disagreements occurred in items that were derived from statements made in national reform documents, I chose to retain them in the survey.

### *a) Biology Faculty (BF) responses*

Introductory biology teaching faculty reported an interesting pattern of responses. For most of the questions, they agreed very strongly as to what were the responses they would like to hear from their students. For most of these questions, 80%-100%, this group agreed with our expert position. However, items 2, 5, and 20 had a greater plurality of agreement. From the faculty responses, MBEX items 5 is particularly interesting:

> Q#5: It is beneficial to me, as a biologist, to also be proficient in physics.
>
> 67% -favorable
>
> 27%-Neutral
>
> 6%-unfavorable

This statement was explicitly derived from the goals and objectives described in several recent education reform mandates and directly correlates to two "Core Concepts" for biology literacy presented in *Visions and Change*. Question 5 illustrates an understanding of the increasing need for interdisciplinary integration within the natural sciences. The mixed response rate and high percentage of neutral faculty responses are interesting (and illuminating) because this indicates that biology faculty is conflicted or ambivalent about this statement.

The faculty comments on the question also support this hypothesis. Of the 17 faculty members who took the survey, five submitted comments to question 5. Here are their responses:

> "[Physics is not relevant], not in the classes I teach."–
>
> (Virology professor)

> “As biologist, we need to understand two things — the central dogma and evolution. The rest is just dressing.”— (Genetics professor),
>
> “This depends on if this is an intro or upper level course.”— (Genetics professor)
>
> “Some physics is necessary to understand biology. When it is relevant to a biological concept, I teach it just as I would chemistry.”— (Entomology professor)
>
> “Modeling biology with mathematics often misleads researchers. For tractability, models require well-behaved parameter spaces. Rarely true in biology. I prefer that students NOT think modeling solves actual biology problems.”— (Biology professor)

From these statements, it appears that some of biology faculty I surveyed are not very enthusiastic about using physics to explain biological phenomenon. At best, physics is relevant in isolated cases in upper division courses; at worst, physics is viewed as detrimental to student learning. It seems that faculty will have to be convinced that these reforms are necessary before faculty will be willing to embrace interdisciplinary course reforms.

#### *b) Science Educator (SE) responses*

The university science educators also reported a very high level of agreement, both with each other and with the introductory biology faculty. Like the teaching faculty, for most of the questions, they agreed very strongly with a particular position (80%-100% favorable agreement). However, item 20 had a large plurality of agreement. Overall, the science educators had a very similar pattern of scores to the teaching faculty but had fewer neutral responses overall. Here, MBEX item 20 is worthy of an explicit discussion:

> Q#20. Ideas I learned in biology are rarely useful in physics.
>
> 38%-favorable
>
> 24%-neutral
>
> 38%-unfavorable

This statement was also derived from the goals and objectives described in *Vision and Change*. Question 20 illustrates an understanding of the increasing need for interdisciplinary integration, specifically physics, within the natural sciences. The mixed response rate and unusually high percentage of neutral responses are interesting because it indicated that even science educators were conflicted about how useful biology concepts were to learning physics.

Of the 10 researchers we surveyed, five commented on this question. All five education researchers responded negatively to this question and all responded similarly. They stated, “Biology students are not likely to encounter ‘physics’” in their introductory courses; therefore, this appears to be an “unfair” question to ask introductory students. In essence, the researchers felt we were setting the students up for failure on this question. Fortunately, our actual survey data indicates that introductory biology students have more sophisticated views than the faculty and researchers gave them credit for!

# V. Chapter 5: The Effects of Student Expectations on Learning: A Case Study from Undergraduate Biology

## A. Introduction

The past 10-15 years have seen numerous calls for reforms in undergraduate biology education (Handelsman et al., 2006; Hulleman & Harackiewicz, 2009; NRC, 1996, 1997, 1998, 1999, 2000, 2003). Traditionally, most introductory biology classes are taught in large (100+) student lectures. Professors often lecture with the aid of a PowerPoint presentation and classes generally follow the structure and topics outlined by the course textbook. Due to the size and structure of the lectures, there is rarely opportunity for interaction and dialogue between the students or between the students and the professor. However, most professors will set aside office hours to provide students an opportunity to get further clarification on lecture topics. There may also be graduate student-led review or discussion sections set up for this same purpose. Often no homework is assigned during the semester; therefore, 2-5 exams comprise almost all performance assessment for these courses. Due to the high volume of students, it is also common for the exams to be multiple-choice, scantron-style exams.

Reform-minded policy makers and educators claim this type of biology curriculum is outdated and ineffective. They assert that a large lecture with little or no interaction between students or students and professors emphasize the wrong types of skills (mainly rote memory) and do not teach the communication, reasoning, and analytic skills students need in order to thrive in an increasingly science and technology-driven world (NRC 1983, 1996, 2003, 2009). They also stress that the way we currently teach biology has not kept pace with the radical advances made in experimental biology and urge instructors to start teaching students about the types of science we do today, and the science we will be doing tomorrow, instead of continuing to teach about the science we did fifty years ago (NRC, 1996, 1997, 1999, 2003, 2000, 2009).

Another theme common in the biology reform literature is that our present system often excludes many students from pursuing science and related fields (Tobias, 1990). Unsurprisingly, these reports recommend that the biological community rethink the way they teach in order to provide more effective preparation for future biologists and health-care professionals and to make science more accessible and relevant in the world today (Handelsman et al., 2006; Hulleman & Harackiewicz, 2009; NRC, 1996, 1997, 1999, 2003).

### B. The Current State of Biology Education Reform

Responding to both of these challenges, university biology faculty have developed undergraduate biology education reforms aimed at changing the content or pedagogical structure of the curriculum. The reforms' explicit purposes are to help students develop: (i) deeper levels of understanding, (ii) transferable knowledge, and (iii) effective scientific reasoning skills (Michael & Modell, 2003). A number of these goals can be achieved, at least for some students, through introducing active classroom learning activities and inquiry-based laboratories (Blumberg & Michael, 1992; Allen & Duch, 1998; Khodor et al., 2004; Rawson & Quinlan, 2002). Often, such efforts reduce lecture time in favor of more interactive formats. They also urge instructors to cover less material more deeply by incorporating collaborative exercises (Goodwin & Davis, 2005; Reingold, 2005; Steen, 2005). There is a growing body of data analyzing the effectiveness of these specific strategies on improving student conceptual difficulties and getting students to practice better critical thinking skills in the biological classroom. Simply knowing that active learning can "work" is an important first step to reform (Boyes & Stanisstreet, 1991; Garvin-Doxas et al., 2007; Klymkowsky & Garvin-Doxas, 2008; Michael, 2006; Walton & Rybarczyk, 2009; Walton, 2008).

Reforming traditional lectures by using student-centered pedagogical approaches has led to documented student learning gains in, for example, conceptual learning and argumentation skills (Blumberg & Michael, 1992; Blumenfeld et al., 1991; Ebert-May et al., 1997; Eisobu & Soyibo, 1995; Niaz et al., 2002; Springer et al., 1999). While both improved conceptual learning and improved argumentation skills are important goals of reform, they are not sufficient. Learning to think scientifically means learning to make sense of the knowledge one is learning in terms of a basic web of principles and concepts, and it means learning to reason in new situations flexibly and productively using those principles and concepts. A student's ability to realize this and to bring to bear appropriate cognitive assets they have for learning new knowledge depends significantly on their expectations — what they bring from their previous experience with similar situations and from their interpretation of cues in the current environment that tells them "what's going on" and what is appropriate behavior.

Research in psychology and physics learning has demonstrated that expectations can play a dramatic role in how individuals perceive the situations they find themselves in and what they pay attention to in those situations. In psychology, it has been shown that expectations can cause subjects to ignore important cues in potentially life-threatening events. For example, pilots in a flight simulator ignored a plane parked in their path on a runway in order to read data projected on the windscreen (Most et al., 2005). In aviation, pilots often have to rely on their instruments in situations where visibility is reduced or even impossible; however, in this case, the plane was clearly visible to the pilots. In this instance, the pilots had come to assume that the instruments were more accurate sources of visual information — even when there was no obvious visual obstructions. The logical assumption is that people do not ignore what they can see with their own eyes, yet it seems that the pilots did exactly that — to disastrous results! In physics, researchers found students will often fail to bring to bear knowledge and insights that they can be shown to possess as a result of their expectation "that isn't the kind of thinking that's useful here" (Lising & Elby, 2005).

Based on this type of research in other disciplines, coupled with my own experience in working with undergraduate biology students, I believe that student ideas about the nature of the knowledge they are learning and the ways that they think it is appropriate to go about learning it will strongly affect how students approach even pedagogically reformed biology courses (Bing & Redish, 2009; Bunce, Grove, & Bretz, 2007; Hall, Watkins, Coffey, Cooke, & Redish, 2011; Redish et al., 1998; Tannen, 1993).

By pedagogical reformed, I mean courses that have been specifically redesigned to a more student-centered perspective. In order to understand what barriers there are to teaching scientific reasoning and critical thinking skills in biology, we will need to understand something about student expectations. In this chapter, I use case-based examples of interviews with students to demonstrate how expectations can play a role in what students learn – and do not learn – in a reformed biology class.

### C. The Role of Expectations in the Student Epistemology Literature

It makes sense that students will try to understand their present learning experiences through their past ones. As a result, they will interpret much of what is going on through the “lens” of these experiences. This interpretation can either provide productive or unproductive ways to think about and approach learning, depending on the quality of their prior experiences with school and schooling.

For researchers, one of the challenges with trying to understand the connection between expectations, epistemologies, and behavior is that students come into the classroom with the potential to draw on a nearly endless supply of these prior experiences. For this reason, it may be difficult to understand exactly why a particular student interpreted a particular learning situation a certain way. Despite the potential difficulties, there is a growing body of research that investigates the link between college students’ epistemologies — their ideas about knowledge construction — and learning (Lising & Elby, 2005; Redish et al., 1998). The research is discipline specific, context-driven, and motivated by the central idea that student ideas about knowledge construction often affect their learning (Lising & Elby, 2005; Scherr & Hammer, 2009). These authors generally describe students’ ways of knowing by using one or more of the following terms — attitudes, expectations, beliefs, or epistemologies. In this chapter, my focus is to identify specific patterns of “expectations,” a term which I use to describe a broad grouping of ideas that students might have about biology and biology learning that reflects on their in-class practice and activities (Redish et al., 1998). I then describe how these expectations potentially influenced both students’ epistemologies and classroom behaviors.

Researchers have previously explored the influence of student expectations and epistemologies in many bodies of research such as physics, chemistry, sociology, psychology, and early and K-12 education (Adams, Wieman, Perkins, & Barbera, 2008; Bing & Redish, 2009; Grove & Bretz, 2007; Lising & Elby, 2005; Redish & Hammer, 2009). A growing number of educational psychologists and STEM education researchers make theoretical and empirical arguments that aspects of students' expectations can affect learning (Dweck, 2000; Hammer, 1989; Lising & Elby, 2005; Redish & Hammer, 2009). The current research literature in biology reform has also begun to identify student expectations and may impact learning in the biology classroom (Hall et al., 2011; Hall, 2010; Semsar et al., 2011; Walker & Cotner, 2008; Watkins et al., 2010)

I argue that to have those biology reforms be successful at the undergraduate level reformers must explore students' expectations as manifested in biology classes. In this chapter, I begin to make a case that a more in-depth understanding of students' expectations may help to explain the ways in which students encounter difficulties with reform and can help us to create more effective curricula the future.

For this chapter, I focus my analysis to a particular subset of student expectations which I refer to as classroom expectations: what students expect to be the nature of the knowledge that they are learning (epistemological expectation), what it is that they think they should be (or are) doing in order to learn that knowledge (learning expectation), and what it is that they think they should be (or are) doing in order to be successful in a particular course (performance expectation). This chapter explores the range of classroom expectations that emerged during in-depth interviews with students in an introductory biology class. These self-reflective statements in turn helped me to better understand the ways in which students attempted to succeed in the course. It also provided me with an analytic lens with which to frame my survey and *in situ* classroom data.

### D. Epistemological Expectations Versus Learning Expectations Versus Performance Expectations — students often report misalignments in their expectations

I initially examined my expectations survey and class evaluation data, and I found gains in several domains including: improved student engagement (verbal participation as reported by professors), improved student perception of the course experience overall (end of semester course evaluation), and an improved awareness of the principles-based nature of biological knowledge (MBEX survey). These data were very promising, given the abundant literature on the efficacy of implementing student-centered pedagogy in the biology classroom. However, I soon discovered that my interview and classroom data told a more nuanced story.

While I saw some general improvements in student responses to the course (survey and individual interviews), a more detailed review of all the data indicated that individual students participated in complex and variable ways. Closer analysis of the interview data and field notes suggests that students had complex, context-dependent, or even seemingly contradictory sets of expectations that were not adequately described by my survey and course evaluations alone. On one hand, many students reported highly sophisticated ideas about what it means to learn biology and the nature of biological knowledge. They described the complexity of living systems, the importance of understanding form and function relationships, and building connections between their own knowledge and the living world around them. Then, these same students reflected on the pressure they felt to perform in their biology classrooms (even in the reformed classrooms). That pressure often appeared to translate into less-than-ideal classroom behavior. For example, some students reported overall satisfaction with the course's new pedagogical format but resisted the classes' shift in focus to more principles and more reasoning with physics and math. In other cases, students made statements consistent with our understanding of a sophisticated view of the nature of biological knowledge (i.e. that science knowledge is tenuous and evolving, rather than a search for absolutes), but those views did not regularly correlate with more effective or "expert" learning strategies.

From these instances, and others like them, I inferred a possible lack of alignment between students' epistemological expectations — views about the nature of knowledge and knowing, their learning expectations — views about the nature of learning, and their performance expectations — views about what they think they should be doing in the classroom. This lack of alignment between expectations appeared to have direct implications for how students actually participated in our classrooms. Therefore, I wish to make a distinction between students' epistemological views or expectations about the nature of knowledge and knowing (and perhaps learning) and students' expectations about what is rewarded in school or in a particular class. For example, it was common for students to state that biology is an integrative and principle-driven science, but at the practical level, still asserted that memorization and recall were going to provide their best chance for success in individual classes. These misalignments were somewhat expected in more traditionally structured, lecture-based courses; however, these misalignments were even reported from students enrolled in classes that were specifically designed to emphasize and reward broader, principled-based learning strategies over memorization. Based on a combined review of our interview and survey analysis, I hypothesized that classroom expectations are one influencing factor of a complex interplay between students' epistemologies and behavior.

In addition to classroom expectations, the learning environment is another important factor that helps to frame the students' perceptions. While we will not be examining the effects of the various learning environments in this paper, I feel that it is important to provide a description of the learning context to help set the stage for my analysis. The next section will discuss the classroom context.

### E. Description of Setting

All undergraduate biology majors (almost 2500 students) at the University of Maryland must complete a three-course introductory biology sequence consisting of Molecular and Cell Biology, Ecology and Evolutionary Biology, and Organismal Biology. This dissertation focuses on the third course in the introductory sequence. Organismal Biology concentrates on the diversity, structure, and function of all organisms. Traditionally, Organismal Biology is taught in large lectures (100+ students) with little or no forms of active-engagement or discussion, such as group-work or whole class discussions.

This traditional approach toward teaching organismal biology is derided by both instructors and students alike. In such courses experienced instructors find the fundamental principles governing the diversity, structure, and function of all organisms do not emerge from the tsunami of isolated organismal facts (Cooke, personal communication, April 15, 2013).

Both due to negative feedback about the course and in response to challenges set forth by the broader scientific community for undergraduate biology education and preparation for medical education, the college agreed to modify the course content

(Handelsman et al., 2006; McCray, Dehaan, & Schuck, 2003; National Research Council, 1996, 1999, 2003, 2009; National Science Foundation, 1996). The development and evaluation of the reforms was funded through the university and an NSF-CCLI grant[21].

This new "improved" version of Organismal Biology focused on altering the curriculum of the class. While the pedagogy was still lecture-driven, and retained much of the subject material presented in the organismal chapters of most introductory biology textbooks (Campbell & Reece, 2008; Freeman, 2008; Raven, Johnson, Losos, Mason, & Singer, 2000), the goal of this new version of Organismal biology was to emphasize the universal physical and chemical principles as well as the common genomic heritage of all life and it encouraged students to think about organisms in terms of this organizational framework[22]. To do this, the conceptual topics of the course were aimed to illustrate the broad principles that yield a coherent unified picture of the structure, diversity, and function of organisms.

In addition to the universal changes in content, the instructors in one section[23] also expanded the pedagogical tools used in order to create a more productive, student-centered learning environment. In this section, the class was restructured in order to foster student engagement and reasoning, as well as improved learning outcomes (as assessed on exams).

The format of this class section consists of 2/3 conventional lectures and 1/3-group active engagement (GAE) periods. While the particular pedagogical strategies varied, each GAE was designed to engage students in active inquiry practices while

---

[21] NSF 09-191816

[22] http://umdberg.pbworks.com/w/page/8039417/FrontPage

[23] This course is co-taught by two pairs of professors each semester.

illustrating an important course topic.

For example, one specific GAE entitled “Circulatory Systems I: Sharing the Wealth” was designed to show how both plant and animal systems must overcome the same physical constraints to effectively to move fluids (as gases or liquids) for carrying matter as dissolved solutes or suspended particles. To illustrate this point, students begin by discussing whether a giraffe or an acacia tree has a more “powerful pump?” To answer this question, students must define a biological pump in terms of flow as it relates to force. In this way, students can begin to understand how to biological needs help determine the pressure, flow rates, concentrations in diverse biological systems.

This approach differs from how circulatory systems are discussed in most introductory biology courses and texts. First, plant and animal systems are rarely discussed together. Second, most biology textbooks focus on detailed descriptions of the relevant structures of both the animal and plant systems rather than describing how these structures evolved to overcome physical and chemical barriers and allow organisms to effectively to move fluids. Finally, this activity allowed students to work productively in groups to discuss ideas and refine their thinking. In this way, students not only have opportunities to compare plant and animal systems directly, which is rare, but also have the chance to work together to define a biological system and determine how each parameter influences the system as a whole.

In another example, in a GAE called “Thermodynamics of Living Systems: Bioenergetics and Metabolism” students build concept maps of energy flows in the biological world. The goal of this exercise is to help students relate the laws of thermodynamics, which specifies the general rules for energy transformations and chemical reactions, with the specific biological mechanisms, such as oxygenic photosynthesis, which is responsible for energy transformations and chemical reactions in organisms.

Once again in most introductory biology courses, the focus of cellular metabolism is on understanding and identifying the specific enzymes, proteins, etc. that carry out the process, not on energy or energy transformations. This GAE helped students to understand how energy “flows” through biological systems and how one form of energy is transformed into another.

In addition to the weekly GAEs, these instructors have also added clicker questions, homework, and reading assignments to the curriculum. The exams are composed primarily of questions that require short written responses.

## F. Methods

### *1. Data sources*

In order to understand how students’ expectations manifest themselves in the context of this biology course, I draw from a multitude of sources, including: (i) faculty (field notes gathered from planning meetings as well as the instructors’ verbal and written course reflections); (ii) individual students (videotaped interviews, survey data, written course evaluations, scanned copies of exams, and students’ grades); and (iii) classroom data (video-taped student participation during both lecture and active engagement exercises). All of these sources have informed my analysis, but this chapter specifically discusses and analyzes student expectations via illustrative vignettes selected from individual student interviews, classroom observations or field notes, and videotaped segments of students’ in class participation. In that data, I looked for specific examples in which student expectations about the classroom and learning became salient for students.

### 2. *Collection and selection of data*

Before discussing the illustrative vignettes, here is a brief description of how I collected and selected the data, and how my definition of classroom expectations emerged from the data set.

From the fall of 2009 through fall 2011, I collected classroom video in our reformed-oriented Organismal Biology class. In addition to video taping all of the whole classroom discussions, I also taped two focus groups each semester (five semesters total) and collected detailed field notes during each class. The field notes for this study were taken by two researchers (myself and one other) in order to establish a more reliable account of each class period. In addition to the classroom data, I collected approximately 40 hours of raw video data from 35 interviews with undergraduate biology students. 25 of these students were enrolled in the reformed-oriented Organismal Biology class, and 10 were enrolled in more traditional, lecture-only sections of the course.

Most students interviewed were biology, pre-med, or pre-allied health majors. Students ranged from first-semester freshman to second-semester juniors. Even though this is the third introductory course, many students reported that this was their first biology class taken at College Park. This was usually due to their having received university credit for high school advanced placement classes, but a significant number of students also had transferred after taking classes at other universities or community colleges. I solicited interview volunteers from the class at various points during the semester. The interviews typically lasted for an hour and were video and audio recorded with the student's permission.

The focus groups were videotaped during each class period throughout the semester. The focus groups were student-selected — meaning, the students' were allowed to choose their own collaborative peer groups at the beginning of the semester. I obtained written and verbal consent from all of the individual members of the groups before I filmed their classroom participation.

### G. Coding for Expectations

I initially transcribed the interviews and then coded them for instances where students talked, either explicitly or implicitly, about expectations. Using my definition of classroom expectations adapted from Redish et al. (1998), I coded all for statements pertaining to the nature of the knowledge that the students were learning, what they felt they should be (or are) doing in order to learn, and what they felt they needed to do in order to do well in the course as classroom expectations. I paid particular attention to sections where students discussed their thoughts on the effectiveness (or ineffectiveness) of the particular class activities as well as reported exam and homework strategies. I found these student reflections on their own exam and homework behaviors particularly useful in understanding classroom expectations in this course because they were concrete moments when students had to explain why one study method or learning strategy was more effective than another. This, in turn, helped me to unpack the different ways in which students perceived these particular tasks. Common themes emerged from iterative coding of utterances that provided some evidence of expectations and approaches within and across students. Using these data, I was able to document some of the expectations students have for doing well in this biology class.

From the initial corpus of 35 interviews, I selected students whose views overlapped a number of other student views expressed in the interviews. From these, I selected four student cases for greater elaboration and deeper analysis. I chose these four students because:

1. *they talked candidly, explicitly, and at length about their views regarding both the nature of biological knowledge and about biology learning;*
2. *they represent epistemologically diverse views, yet made statements that appeared frequently in our data corpus;*
3. *all four students have nearly identical demographic profiles – meaning, at the time of the first interview, each student was a pre-allied health or biology major and each received the same final grade (B) in our target course; and*
4. *these students made statements that have strong implications for biology reform.*

After I identified the four vignette examples, I went back through the data corpus an looked for specific points in the interviews when the students discussed, either explicitly or implicitly, their ideas about the nature and structure of biology knowledge, how they learn, or the ways they study or try to succeed in their courses. I then examined the classroom data (video and field notes) for examples of how these particular views became salient for student participation in our course.

## H. Data Analysis

### *1. The case vignettes*

This section is divided into four subsections. Each is dedicated to an individual student. The view expressed in these vignettes emerged during one to two hour-long interviews. Three of the four students also came back for follow-up sessions. Therefore, most the statements presented have been taken from several interviews. Within each subsection, I focus on several specific instances when interview participants discussed, either explicitly or implicitly, their expectations and how those expectations influenced their self-reported class participation. I also provide potential classroom examples where students may have struggled due to epistemological, rather than purely conceptual, miscues. Our evidence for the classroom participation comes from field notes, classroom, video, exam, and interview data. The students in first two vignettes described their ideas more generally, both about the nature of biology and learning in biology.

Keeping with the specific reform goals described earlier in the methods section of this chapter, the students in the final two vignettes specially discussed how the pedagogical decision to incorporate mathematical and physical principles into the curriculum had impacted or influenced their epistemological understanding of biology or the ways in which they approached learning in biology.

While these represent only a fraction of the expectations the students reported, the illustrative vignettes allow us to show, with data, some of the ways in which specific classroom expectations can influence student participation in a particular course. It also allows me to show, at least in one instance, how specific pedagogical interventions can challenge these perceptions. In this way, we can demonstrate why student expectations are an important element to understanding the success of course reforms. I also demonstrate that student expectations can be dynamic and susceptible to change, a result that may also have implications for instruction.

### *a) Vignette I: Patrick*

Our first student is Patrick, a freshman biology major. Patrick took this course in order to fulfill a mandatory requirement for his major. At the time of this interview, he thought he wanted to go to medical school, but was still somewhat unsure of his ultimate career path. At the beginning of the interview, Patrick explained that high school was much easier for him in a lot of ways because the expectations were much clearer to him. Since coming to college, Patrick has experienced a lot of anxiety and has had a difficult time maintaining a balance between school and social obligations. Our conversation naturally transitioned to from his obligations as a student to his views regarding his role as a student. On this subject, Patrick reported that his introductory science classes do not reward what he called “free thinking.” Patrick’s understanding of his job as a student was to learn what his professors wanted him to learn. In a way, this seemed to be comforting to Patrick because it reduced his anxiety and defined his role as a student; however it also seemed to frustrate him because he felt restricted in how he could think. Patrick explained that the reason he felt restricted was he was always trying to get the “right answers.” When asked if he ever used his own intuitions to think about his learning, Patrick answered: “Yes, but not in science [pause] I always thought that [pause] I always felt that science is structured for a reason. It's not really a place for you to have, at least as a student, to have free thinking because there's a penalty for free thinking, in that you get points docked, because many times you don't get the right answer.” Patrick admitted that he frequently accepted a piece of knowledge as “true” simply because his professor told him it was true: “Why do I believe [that hox genes[24] evolved in the way it was described in class?]? Because two people with Ph.D.'s and 30, 45, 50 years of combined research experience told me to and I know better than to question that because I'm not that smart. I don't have that research experience, and I know my limitations.”

Patrick explained that he has not yet acquired the level of mastery that would be necessary for him to challenge his professors and perhaps even to understand their reasoning — he simply accepted their authority. While Patrick appeared sophisticated to respect expertise in choosing what to believe, it is epistemologically problematic for him to think that he cannot construct his own understanding of the expert’s ideas. It is this notion — that his role as a student was to acquire pre-formed knowledge from his professors and not to build his own understanding from what he is learning appeared drive much of how Patrick interacted in the class. He also reported that for most of the concepts his professors presented in this class, he could just “blindly accept it and then move on.” Expanding on that thought, Patrick stated that asking him to explain how he knows that something is true involved thinking about his knowledge in a new way and is “beyond the scope” of introductory courses. Patrick was fairly consistent about his classroom expectations throughout his three interviews. Patrick felt it was inappropriate for him to use his own intuitions when thinking about science, particularly school science. Science, for Patrick, was a discipline that penalizes “free thinking;” therefore, his primary role as a learner was to accept and receive knowledge from his professors

---

[24] Hox genes are a highly conserved group of related genes that help determine both the basic structure and orientation (anterior/ posterior) of an organism.

without interpretation or question. As a result, Patrick also reasoned in order to well in class he needed to directly take the knowledge he acquired from class and use it to "get the right answers." For him, thinking and reasoning became counter-productive because it often resulted in losing points. It was not surprising then that Patrick's expectations had implications for how he behaved in the classroom. He took careful and copious notes each and every class, which he was eager to display for our interviewer. He also reported that he committed large portions of his notes to memory and expected to be tested on them later.

When preparing for exams, Patrick talked about finding the "key words" on exams and trying to anticipate a correct answer based on his knowledge of his professors and on his previous experiences with taking tests in this class, rather than his own knowledge of the subject matter:

> S: I tried to think about what they were looking for.
>
> I: What do you mean by that?
>
> S: I looked for key words and then tried to see how they paired up with the rest of the sentence — like the first one "haploid" and "zygote" those seem to be the main key words in that sentence, and they may have thrown a concept in there, but they didn't on the last test so I didn't think they would do it on this one, so I didn't really pay attention…

In this segment[25] of transcript, Patrick described using the "key words" and the structure of the sentences, not his understanding of the biological phenomenon, to select the correct answer. He stated he did not even really "pay attention" to the full question, and

---

[25] The original exam question was written: Frequently, the haploid zygote is resistant to adverse environmental conditions. (True or False. If false, rewrite statement).

was mainly focused on figuring out how the professor structured the question. He expanded on that theme:

> I: So was that your basic test taking strategy for this? [The True/False section of the test]
>
> S: Yes [to determine the clauses]. That and I thought every question was immediately false.
>
> I: Why was that?
>
> S: A test taking strategy that I learning from the first test.

As he said before, Patrick used the format of previous tests to predict the types of questions he would encounter on future tests. Because Patrick assumed all of the statements to be false, he expected that this test would be patterned like the old test.

Much like with other pattern matching games, the assumption seemed to be that the goal is to figure out the pattern. While it is a sophisticated test taking strategy, and one that proved successful in raising his grade for this exam, the strategy came at the expense of him actually thinking deeply about the subject of his exam. Taken together, Patrick's underlying ideas about his role as a student and his expectations about exams are fairly consistent. When discussing his role as a student, in the classroom he seemed to accept his professor as the authority without question, but with the exams he tries to subvert the professor's authority a bit by beating the professor with testing strategies. Patrick summed it up this way:

> I guess it's like the way I've always kind of thought of things. I ask 'what do they want me to get out of it?' Not what necessarily do I want to get out of it. If I wanted to get something, I'll read it myself and get out of it

> what I want. What does an educator want to get out of the text? What does he want me to get out of the text? Because everything that an educator does is deliberate. Trust me.

Patrick consistently maintained the learning expectation that the professor was the authority and his role as a student was either to absorb or to produce “right answers” for the benefit of the professor or grader, rather than to reason for himself and his own understanding.

Patrick also disliked the GAE sessions and did not think that they were effective teaching or learning tools. Both in interviews and during class, he expressed that he did not “believe” in group learning, and he even requested that we “not do any more of those stupid group work assignments.” He most often worked alone in class, even when required to sit in a group. He reported that he felt “the most effective teachers will teach straight from the book and it's the responsibility of the student to go back and fill in the blank, basically.” He elaborated, “they [the good instructors] just have to. They go in sequence, they go in chapter, they go in order in the way that the material is presented, or in their most logical way for it to be presented. If you go back to the book, you can see where they're pulling the information from.” Patrick explained that the format of book teaching and recall was “basically a common theme in pretty much any well-structured college class.” This was not surprising, given his previous statements about authority. As a result, Patrick was “frustrated” with the format and structure of this organismal biology class.

True to his word, Patrick did not turn to his peer group to study for the exams, nor did he change his study habits. Midway through the semester, he continued to spend most of his study time copying the lecture notes and making flashcards. At the end of the semester, Patrick had managed to raise his grade from a C to a B average, but did not embrace any of the epistemological messages of the course, such as encouraging students to think critically about biological concepts instead of simply memorizing them or the value of working collaboratively. Instead, he attributed his improved grades to better testing strategies:

> I think a lot of students, at least that I've known, if they don't know the full part of the question, especially essay questions, they won't answer it, they get, like, too intimidated for it. And I've always been taught to answer as much as you can, 'cause you don't need all the credits to get an A. You don't need all the points. So … it was a calculated error into my strategy. And I mean, it worked out well, I did well on the — I did better on the test.

This kind of learning and study preparation that Patrick felt he needed to succeed on tests appeared to differ from the kind of learning needed to achieve long-term understanding. For example, Patrick reported that, while his testing strategies were fairly effective in earning him partial points for the exams, he was rarely able to reason about novel questions during exams. Patrick explains “if [he does not] know the answer within the first three seconds [he] pretty much [is] not going to get the answer.” Therefore, Patrick’s strategy of focusing on “key words” and relying on the grading using partial points worked for Patrick in the short term, potentially, at the expense of a broader understanding of the concepts. He only focused on accruing enough points to score well on his exams, and we have no evidence to suggest that Patrick ever revisited any of the concepts to build a broader understanding of the knowledge. If he believed that deep understanding was the only way to do well on tests, his short- and long-term goals would not have been in conflict. Instead, his in class behavior and interview statements indicate that almost all of Patrick's energy was directed at the short-term, focused on passing tests and not on building long term knowledge. When viewed holistically over the entire semester, Patrick preferred to memorize terminology, work alone, and use test "strategies" to gain extra points on exams. He heavily resisted talking about his ideas with other students and rarely saw the value in the group work or homework assignments. He explicitly stated that it is not his place to generate new knowledge and his approach to learning in this class seems to reflect that expectation. From Patrick we can see how classroom success is not always an accurate measure of deeper understanding and, in some cases, can even act to reinforce unproductive classroom strategies and further deepen students' negative assumptions about knowledge and learning — even in reformed classrooms.

### *b) Vignette II: Joseph*

Our second student, Joseph was also a sophomore, pre-med major. Unlike Patrick, Joseph was adamant that he wanted to go to medical school. In fact, he stated that he did not enjoy studying biology at all; he was only a science major because he believed it would improve his chances of getting into medical school. Joseph reported many more positive views about the course than Patrick and recognized, at least verbally that the goal of the class was to teach overarching concepts, rather than learn through rote memorization. However, Joseph approached exams primarily by memorizing lecture material and "cramming". Unfortunately for Joseph, this particular mismatch between his epistemological, learning, and performance expectations set him up for a frustrating pattern of understudying and underperforming on exams.

Joseph acknowledged that this course was taught differently from his other introductory courses:

> I have to understand instead of answering multiple choice tests that I can memorize stuff for. So I've got to actually be able to explain it… That's the whole point of the concept learning. So [the professor will] ask you to know a concept and then instead of just having to know straight up what is this concept it's like here's the scenario...apply that concept to it to make sure you really understand it.

Joseph continually emphasized that this course required students to explain and understand the concepts introduced.

Joseph seemed to understand on a conceptual level that this biology class tried to emphasize biological principles and encourage students to reason about ideas instead of just asking him to memorize specifics. He called this type of instruction “concept learning.” In his words, this type of instruction required him to explain and apply his knowledge, rather than simply commit to facts to memory.

Despite having some awareness of these rather sophisticated constructivist ideas about the nature of biological knowledge, I have reason to suspect that these ideas were not often activated for Joseph in the classroom. When he talked about learning, and his role as a student, Joseph described himself as passive because he expected his professors in this class to look for specific types of factual knowledge, not independent reasoning. This expectation (that authority is the source of knowledge) directly affected the way

Joseph talked about how he approached learning in the course and how he studied for exams.

For example, Joseph reported that, even though he understood the class to be about learning concepts, he claimed that he rarely needed to pay attention or think very deeply during lectures because he simply “Googles everything.” When asked to explain how the Internet helps him to study, he responded “people have already put up questions from homework that are verbatim from our assignments.” He also explained that most of the “exact problems” he expected to encounter on his exams could all be found on such sites as “Wikipedia” or “Google Answers”. Joseph asserted that he was not overly concerned with paying attention in class and trying to understand the lectures because “everything can be learned a couple days before the exam.”

While these statements appeared in direct contrast to his statements about needing to explain and understand the concepts, they make sense if you uncouple the knowledge goals of the course with learning and performance goals. It is still somewhat unclear what “concept learning” means for Joseph. It is possible that, to Joseph, his understanding of what it means to reason in biology may equate to little more than memorizing. If that is the case, it appears that Joseph did not make the connection that he might have to develop new ways to learn or study in this class in order to understand this different form of biology knowledge. What we do know is that he spoke as though this class taught biology knowledge in a new way, but in the classroom, he seemed to rely on his old “tools.”

In another example, Joseph talked in depth about how he reviewed old exam keys to discover what instructors focused on in student answers: “It's not how much you know, it's how you can put it into words to answer the question best. So, I may know everything, but when I see how he words the question, you have to be able to fit that mold and give him what he wants to hear. 'Cause like there'll be a question where you can give him an entire answer, and it's wrong because it's missing one word that was circled on the key." Later, when reviewing a question he answered incorrectly, Joe restated that the instructors looked for a specifically worded answer. The question asked him to modify a phylogenetic tree[26] to reflect a given hypothesis.  Joseph drew a coherent phylogenetic tree, but not one consistent with the provided hypothesis.

Discussing his exam with the interviewer, Joseph's focus on finding a right answer to satisfy the professor might have played a role in directing his attention away from analyzing the hypothetical situation requested: "[My answer] is a completely correct phylogeny, but it's just not the one they wanted. It all fits in, things evolved where they should be. But that's just not how they wanted it… I didn't understand enough to put it into their… the way they wanted." Because he expected his performance on the exam to be about finding singular "right" answers, it is plausible that Joseph was unable see the possibility for hypothetical questions on the exams. Joseph's ideas about what the instructors valued also affected how he approached studying for later exams.

Joseph reported that he did not look over his earlier graded exams after receiving them back: "When I go back for the final exam, I'll look at the keys… If I got it right, it's going to be the same thing on the key. If I got it wrong, there's no point in studying it." Joseph consistently stressed the importance of knowing the specific wording or example the instructors desired, leading him to look for the "right" words on the answer key.

---

[26] A phylogenetic tree is a diagrammatic representation that infers evolutionary relationships among various species.

It appears as though Joseph's performance expectations could be blocking his ability to reason productively. In practice, the instructor reported (Cooke, private communication, April 15, 2013) that changing students' performance expectations (what they would be graded on) proved to the hardest challenge.

Midway through the semester, Joseph had to drop a chemistry course due to his lower than expected exam grades. Despite his poor grades, Joseph felt that his best chance to improve his scores was to do more of the same — increase his time spent reading his notes and copying study guides from the Internet. Joseph could have had multiple reasons for not changing his study habits. For one, Joseph might have assumed the assessments in the course reflected or rewarded different types of knowledge than the professors claimed to emphasize. It is also possible that Joseph did not know any other ways to study. Either way, our look at Joseph reveals that enthusiastic students (who use language consistent with what the instructor might want them to say) can be hindered by their inability to change the way they approach learning in these reformed courses.

### *c) Vignette III: Ashlyn*

In a large number of our interviews, students reported that math and physics were rarely (if ever) components of their introductory biology courses. When asked what role physics could play, most students responded either that they were unsure whether or not physics was relevant or that physics was only relevant in special cases. For mathematics, many students responded that mathematics only provided definitive quantities to some observed phenomenon — meaning they would only use it to either verify or calculate a more precise description of the phenomenon. A large number of students did not view mathematics as a productive tool to reason about biology or biological phenomenon.

Some of these students also expressed a high level of resistance or anxiety when asked to reason about biology using equations. Many students were ambivalent at best and, at worse, vehemently against using math and physics to reason about biology

These findings are problematic, to say the least, given our commitment to reform our biology class grounded in the recommendations presented in reports such as *Vision and Change* and *Scientific Foundations for Future Physicians*. (AAAS, 2011; AAMC-HHMI committee, 2009; Labov et al., 2010).

In interviews, some students strongly questioned the value of using equations to learn biology. Our third example, Ashlyn, a freshman biology student reported that she perceived that math did not help her think biologically: "I don't like to think of biology in terms of numbers and variables. I feel like that's what physics and calculus is for." For most of the interview, Ashlyn did not view math or physics as being conceptually relevant to biology. In some ways, the instructors' pedagogical choice to use physics and math to explain biological phenomenon violated Ashlyn's epistemological expectations about "what counts" as biology. This violation caused Ashlyn to have great difficulty seeing how physics or math was important in learning biology. For her, it seemed like these concepts rarely "come into play" for biology majors. Despite taking calculus II, Ashlyn asserts, "bio majors really don't need math, and people who don't like math will maybe like biology more because there's less math in it." When whether she felt that biology students need any mathematics background at all, she responded that, while all science majors have to take calculus, biology majors only take "low-level math classes," which "basically that tells [her] that bio majors really don't need math." For her, we have created entirely separate disciplines so that we can think about phenomena from different perspectives—i.e. that's what physics and calculus is for. For Ashlyn, trying to force her to think about biology in terms of physics and math is not only unnecessary, it goes against one of the things she feels attracted her to biology in the first place — that biology is the science with "less math."

Given that this course was specifically designed to teach physical, chemical, and mathematical principles in order to help students understand biology, it is interesting that Ashlyn explicitly rejected thinking about biological phenomenon in these "terms." One possibility is that her epistemological expectation that math and physics are not relevant to biology understanding undermined her ability to pay attention to what the professor in the class is trying to show — that math helps one understand many things in biology, including the relation of concentration and flow. Another is that she picked up on cues that the class could be (inadvertently) sending that although the math and physics are relevant in principle that in practice, they can be ignored.

Ashlyn's views of the value of math and physics specifically influenced how she approached learning in the course and in specific physics-based GAEs. For example, after her instructor used Fick's laws[27] of diffusion in a series of lectures primarily as a referent in understanding the affordances and constraints in evolutionary development, Ashlyn questioned the approach:

> I think that biology is just — it's supposed to be tangible, perceivable, and to put that in terms of letters and variables is just very unappealing to me, because like I said, I think of it as it would happen in real life, like if you had a thick membrane and you try to put something through it, the thicker

---

[27] Fick's two laws predict (i) the direction and speed of diffusion and (ii) how diffusion causes the concentration to change with time.

> it is, obviously the slower it's gonna go through. But if you want me to think of it as ‘this is x’ and ‘that's d’ and then ‘this is t,’ I can't do it. Like, it's just very unappealing to me.

During the interview, Ashlyn explained that she resisted using letters and symbols when discussing the equations in a specific activity about diffusion. One reason Ashlyn found using the equations “unappealing” and of little general use in her diffusion exercise is because she already understood the concept beforehand. She clarified that before going into the exercise, she already knew “how diffusion worked” and could describe the phenomenon qualitatively in terms of membrane thickness and molecule size. She went on to explain that most biological situations, like diffusion, only require this qualitative or descriptive understanding of the phenomenon: “So the equation, like I said before, like, I will memorize it because I have to, but knowing that, it's — the time is directly proportional to distance and indirectly proportional to the diffusion constant, I think in my mind is enough.”[28] In this example, using mathematics to describe biological systems seemed unnecessary to Ashlyn because she was satisfied with her qualitative explanation. The equation became just a redundant thing to memorize without little, if any, additional explanatory power.

Due to her views about the value of equations, Ashlyn admitted to “blocking” the equations from her general understanding of biology and only memorized them in order to be able to do the specific calculations she thought would be on the class exams. Ashlyn resisted using equations to understand diffusion is because she did not see how

---

[28] This is, of course, one of the problems of not using the math. The time is *not* directly proportional to the distance but to the square root of the distance. This is one thing that the equation, or even just the units of the symbols involved, would tell you.

the equations improved her ability to express the concepts: "it's basically a way to put it, put the concept into words. I think that's what the only function of the equations are." She found thinking about diffusion in terms of equations as being just another way to verbalize concepts. Ashlyn understood that, in principal, equations express concepts, but did not see the value of doing so. Moreover, she felt that the approach undermines what attracts her to biology. Even after the exercise, she still did not like thinking about biology in terms of letters and variables. Because Ashlyn did not expect equations to add to her understanding of diffusion, she did not feel like she took much away from this particular activity.

Ashlyn was not alone in her views about the limitations of math and physics to understanding diffusion in biological systems. As an example, we return to our discussion of Joseph. Joseph also saw the little utility in using equations to explain the limits of diffusion because he assumed that biology professors could not expect their students to do much with them. When asked if he saw the math as helpful, Joseph answered "no" because he believed the math in this problem was simply there to add extra work, not to explain anything additional about the biological phenomenon. Following that statement, Joseph reported that, on the positive side, he was able to earn extra exam points with some easy calculations, but he still did not see the math as providing him with a deeper, more complex understanding of the information:

> I: So is it useful to have the math here (to understand the limits of diffusion in the context of this exam question?)?
>
> S: I mean it's an easy problem. An easy three points.
>
> I: Did that help your understanding of biology?

> S: No. I mean this is such a simple concept. It was just extra work [on the exam].

He appears just focused on doing the calculations, and not on what the calculations potentially mean for him in terms of improving his understanding of the material. Joseph and Ashlyn's experiences are representative of a large number of the students I interviewed. My interview, classroom, and survey data indicate that biology students often do not have much experience with physics and math, especially in introductory courses. Therefore, it is not unreasonable that many would have reservations about changing the status quo.

However, it seems that student resistance can diminish, in some cases, with appropriate pedagogical supports. Perhaps if Ashlyn and Joseph had different epistemological expectations about what equations could do for them in this context, they would have been able to find more value in the class exercises.

To illustrate the last point, we return to our discussion of Ashlyn. At one specific point in the interview, Ashlyn reported a different perception about the value of using mathematics and physics to explain biological phenomenon. For most of her interview, Ashlyn reported views about the class appear directly oppositional to the stated goals of reform, in particular, to the explicit use of math and physics as organizing and explanatory tools. However, this time, she responded in a strong positive way to using mathematics when discussing a specific course activity about scaling.

She recalled a demonstration in which two wooden horses were held next to each other, one of which was twice the size of the other (each dimension was scaled by two). The small horse was able to stand while the larger horse collapsed. In subsequent discussions, the students and instructor worked through the mathematical relationship between surface area and volume. Ashlyn stated that she found this exercise particularly helpful for understanding biology:

> The little one and the big one, I never actually fully understood why that was. I mean, I remember watching a Bill Nye episode about that, like they built a big model of an ant and it couldn't even stand. But, I mean, visually I knew that it doesn't work when you make little things big, but I never had anyone explain to me that there's a mathematical relationship between that, and that was really helpful to just my general understanding of the world. It was, like, mindboggling.

Although she talked about this demonstration in the same interview where she spoke of the unappealing nature of equations, she voiced a very different opinion about the usefulness of mathematics in understanding biology, now finding it “really helpful” and “mindboggling” rather than “unappealing” and pointless. Not only does Ashlyn talk differently about the value she sees in these two examples, her entire demeanor appeared to change. When describing the diffusion activity, she appeared rigid and frowning. By contrast, she was smiling, leaning forward and talking rapidly and excitedly when discussing the activity on scaling. These quotes show that students’ can shift the way they interpret and respond to the class based on the content, instructional environment, or other contextual cues. It is important for biology researchers to understand how the specific features of pedagogical interventions, like this scaling example, worked to help students like Ashlyn, while similarly designed activities, like the Diffusion example, did not.

### *d) Vignette IV: Ginny*

While a number of our students found the emphasis on mathematical reasoning and explicit use of physical principles, such as diffusion, difficult or unhelpful, other students responded positively and were excited at the opportunity to expand the ways they thought about biology. I am able to illustrate the potential for positive shifts in a student's expectations with my final case, Ginny. An ecology major, Ginny took organismal biology in the first semester of her sophomore year. Though these statements were all taken from a single interview, her interview comments reflect not only her incoming expectations about what it means to learn in biology, including the value of incorporating interdisciplinary content, but also how her ideas have changed over the course of the semester. I chose her interview for several reasons: (i) I believe Ginny's initial views about biology and biology learning to be representative of the understandings of many introductory biology students,[29] (ii) Ginny's case provides an excellent example of how a single course can potentially shift students' classroom expectations, (iii) this case also illustrates how productive epistemological expectations can influence student perceptions about how to learn and be successful, and (iv) how improved classroom expectations can translate into more constructive classroom strategies.

In many ways, Ginny's story most closely reflects the shift in classroom expectations I documented in my expectations survey and class evaluation data. Before starting this class, Ginny's perception was that biology had been mainly about memorizing lists of biological facts. She lamented that her high school biology class

---

[29] As indicated by our expectations survey and classroom evaluation data.

required a large amount of redundant memorization and that conceptual topics were rarely ever revisited after examination. Even less common in her high school experience was the mention or use of conceptual topics from other disciplines to help explain biological phenomenon. Specifically, Ginny explained that math was rarely used to explain concepts in biology. As a result of her past high school experiences, Ginny did not come to this class with an understanding that the sciences were in any way related. If anything, Ginny came to class with the implicit assumption that biology did not have “anything to do” with physics or math. As mentioned before, these ideas about math and physics in biology are not uncommon. Pre-course MBEX survey results suggest that many introductory biology students do not see the connection between biology and math or physics.

Despite her prior epistemological expectations about these disciplinary connections, or lack thereof, she reported that her experiences in this organismal biology course helped her develop new ideas about the nature of biological knowledge, especially regarding the potential value of math and physics to explain biological phenomenon:

> But in this case, they've used physics to explain a lot of the different things so that's been I think the big focus in the class is that there's unity and diversity and you have to figure out how to reconcile those two different things because you have the unity from evolution from the genetics…But then when you take different physical principles, that's where you're going to have different...where you're going to have evolutionary changes. Like the dolphins and cows, for example, because there's so many different principles of physics involved with living in those different habitats. Air

> versus water...so you know that they would have had to develop different characteristics.

Throughout the interview, Ginny talked about how this organismal biology course helped her to learn biology in news ways. By introducing new concepts from the disciplines of math, physics into her biology, Ginny was able to make new and deeper connections of her own.  At several different points in the interview, Ginny illustrated how the different math and physics principles of the course helped organize the biological ideas and provided a framework for understanding complex concepts. For example, Ginny explained that the physics and math used in this class helped her to understand how circulatory systems evolved in different organisms:

> The physics and the math behind diffusion...being able to calculate how much time it would take for a molecule to get from...It all depends on the distance...You've got these flatworms that are so flat that they can just diffuse everything through their skin to the center of their body because they're that thin. But when you get animals that are bigger and thicker then you know that diffusion's not gonna work so that's when you know you have to have circulatory systems and different ways of...different gas exchange systems and we never really incorporated physics in that way in my AP biology class because it was just sort of ‘ok so these have diffusion but these don't’… actually going through the equations and figuring out that a molecule has to go this distance and then calculating how much time it takes...Then it clicks.

In many ways, the introduction of math and physics concepts help change Ginny’s perceptions about what counts as biological knowledge as well as how to approach learning in biology.

One way the instructors changed Ginny's expectations and perceptions of how to learn in was by linking the physics and math concepts with the biological principles of unity and diversity in organismal development. In the interview, Ginny explained that biologists typically talk of biological relationships, such as unity and diversity or form and function in episodic or qualitative terms. She described how a better understanding of physical principles also helped her to understand the limits and constraints of an organisms and their environment. This new understandings provided additional insight into form and function relationships as well as the causes of biological diversity. These ideas were reflected in Ginny's self-reported classroom practice. Without these broader connections, Ginny says, biology "would just be memorizing lists."

After discussing the importance of phylogenies and the concept of "common ancestors," Ginny volunteered how her own ideas about the utility of mathematics and physics have changed since taking this course:

> What also made this really different from the AP biology course is that they've used physics and math a lot more. There was that survey that we had to take at the beginning and before we had really started anything in this class and I thought: Physics and math?! Oh those are completely separate. They don't have anything to do with biology. What are you talking about?" But in this course...I've really been amazed at how many different physics principles and how much more math there is involved than what I thought there was.

Beyond helping her understand the biological content, Ginny also elaborated how these broad principles helped her change her approach to learning biology. At multiple points in the interview, Ginny explicitly referred to the role physics had on her approach to learning biology. For Ginny, biology became less about memorizing lists and more about constructing a cohesive story for understanding the evolution of different characteristics and mathematics and physics became two more potential elements that allowed to her to construct a better, richer story.

In her interview, Ginny provided several examples (such as diffusion), where she explicitly attempted to make broad connections between ideas, rather than simply memorizing specifics. For Ginny, this approach directly mirrored how she studied for exams. When discussing exams, Ginny reported that she now rarely memorized, and preferred "just thinking through it" instead. For example, Ginny chose not to memorize specific phylogenetic trees presented in class. It was her understanding that the course was about "knowing how to read these trees" rather than memorizing specific items or relationships on the trees. She elaborated, "a lot of big mistakes people make who don't know how to read trees is that they just look at it saying ok these came first and this one came next and next and next… that is not the way you do it…because they could just flip things over and it would still mean the same thing." Ginny's statements reflected a new understanding about what type of learning is rewarded in her classes. She no longer felt the need to memorize lists and know all of the specific examples presented in class like she did in high school because she is now asked to reason through each question. Ginny exemplifies how the introduction of interdisciplinary concepts can sometimes help students develop their understanding of what it means to think biologically and change their approach to learning in the biology classroom.

## I. Implications

In addition to identifying some specific classroom expectations, or set of classroom expectations, students had about what they were learning in the class, the data indicated three additional things that have implications for instruction. First, students did not all progress towards more sophisticated (or less sophisticated) views about the nature of biological knowledge and biology learning as indicated by the MBEX. Second, I found that were not automatically “on board,” with the implicit goals set out for them by their instructors, and instead resisted the reforms by maintaining their own expectations about learning biology. Third, and perhaps most importantly, these expectations affected how students approached learning, even in a reform-oriented class.

In order to maximize the benefits of reforms, it seems appropriate that instructors be aware of and explicitly and consistently address the multitude of students’ expectations, attitudes, beliefs etc. about what biology is, what it means to learn and understand in biology, and the ways that this course will help to achieve those goals.

Our interview data also indicate that some students have robust expectations about learning that impede the successful implementation of even well orchestrated reforms. For example, students may reject the reforms as unhelpful and pointless as seen in Patrick’s vignette or in Ashlyn’s diffusion example, and decide not to participate in the exercise at all, or they may misinterpret their role as students in the learning process. Joseph enthusiastically described the importance of understanding and application in “concept learning” classes, but then was unable to translate those ideas into an effective study approach. Similarly, Ashlyn explained how she has diligently and methodically learned to memorize equations in this course, not because she felt they helped her better understand biology, but because she knew she would be tested on them. Clearly, this is not what the course professors had intended their students to take away from the class!

Instructors may change the (content and pedagogical) focus in their classes to a principles-based course, but that does not guarantee that the students will modify their expectations about how to do well on exams or approach learning. In order for reforms to succeed, it is also important to consider the students' expectations, goals, and objectives, independent of those set out by the course and the instructor, and to realize that just telling students that the situation has changed may not suffice to get them to change inappropriate in-class attitudes and behaviors. Meta messages left over from extensions of traditional pedagogy, statements interpreted one way by a faculty member and another way by students, and even "the word on the street and the internet" about the class from previous students can inadvertently confirm students' inappropriate expectations. When such misalignments go ignored and unaddressed in the classroom, it may undermine even carefully orchestrated reforms.

## J. Chapter 5 Summary

A growing movement among biology educators has urged a rethinking of introductory biology courses in order to both address problems within the current system and to foster more sophisticated ways of thinking about biology and effective scientific reasoning skills. To accomplish these goals, most efforts so far focus on content and pedagogy: instructors are urged to "get over coverage" and, instead, concentrate on incorporating collaborative active learning strategies and other reformed pedagogical approaches in order to emphasize thinking over memorization (Handelsman et al., 2006;

Hulleman & Harackiewicz, 2009; NRC, 1996, 1997, 1999, 2003). I agree, and these recommendations served as the starting place for the course reforms of OrgBio. However, previous research on curricular change and my own data now suggest, that many students may not benefit from these changed courses unless the reforms also take into account — and try to change — students' epistemologies and expectations. By expectations, I mean their views about what counts as knowing and understanding in biology and about what kinds of knowledge and learning specific courses reward (NRC, 1996; 1997; 1998; 1999; 2003; 2009).

# VI. Chapter 6: Discussion and Conclusions

I have argued that classroom expectations — epistemological, learning and performance, play an important role in how well the students attempted the kind of learning the instructor was trying to encourage (Hall et al., 2011). Because I am interested in understanding the factors that led to successfully implementing pedagogical reforms, I felt it was important to understand how students' classroom expectations shape their classroom interactions. Students do not come into the classroom as *tabula rasae*, and instead, use these pre-existing expectations to interpret a particular instructional situation.

I measure classroom expectations in a variety of ways. In this dissertation, I perform both a quantitative and qualitative analysis of introductory biology students' classroom expectations, meaning their views about the nature of the knowledge they are learning and how they learn it (National Research Council, 2000). Previous research in physics demonstrated that epistemological expectations impacted how students behaved in the classroom, and I felt that it was important to understand and analyze student expectations in biology classrooms. (Bing & Redish, 2009; Redish, 2009a; Tuminaro & Redish, 2007).

In the first chapter, I indicated that this study addresses the following research questions:

1. *What are the specific epistemological orientations and expectations toward learning that students bring to their introductory biology classes?*
2. *How are these expectations changed as the result of one semester of instruction in various learning environments?*

3. *How do students' expectations and epistemologies effect their participation in an introductory biology course?*

In Chapter 2, I present an extensive literature review to situate this work within the current and relevant frameworks in the literature. To develop the methodology for all three studies, I draw from several disciplines — including educational psychology, physics education research, cognitive science and biology education research. I begin with a review of the current state of biology education reform. A growing number of biology educators, at least at the collegiate level, have grown dissatisfied with undergraduate biology education (AAAS, 2011; AAMC-HHMI committee, 2009; D. Ebert-May et al., 1997; "Summer institute to improve university science teaching," 2009). These stakeholders have invested considerable time and effort to reform the way we think about and teach biology students. These dedicated reformers have already targeted the curricular content as outdated and lecture style pedagogy as ineffective. In an effort to engage students in the learning process, many of these instructors have chosen "Active learning" pedagogy as a mechanism to shift the content and pedagogy away from teacher-centered instruction and toward a progressive student-centered classroom (D. Allen & Tanner, 2005; Bonwell & Eison, 1991; Miller & Cheetham, 1990; Skinner & Hoback, 2003; Udovic et al., 2002). A number of studies have shown that introducing active learning pedagogy into the classroom improves student-learning outcomes (Michael, 2006). I then explained that, while content and pedagogical reforms, such as active learning represent a crucial first step toward successful reforms, they are not by themselves sufficient. Students have too much prior experience with traditional pedagogical approaches, and it is common that students misinterpret the goals for reform.

In these cases, it is equally common for instructors to misinterpret the students actions and incorrectly label the students epistemological miscues as misconceptions (Hammer & Smith, 1996; Hammer, 1996a; Smith et al., 1993). An incorrect answer on a concept inventory may not stem from a robust stable misconception. Therefore, I argue that any well-designed curricular reform must directly address students' ideas about what it means to "know" or "learn" in biology. Finally, I explain that student learning has typically been viewed in two ways: either as an individual internal or cultural/social process (Cobb, 1994). I argue that, in practice, it is nearly impossible to separate the two as one continuously influences the other.

After the literature review, this dissertation presents three studies. The first two studies employ a Likert-scale instrument, adapted from the Maryland Physics Expectation Survey (MPEX) for use in the new context of undergraduate biology classes (E.F. Redish et al., 1998). Building from work in both physics and biology education, the Maryland Biology Expectations Survey (MBEX) was designed to address my first and second research questions and assess to what extent biology students see biological knowledge as: (i) principle-based (rather than just fact-based), (ii) constructed (rather than memorized), (iii) part of a common scientific way of thinking, and (iv) existing in a coherent framework (rather than as a series of disconnected bits of knowledge).

In the first study, I describe the motivation, administration, and validation of the MBEX. I also document two major results that have important implications for biology reform. First, I document that certain pedagogical contexts correlated with significant epistemological improvements in the course of a semester. For example, a large, student-centered classroom produced consistent, favorable shifts in students' classroom expectations about what it means to learn biology. These positive shifts appeared to be especially significant in the clusters that probed for students' ideas about biological knowledge and students views about a common scientific way of thinking. These results were documented with multiple instructor pairs over multiple semesters. Second, large, lecture-based classrooms appeared to have the opposite effect — students in these sections reported declines in clusters of the MBEX. The declines were most significant in the clusters that probed for ideas about principle-based learning and the value of incorporating interdisciplinary concepts and reasoning into the curriculum.

The second study utilizes a modified version of the first MBEX survey and focuses on exploring students' interdisciplinary views. This second survey replaces and expands the original third cluster (Interdisciplinary Perspectives versus Silo Maintenance) of the MBEX with the Interdisciplinary Expectations Cluster (IEC). In the second study, I describe the motivation, administration, and validation of the IEC of the MBEX II. This study documents four major findings. First, biology students have discipline-specific classroom expectations, meaning that biology students expected mathematics to be more helpful to them than physics in understanding biology. Second, the students we surveyed have context-dependent classroom expectations, meaning the results I found in biology courses were not automatically duplicated in the physics courses. Third, biology students responded more favorably to the introduction to interdisciplinary content (such as physics equations) introduced into biology courses than when physics courses attempted to teach physics using biology examples. Fourth, the faculty we surveyed was not fully "on board" with the interdisciplinary and integrative curriculum initiatives commonly endorsed in the current reform literature. Many expressed concerns that these reform initiatives were unnecessary for their students or the course topics they taught.

I address my third research question with my third study. The third study is a detailed case study of several students' classroom expectations about biology learning in the context of a reform-oriented introductory biology course. The case study primarily uses interview data and identifies a number of discrete patterns of biology-specific classroom expectations. These classroom expectations appeared salient for how the students approached the course in general and how they perceived the course activities. These case studies provide a counter to the survey data and allow for a deeper, finer grained analysis of how the students interact with (and interpret) the course reforms.

## A. Summary

Currently, most of the biology education literature focuses on describing students' difficulties with biological facts and concepts. It is necessary to move beyond describing difficulties to a characterization of students' classroom expectations. Such an investigation will better identify the origins, nature, and contextual cues that drive student difficulties. There is a critical need for research on how biology students think they learn, both in traditional and reformed classrooms. While understanding the functional role of students' expectations and epistemologies is critical for informing reforms in biology education, most of the work to date on students' expectations and epistemologies has been conducted in the context of physics. Physics education researchers have characterized students' epistemologies in their introductory physics courses, focusing on students' ideas about: (i) the meanings of "knowing" and "understanding" in physics in general, (ii) what kinds of knowledge and understanding they should learn in their own physics courses, and (iii) the learning activities that are appropriate for them to engage in (Elby, 2001; D. Hammer & Elby, 2003; D. Hammer, 1989; Lising & Elby, 2005; E. F. Redish, 2009a; Roth & Roychoudhury, 1994). Importantly, researchers have also found that students' naïve expectations and epistemologies can negatively affect their approaches can hinder their learning (Elby & Hammer, 2001). Previous research also suggests that some of the obstacles to reformed instruction arise from a fundamental misalignment in expectations about learning between students and instructors. Students may resist change because they hold conflicting attitudes and expectations (i.e. naïve ideas about what it means to know and understand in science and what types of knowledge and learning their courses are really trying to emphasize). Simply put, students and instructors often do not have the same conceptualization of what "learning" means. Successfully creating lasting biology reform requires courses that are designed to "bridge the gap" between instructors and students expectations. This is accomplished by improving our own understanding about students' preconceptions about learning as well as incorporating both reformed content and novel, research-based, pedagogical interventions.

To guide the development of new curricula and pedagogies in biology, we need to know how best to address students' expectations and how to encourage students to approach learning biology more productively. This dissertation can aid curriculum developers, and can help instructors think about educational reform in biology.  It will provide a unique perspective to current research in biology. This dissertation also provides several ways to document and understand students' expectations in the context of a biology course.

## B. Future Work

### *1. Further validation of MBEX in novel student populations*

Although I created the MBEX and MBEX II for use in an introductory biology course, the survey is not yet validated for multiple introductory biology courses. I believe that course context in a survey is very important — if the course context changes, the survey results should also change. If one wants to survey biology students using the MBEX, he or she may need to modify the survey to fit the course context more appropriately. In an effort to correct this shortcoming, I am currently piloting the MBEX in one introductory and one upper division biology course at the University of Maryland: BSCI 105 (Principles of Biology I) and BSCI 338V (Biology of Vision). Also, since I observed so much variance in the moment-to-moment comments of the student interviews, I am very aware that students are more sensitive to contextual cues than the MBEX results would suggest. Therefore, I recommend that the MBEX survey not exist as a complete, "stand alone" measure to demonstrate epistemological gains and, instead, serve as a first pass analysis of the effect of pedagogical interventions on student ideas and expectations.

### *2. A complete analysis of the MBEX II*

For this dissertation, I only included an analysis of the third cluster of the MBEX II. I focus of the third cluster because this was the only cluster that changed significantly from the MBEX I. Also, this was the only cluster that was inserted into the original MPEX and piloted in physics for the life sciences courses (Phys 121-122). However, I believe that a full analysis of the MBEX still has merit, especially a comparative analysis of the traditional students, honor students, and disciplinary experts. In the future, I intend to finish the complete analysis of all of the clusters of the MBEX II.

### *3. Indentify specific characteristics of the favorable and unfavorable Cohorts — analysis of the bottom 25% of the MBEX*

By developing the MBEX, I was able to show that student-centered curriculum was correlated with a significant positive shift in students' expectations about learning biology. Those shifts were particularly impressive when instructors explicitly addressed students' native ideas and when the course curriculum included positive epistemological messages about how to approach learning. In most cases, a large number (~75%) of students in our reformed classes reported more favorable expectations in the posttest. While this result is impressive, this still means that a lesser, yet still significant amount (~25%) of students were not "helped" by the course reforms. I intend to take the data from the MBEX and examine whether any patterns can be found in these two cohorts.

### *4. Investigate potential correlations between the epistemological (expectations) gains seen on the MBEX and educationally significant conceptual gains.*

So far, I have demonstrated that a positive shift on the MBEX can be linked with student-centered pedagogy. Previous research has shown that students in student-centered, "active" classrooms often do better on conceptual measures than students taking traditionally taught courses (Hake, 1998; Michael, 2006). From this, I logically concluded that the active learning pedagogy "worked" to improve both the epistemologies of OrgBio B and C students and their conceptions of science. I attempted to verify my hypothesis with individual student interviews, but I was unable to make direct conceptual comparisons (i.e. pared exams questions, concept inventories, etc.). In the future, I would like to examine whether the scores on the MBEX correlate with larger gains on concept inventories or other widely excepted measures of conceptual learning.

## VII. Appendix I: The MBEX I

1. Biology courses should focus on biological subjects and should not present much chemistry and/or physics.

2. All I need to do to understand most of the material in a biology class is to memorize the basic facts, read the textbook, and/or play close attention in class.

3. Knowledge in biology consists of many unrelated facts.

4. I believe it is possible to get a "C" or better in this course without understanding the course topics very well.

5. If biology professors gave really clear lectures, then most good students could learn the material without having to spend a lot of time thinking outside of class.

6. I am more interested in general biological principles than the specific facts that demonstrate those principles.

7. The knowledge of evolutionary processes is relatively unimportant for understanding human biology.

8. Using mathematics to explain biological phenomena is more confusing than helpful to students.

9. The knowledge that I acquired in this biology class is directly applicable to important issues currently facing the world.

10. When studying for a biology exam, the key thing is knowing all the facts about the topics to be covered on the exam. Understanding the big ideas might be helpful for some essay questions, but not for most of the exam.

11. Studying the simple organisms in this class, like sea urchins, jellyfish, and snails, tells

me very little about how human systems work.

12. Even if this class were not a requirement for my major, I would still take it.

13. Learning biology requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text.

14. Although math in biology provides another way of describing biological phenomena, it does not really help provide a deeper understanding.

15. I don't need to be good at math to be good at biology.

16. Biology classes should be designed to help the students master the factual material for doing well on the MCATs, GREs, and other professional exams.

17. This biology class gives me knowledge and skills to think critically about biological topics in current events.

18. Learning biology is mostly a matter of acquiring the factual knowledge presented in class and/or in the textbook.

19. I don't need to be good at physics to be good at biology.

20. Biology class should just present all the different facts. Trying to present the unifying theories doesn't really help us understand anything.

21. I find that I often forget the material I've learned for a biology test soon after the exam.

22. I don't need to be good at chemistry to be good at biology.

23. Memorizing all of my lecture notes in this class verbatim is all I need to do to get an "A" in this course.

24. We use this statement to discard the survey of people who are not reading the questions. Please select agree - option 4 - for this question to preserve your answers. (do

not mark option 5)

25. The benefits of learning to be proficient using math and physics in biology are worth the extra effort.

26. Physics is relatively unimportant for understanding most biological processes.

27. I expect my exam performance in biology courses to reflect how well I can:

    A. recall course materials the way they are presented in class.

    B. apply course materials in situations not discussed in class.

28. Justin and Dave are studying together for an upcoming test and discussing the best way for them to study. Justin: When I'm learning biology concepts for a test, I like to put things in my own words, so that they make sense to me. Dave: But putting things in your own words doesn't help you do well in the class. The textbook and lectures were written by people who know biology really well. You should learn things the way the textbook and lectures present them.

    A. Justin's study method is most effective.

    B. Dave's study method is most effective.

29. Brandon and Jamal are discussing how a good biology textbook should be organized. Brandon: A good biology textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each chapter as separate because they're not really separate. Jamal: But most of the time, each chapter is a bout a different topic and those topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.

    A. Brandon's textbook organization is best.

    B. Jamal's textbook organization is best.

30. Of the following test formats, which is best for measuring how well students understand the material in biology?

A. A large collection of short-answer or multiple-choice questions, each of which covers one specific fact or concept.

B. A small number of longer questions and problems, each of which covers several facts and concepts.

31. Samantha and London are studying for an upcoming test on evolution.

Samantha: In order to do well on this test, I'm just going to concentrate on understanding the few underlying principles, which I will be able to apply to different situations.

London: I don't think understanding the principles tells you enough about every situation, I think I'm going to focus on memorizing as many different ways that organisms have evolved as I can.

A. It is best to study like Samantha.

B. It is best to study like London.

32. Biology and physics are:

A. related to each other by common principles.

B. are separate and independent of each other.

# VIII. Appendix II: Results of the Facts v. Principles Cluster — Results for all Questions by Class

| Class | | **Pre** | | **Post** | | **% Difference** | |
|---|---|---|---|---|---|---|---|
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 1 | 3 | 76% | 8% | 74% | 11% | -2% | 3% |
| | 6 | 26% | 49% | 28% | 41% | 2% | -9% |
| | 10 | 35% | 37% | 37% | 43% | 1% | -9% |
| | 11 | 58% | 19% | 56% | 23% | -2% | 5% |
| | 18 | 31% | 40% | 26% | 44% | -4% | 4% |
| | 20 | 76% | 7% | 85% | 5% | 9% | -3% |
| | 27 | 13% | 50% | 16% | 48% | 2% | -2% |
| | 28 | 71% | 11% | 69% | 11% | -2% | 0% |
| | 30 | 42% | 25% | 48% | 23% | 6% | -2% |
| | 31 | 50% | 13% | 45% | 19% | -5% | 6% |
| | 32 | 59% | 26% | 59% | 24% | 0% | -2% |
| ST DEV | | 0.21 | 0.16 | 0.22 | 0.15 | 0.04 | 0.05 |
| AVG | | 49% | 26% | 49% | 27% | 0% | -1% |
| Class | | **Pre** | | **Post** | | **% Difference** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 2 | 3 | 80% | 6% | 75% | 9% | -5% | 3% |
| | 6 | 28% | 38% | 36% | 31% | 8% | -7% |
| | 10 | 47% | 35% | 47% | 36% | 1% | 1% |
| | 11 | 55% | 18% | 54% | 23% | 0% | 5% |
| | 18 | 33% | 47% | 35% | 42% | 2% | -5% |
| | 20 | 86% | 2% | 82% | 7% | -4% | 5% |
| | 27 | 16% | 42% | 19% | 41% | 4% | -1% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 28 | 66% | 11% | 70% | 13% | 4% | 2% |
| | 30 | 41% | 25% | 47% | 26% | 6% | 0% |
| | 31 | 51% | 17% | 51% | 17% | 0% | 0% |
| | 32 | 62% | 23% | 68% | 18% | 5% | -4% |
| ST DEV | | 0.21 | 0.15 | 0.19 | 0.12 | 0.04 | 0.04 |
| AVG | | 51% | 24% | 53% | 24% | 2% | 0% |
| Class | | **Pre** | | **Post** | | **% Difference** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 3 | 3 | 77% | 9% | 68% | 14% | -9% | 5% |
| | 6 | 20% | 49% | 30% | 41% | 10% | -7% |
| | 10 | 43% | 35% | 40% | 35% | -2% | 0% |
| | 11 | 63% | 15% | 50% | 25% | -14% | 10% |
| | 18 | 32% | 36% | 30% | 45% | -2% | 8% |
| | 20 | 68% | 8% | 73% | 8% | 5% | 0% |
| | 27 | 16% | 43% | 12% | 56% | -4% | 13% |
| | 28 | 70% | 15% | 62% | 15% | -8% | 0% |
| | 30 | 46% | 25% | 48% | 21% | 2% | -4% |
| | 31 | 51% | 22% | 52% | 19% | 0% | -3% |
| | 32 | 62% | 25% | 59% | 21% | -3% | -4% |
| ST DEV | | 0.21 | 0.14 | 0.18 | 0.15 | 0.07 | 0.07 |
| AVG | | 50% | 26% | 48% | 27% | -2% | 2% |
| Class | | **Pre** | | **Post** | | **% Difference** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio B | 3 | 76% | 6% | 84% | 7% | 8% | 2% |
| | 6 | 31% | 39% | 37% | 36% | 6% | -3% |
| | 10 | 40% | 39% | 50% | 28% | 9% | -10% |
| | 11 | 64% | 12% | 64% | 14% | 0% | 2% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 18 | 27% | 42% | 41% | 32% | 14% | -10% |
| | 20 | 77% | 7% | 83% | 6% | 6% | -2% |
| | 27 | 17% | 43% | 15% | 37% | -2% | -6% |
| | 28 | 71% | 9% | 72% | 11% | 2% | 2% |
| | 30 | 44% | 26% | 37% | 31% | -7% | 5% |
| | 31 | 47% | 19% | 57% | 13% | 10% | -6% |
| | 32 | 64% | 20% | 83% | 6% | 20% | -15% |
| ST DEV | | 0.21 | 0.15 | 0.23 | 0.13 | 0.07 | 0.06 |
| AVG | | 51% | 24% | 57% | 20% | 6% | -4% |
| Class | | **Pre** | | **Post** | | **% Difference** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio C | 3 | 79% | 6% | 87% | 3% | 8% | -3% |
| | 6 | 30% | 45% | 42% | 31% | 13% | -14% |
| | 10 | 60% | 29% | 73% | 15% | 13% | -13% |
| | 11 | 65% | 11% | 70% | 13% | 6% | 1% |
| | 18 | 41% | 35% | 56% | 20% | 15% | -16% |
| | 20 | 91% | 0% | 86% | 8% | -6% | 8% |
| | 27 | 13% | 30% | 28% | 27% | 15% | -4% |
| | 28 | 73% | 17% | 76% | 6% | 3% | -11% |
| | 30 | 24% | 26% | 23% | 49% | -2% | 24% |
| | 31 | 59% | 8% | 58% | 8% | -1% | 0% |
| | 32 | 62% | 18% | 82% | 7% | 20% | -11% |
| ST DEV | | 0.24 | 0.14 | 0.23 | 0.14 | 0.08 | 0.12 |
| AVG | | 54% | 21% | 62% | 17% | 8% | -3% |

# IX. Appendix III: Results of the Independence v. Authority Cluster — Results for All Questions by Class

| Class | | **Pre** | | **Post** | | **% Difference** | |
|---|---|---|---|---|---|---|---|
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 1 | 2 | 26% | 53% | 32% | 51% | 6% | -2% |
| | 4 | 71% | 11% | 71% | 10% | 0% | 0% |
| | 5 | 38% | 36% | 32% | 40% | -5% | 4% |
| | 13 | 66% | 10% | 62% | 12% | -4% | 2% |
| | 18 | 31% | 40% | 26% | 44% | -4% | 4% |
| | 21 | 39% | 34% | 23% | 49% | -16% | 16% |
| | 23 | 77% | 7% | 67% | 17% | -10% | 11% |
| | 27 | 13% | 50% | 16% | 48% | 2% | -2% |
| | 28 | 71% | 13% | 69% | 11% | -2% | -2% |
| | 29 | 71% | 12% | 65% | 19% | -6% | 7% |
| | 30 | 42% | 27% | 48% | 23% | 6% | -4% |
| | 31 | 50% | 13% | 45% | 19% | -5% | 6% |
| | 32 | 59% | 26% | 59% | 24% | 0% | -2% |
| ST DEV | | 0.20 | 0.14 | 0.20 | 0.15 | 0.06 | 0.06 |
| AVG | | 50% | 25% | 47% | 28% | -3% | 3% |
| Class | | **Pre** | | **Post** | | **% Difference** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 2 | 2 | 29% | 54% | 37% | 44% | 9% | -10% |
| | 4 | 74% | 13% | 68% | 14% | -6% | 1% |
| | 5 | 38% | 39% | 33% | 47% | -5% | 8% |
| | 13 | 65% | 9% | 63% | 11% | -2% | 2% |
| | 18 | 33% | 47% | 35% | 42% | 2% | -5% |
| | 21 | 40% | 35% | 32% | 39% | -9% | 5% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 23 | 78% | 11% | 77% | 15% | -1% | 4% |
| | 27 | 16% | 42% | 19% | 41% | 3% | -1% |
| | 28 | 66% | 11% | 70% | 13% | 4% | 2% |
| | 29 | 75% | 11% | 70% | 12% | -4% | 1% |
| | 30 | 46% | 25% | 47% | 26% | 1% | 0% |
| | 31 | 51% | 17% | 51% | 17% | 0% | 0% |
| | 32 | 62% | 23% | 68% | 18% | 5% | -4% |
| ST DEV | | 0.20 | 0.16 | 0.19 | 0.14 | 0.05 | 0.05 |
| AVG | | 52% | 26% | 52% | 26% | 0% | 0% |
| Class | | **Pre** | | **Post** | | **% Difference** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 3 | 2 | 43% | 40% | 35% | 42% | -8% | 2% |
| | 4 | 74% | 10% | 72% | 11% | -2% | 1% |
| | 5 | 50% | 30% | 30% | 50% | -20% | 21% |
| | 13 | 63% | 11% | 63% | 12% | 0% | 2% |
| | 18 | 32% | 36% | 30% | 45% | -2% | 8% |
| | 21 | 35% | 30% | 26% | 48% | -8% | 18% |
| | 23 | 78% | 8% | 68% | 14% | -10% | 6% |
| | 27 | 16% | 43% | 12% | 56% | -4% | 13% |
| | 28 | 70% | 15% | 62% | 15% | -8% | 0% |
| | 29 | 70% | 13% | 68% | 12% | -2% | -2% |
| | 30 | 46% | 25% | 48% | 21% | 2% | -4% |
| | 31 | 51% | 22% | 52% | 19% | 0% | -3% |
| | 32 | 62% | 25% | 59% | 21% | -3% | -4% |
| ST DEV | | 0.19 | 0.12 | 0.19 | 0.17 | 0.06 | 0.08 |
| AVG | | 53% | 24% | 48% | 28% | -5% | 4% |
| Class | | **Pre** | | **Post** | | **% Difference** | |

|  | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
|---|---|---|---|---|---|---|---|
| OrgBio B | 2 | 28% | 50% | 44% | 36% | 17% | -15% |
|  | 4 | 77% | 6% | 70% | 9% | -7% | 3% |
|  | 5 | 38% | 34% | 45% | 38% | 7% | 4% |
|  | 13 | 71% | 13% | 68% | 13% | -2% | 0% |
|  | 18 | 27% | 42% | 41% | 32% | 14% | -10% |
|  | 21 | 28% | 43% | 26% | 43% | -2% | 0% |
|  | 23 | 76% | 6% | 75% | 9% | -1% | 3% |
|  | 27 | 17% | 43% | 15% | 37% | -2% | -6% |
|  | 28 | 71% | 9% | 72% | 11% | 2% | 2% |
|  | 29 | 76% | 7% | 76% | 6% | 1% | -1% |
|  | 30 | 44% | 26% | 37% | 31% | -7% | 5% |
|  | 31 | 47% | 19% | 57% | 13% | 10% | -6% |
|  | 32 | 64% | 20% | 83% | 6% | 20% | -15% |
| ST DEV |  | 0.22 | 0.16 | 0.22 | 0.14 | 0.09 | 0.07 |
| AVG |  | 51% | 24% | 55% | 22% | 4% | -3% |
| Class |  | **Pre** |  | **Post** |  | **% Difference** |  |
|  | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio C | 2 | 31% | 46% | 41% | 38% | 9% | -8% |
|  | 4 | 68% | 10% | 63% | 13% | -4% | 3% |
|  | 5 | 41% | 34% | 27% | 35% | -14% | 1% |
|  | 13 | 55% | 14% | 61% | 19% | 6% | 4% |
|  | 18 | 41% | 35% | 56% | 20% | 15% | -16% |
|  | 21 | 51% | 30% | 41% | 27% | -10% | -3% |
|  | 23 | 81% | 1% | 80% | 6% | -1% | 4% |
|  | 27 | 13% | 30% | 28% | 27% | 15% | -4% |
|  | 28 | 73% | 17% | 76% | 6% | 3% | -11% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 29 | 83% | 6% | 79% | 6% | -4% | 0% |
| | 30 | 24% | 26% | 23% | 49% | -2% | 24% |
| | 31 | 59% | 8% | 58% | 8% | -1% | 0% |
| | 32 | 62% | 18% | 82% | 7% | 20% | -11% |
| ST DEV | | 0.22 | 0.13 | 0.21 | 0.14 | 0.10 | 0.10 |
| AVG | | 53% | 21% | 55% | 20% | 2% | -1% |

## X. Appendix IV: Results of the Interdisciplinary Perspectives v. Silo Maintenance Cluster — Results for All Questions by Class

| Class | | **Pre** | | **Post** | | **% Difference** | |
|---|---|---|---|---|---|---|---|
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 1 | 1 | 41% | 38% | 38% | 40% | -4% | 2% |
| | 8 | 39% | 30% | 27% | 40% | -12% | 10% |
| | 14 | 38% | 33% | 35% | 33% | -3% | -1% |
| | 15 | 19% | 44% | 27% | 45% | 8% | 1% |
| | 19 | 13% | 51% | 21% | 53% | 8% | 2% |
| | 22 | 54% | 21% | 58% | 21% | 4% | 0% |
| | 25 | 63% | 7% | 56% | 15% | -8% | 8% |
| | 26 | 43% | 18% | 37% | 23% | -6% | 5% |
| | 32 | 59% | 26% | 62% | 24% | 3% | -2% |
| ST DEV | | 0.17 | 0.14 | 0.15 | 0.13 | 0.07 | 0.04 |
| AVG | | 41% | 30% | 40% | 33% | -1% | 3% |
| Class | | **Pre** | | **Post** | | **% Difference** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 2 | 1 | 43% | 38% | 47% | 32% | 4% | -6% |
| | 8 | 27% | 43% | 40% | 41% | 13% | -3% |
| | 14 | 35% | 38% | 42% | 39% | 7% | 0% |
| | 15 | 32% | 45% | 23% | 48% | -8% | 3% |
| | 19 | 22% | 51% | 20% | 51% | -2% | 0% |
| | 22 | 52% | 23% | 43% | 27% | -8% | 4% |
| | 25 | 54% | 8% | 55% | 13% | 1% | 5% |
| | 26 | 49% | 21% | 45% | 19% | -4% | -2% |
| | 32 | 62% | 23% | 68% | 18% | 5% | -4% |
| ST DEV | | 0.14 | 0.14 | 0.15 | 0.13 | 0.07 | 0.04 |

| AVG | | 42% | 32% | 43% | 32% | 1% | 0% |
|---|---|---|---|---|---|---|---|
| Class | | **Pre** | | **Post** | | **% Difference** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A<br>3 | 1 | 40% | 28% | 43% | 30% | 3% | 2% |
| | 8 | 36% | 33% | 26% | 36% | -10% | 4% |
| | 14 | 39% | 30% | 34% | 32% | -5% | 2% |
| | 15 | 28% | 44% | 17% | 54% | -11% | 10% |
| | 19 | 21% | 50% | 21% | 51% | 1% | 1% |
| | 22 | 60% | 17% | 53% | 21% | -7% | 3% |
| | 25 | 66% | 7% | 52% | 21% | -14% | 13% |
| | 26 | 49% | 11% | 45% | 20% | -3% | 9% |
| | 32 | 62% | 25% | 59% | 21% | -3% | -4% |
| ST DEV | | 0.16 | 0.14 | 0.15 | 0.13 | 0.06 | 0.05 |
| AVG | | 45% | 27% | 39% | 32% | -6% | 5% |
| Class | | **Pre** | | **Post** | | **% Difference** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio B | 1 | 39% | 34% | 56% | 19% | 17% | -15% |
| | 8 | 31% | 31% | 48% | 24% | 17% | -7% |
| | 14 | 49% | 26% | 57% | 21% | 8% | -4% |
| | 15 | 33% | 39% | 25% | 44% | -8% | 5% |
| | 19 | 21% | 42% | 33% | 44% | 11% | 2% |
| | 22 | 54% | 21% | 48% | 28% | -6% | 7% |
| | 25 | 71% | 5% | 69% | 6% | -3% | 1% |
| | 26 | 54% | 16% | 66% | 12% | 12% | -4% |
| | 32 | 64% | 20% | 83% | 6% | 20% | -15% |
| ST DEV | | 0.16 | 0.12 | 0.18 | 0.15 | 0.10 | 0.08 |
| AVG | | 46% | 26% | 54% | 23% | 7% | -3% |

| Class | | **Pre** | | **Post** | | **% Difference** | |
|---|---|---|---|---|---|---|---|
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio C | 1 | 56% | 25% | 66% | 21% | 10% | -4% |
| | 8 | 39% | 24% | 55% | 24% | 15% | 0% |
| | 14 | 53% | 26% | 56% | 27% | 3% | 1% |
| | 15 | 25% | 42% | 31% | 39% | 6% | -3% |
| | 19 | 24% | 38% | 28% | 38% | 4% | 0% |
| | 22 | 76% | 9% | 69% | 11% | -7% | 3% |
| | 25 | 70% | 7% | 73% | 6% | 3% | -1% |
| | 26 | 48% | 14% | 76% | 8% | 28% | -6% |
| | 32 | 62% | 18% | 82% | 7% | 20% | -11% |
| ST DEV | | 0.18 | 0.12 | 0.19 | 0.13 | 0.10 | 0.04 |
| AVG | | 50% | 23% | 60% | 20% | 9% | -2% |

# XI. Appendix V: Results of the Connected v. Isolated Cluster — Results for All Questions by Class

| Class | | **Pre** | | **Post** | | **% Change** | |
|---|---|---|---|---|---|---|---|
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 1 | 7 | 77% | 12% | 77% | 12% | 0% | 0% |
| | 9 | 64% | 12% | 50% | 26% | -14% | 14% |
| | 11 | 58% | 19% | 58% | 23% | 0% | 5% |
| | 16 | 17% | 60% | 17% | 61% | 0% | 1% |
| | 17 | 76% | 5% | 76% | 18% | 0% | 12% |
| ST DEV | | 0.25 | 0.22 | 0.25 | 0.19 | 0.06 | 0.06 |
| AVG | | 58% | 21% | 56% | 28% | -3% | 6% |
| Class | | **Pre** | | **Post** | | **% Change** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 2 | 7 | 74% | 15% | 73% | 13% | -1% | -1% |
| | 9 | 57% | 16% | 54% | 22% | -3% | 6% |
| | 11 | 55% | 18% | 54% | 23% | 0% | 5% |
| | 16 | 21% | 58% | 18% | 62% | -3% | 4% |
| | 17 | 73% | 8% | 65% | 14% | -8% | 6% |
| ST DEV | | 0.22 | 0.20 | 0.21 | 0.20 | 0.03 | 0.03 |
| AVG | | 56% | 23% | 53% | 27% | -3% | 4% |
| Class | | **Pre** | | **Post** | | **% Change** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio A 3 | 7 | 74% | 10% | 78% | 11% | 4% | 1% |
| | 9 | 69% | 8% | 45% | 27% | -24% | 19% |
| | 11 | 63% | 15% | 50% | 25% | -14% | 10% |
| | 16 | 26% | 50% | 31% | 42% | 5% | -8% |
| | 17 | 83% | 7% | 55% | 21% | -27% | 14% |
| ST DEV | | 0.22 | 0.18 | 0.17 | 0.11 | 0.15 | 0.11 |
| AVG | | 63% | 18% | 52% | 25% | -11% | 7% |
| Class | | **Pre** | | **Post** | | **% Change** | |
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio B | 7 | 79% | 11% | 76% | 13% | -2% | 2% |
| | 9 | 66% | 9% | 48% | 17% | -18% | 8% |
| | 11 | 64% | 12% | 64% | 14% | 0% | 2% |
| | 16 | 17% | 60% | 24% | 58% | 7% | -2% |
| | 17 | 79% | 6% | 64% | 14% | -15% | 9% |
| ST DEV | | 0.26 | 0.23 | 0.20 | 0.20 | 0.10 | 0.04 |
| AVG | | 61% | 19% | 55% | 23% | -6% | 4% |

| Class | | **Pre** | | **Post** | | **% Change** | |
|---|---|---|---|---|---|---|---|
| | Question | Fav | Unfav | Fav | Unfav | Fav | Unfav |
| OrgBio C | 7 | 79% | 13% | 76% | 14% | -3% | 1% |
| | 9 | 77% | 3% | 54% | 17% | -23% | 14% |
| | 11 | 65% | 11% | 70% | 13% | 6% | 1% |
| | 16 | 20% | 49% | 24% | 50% | 5% | 1% |
| | 17 | 86% | 0% | 76% | 6% | -10% | 6% |
| ST DEV | | 0.27 | 0.20 | 0.22 | 0.17 | 0.12 | 0.06 |
| AVG | | 65% | 15% | 60% | 20% | -5% | 5% |

## XII. Appendix VI: The MBEX II

1. Learning biology is mainly a matter of memorizing the various facts presented.

2. Time should not be taken out of biology courses to present physics.

3. Knowledge in biology consists of many unrelated facts.

4. I believe it is possible to get a "C" or better in this course without understanding the course topics very well.

5 It is beneficial to me, as a biologist, to also be proficient in physics.

6. If biology professors gave really clear lectures, then most good students could learn the material without having to spend a lot of time thinking outside of class.

7. I am more interested in general biological principles than the specific facts that demonstrate those principles.

8. Knowledge of evolutionary processes is relatively unimportant for understanding human biology.

9. Mathematics helps me make deeper sense of biological phenomena.

10. We use this statement to discard survey respondents who are not reading the questions. Please select agree - option 4 - for this question to preserve your answers. (do not mark option 5)

11. The knowledge I acquired in this biology class is directly applicable to important issues currently facing the world.

12. Studying the simple organisms in this class, like sea urchins, jellyfish, and snails, tells me very little about how human systems work.

13. Ideas I learned in physics are rarely useful in biology.

14. Math provides another way of describing biological phenomena, but rarely provides a deeper or better understanding.

15. Biology classes should be designed to help the students master the factual material for doing well on the MCATs, GREs, and other professional exams.

16. Physics helps me make sense of biological phenomena.

17. Ideas I learned in math are rarely useful in biology

18. This biology class gives me knowledge and skills to think critically about biological topics in current events.

19. Biology class should just present all the different facts. Trying to present the unifying theories doesn't really help us understand anything.

20. Ideas I learned in biology are rarely useful in physics.

21. Memorizing all of my lecture notes in this class verbatim is all I need to do to get an "A" in this course.

22. It is beneficial to me, as a biologist, to also be proficient in math.

23. Physics is largely irrelevant for understanding biological processes.

24. It is beneficial to me, as a biologist, to also be proficient in chemistry.

25. In the future, do you anticipate using the skills you are developing in this class? Please elaborate on how you think you will (or will not) use these skills.

26. In the future, do you anticipate using principles from physics? Please elaborate on how you think you will (or will not) use these principles.

27. How do you think the physics from this class will be valuable (or not valuable) to you in your career?

28. I expect my exam performance in biology courses to reflect how well I can:

A. recall course materials the way they are presented in class.
B. apply course materials in situations not discussed in class.

29 Justin and Dave are studying together for an upcoming test and discussing the best way for them to study.
Justin: When I'm learning biology concepts for a test, I like to put things in my own words, so that they make sense to me.
Dave: But putting things in your own words doesn't help you do well in the class. The textbook and lectures were written by people who know biology really well.
You should learn things the way the textbook and lectures present them.

A. Justin's study method is most effective.
B. Dave's study method is most effective.

30 Brandon and Jamal are discussing how a good biology textbook should be organized.
Brandon: A good biology textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each chapter as separate because they're not really separate.
Jamal: But most of the time, each chapter is about a different topic and those topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.

A. Brandon's textbook organization is best.
B. Jamal's textbook organization is best.

31 Of the following test formats, which is best for measuring how well students understand the material in biology?

A. A large collection of short-answer or multiple-choice questions, each of which
covers one specific fact or concept.
B. A small number of longer questions and problems, each of which covers several facts and concepts.

32 Samantha and London are studying for an upcoming test on evolution.
Samantha: In order to do well on this test, I'm just going to concentrate on understanding the few underlying principles, which I will be able to apply to different situations.
London: I don't think understanding the principles tells you enough about every situation, I think I'm going to focus on memorizing as many different ways that organisms have evolved as I can.

A. It is best to study like Samantha.
B. It is best to study like London.

# XIII. Appendix VII: Comparison of MBEX I to MBEX II

| MBEX 1 | MBEX 2 | MBEX 2 | MBEX 1 |
|---|---|---|---|
| 1 = | Dropped | 1 = | 18 |
| 2 = | Dropped | 2 = | New |
| 3 = | 4 | 3 = | 5 |
| 4 = | 5 | 4 = | 4 |
| 5 = | 7 | 5 = | New |
| 6 = | 8 | 6 = | 5 |
| 7 = | 9 | 7 = | 6 |
| 8 = | Dropped | 8 = | 7 |
| 9 = | 12 | 9 = | New |
| 10 = | Dropped | 10 = | 24 |
| 11 = | 13 | 11 = | 9 |
| 12 = | Dropped | 12 = | 11 |
| 13 = | Dropped | 13 = | New |
| 14 = | Dropped | 14 = | 14 |
| 15 = | 23 | 15 = | 16 |
| 16 = | 16 | 16 = | New |
| 17 = | 19 | 17 = | New |
| 18 = | 2 | 18 = | 17 |
| 19 = | Dropped | 19 = | 20 |
| 20 = | 20 | 20 = | New |
| 21 = | Dropped | 21 = | 23 |
| 22 = | Dropped | 22 = | 15 |
| 23 = | 22 | 23 = | 26 |
| 24 = | 11 | 24 = | New |
| 25 = | Dropped | 25 = | New |

26 = 24

27 = 29

28 = 30

29 = 31

30 = 32

31 = 33

32 = Dropped

26 = New

27 = New

28 = 27

29 = 28

30 = 29

31 = 30

32 = 31

## XIV. Bibliography

AAMC-HHMI committee. (2009). *Scientific Foundations for Future Physicians*. Washington, D.C. Retrieved from http://www.hhmi.org/grants/pdf/08-209_AAMC-HHMI_report.pdf

AAMC-HHMI committee, & AAAS. (2011). *Vision and Change in Undergraduate Biology Education: A call to action. American Association for the Advancement of Science.* Washington, D.C.: American Association for the Advancement of Science.

Ackerman, P. (1996). A theory of adult intellectual development: Process, personality, interests, and knowledge. *Intelligence*, *Volume 22*(2), 227–257. Retrieved from http://www.sciencedirect.com/science/article/pii/S0160289696900161

Adams, W. K., & Perkins, K. K. (2004). The design and validation of the Colorado Learning Attitudes about Science Survey. In J. Marx, P. Heron, & S. Franklin (Eds.), *2004 Physics Education Research Conference* (pp. 2–5).

Adams, W. K., Perkins, K. K., Podolefsky, N. S., Dubson, M., Finkelstein, N. D., & Wieman, C. E. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey. *Physical Review Special Topics - Physics Education Research*, *2*(010101), 010101. doi:10.1103/PhysRevSTPER.2.010101

Adams, W. K., Wieman, C. E., Perkins, K. K., & Barbera, J. (2008). Modifying and Validating the Colorado Learning Attitudes about Science Survey for Use in Chemistry. *Journal of Chemical Education*, *85*(10), 1435. doi:10.1021/ed085p1435

AIB Education Office. (2010). *The Influence of Bio2010: Results of a Survey*.

Albanese, M., & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine*, *68*(1), 52–81.

Allen, D. E., & Duch, B. J. (1998). *Thinking toward solutions: Problem-based learning activities for general biology*. Harcourt College Publishing.

Allen, D., & Tanner, K. (2005). Infusing active learning into the large-enrollment biology class: seven strategies, from the simple to complex. *Cell Biology Education*, *4*(4), 262–268. Retrieved from http://ww.lifescied.org/content/4/4/262.full

Armbruster, P., & Patel, M. (2009). Active learning and student-centered pedagogy improve student attitudes and performance in introductory biology. *CBE—Life Sciences Education*, *8*, 203–213. Retrieved from http://lifescied.org/cgi/content/abstract/8/3/203

Baldwin, J. A. J., Ebert-May, D., & Burns, D. J. D. (1999). The Development of a College Biology Self-Efficacy Instrument for Nonmajors. *Science Education*, *83*, 397–408. Retrieved from http://first2.plantbiology.msu.edu/resources/literature/pdfs/Baldwin_99.pdf

Bauersfeld, H. (1980). Hidden dimensions in the so-called reality of a mathematics classroom. . *Educational Studies in Mathematics*, *11*, 23–41.

Bauersfeld, H. (1988). Interaction, construction, and knowledge: Alternative perspectives for mathematics education. In *T. Cooney & D. Grouws (Eds.), Effective Mathematics Teaching.* (pp. 27–46). Reston, VA: National Council of Teachers of Mathematics and Lawrence Erlbaum Associates.

Belenky, Mary Field, Clinchy, B. M., Goldberger, N. R., & Tarule, J. M. (1986). *Women's ways of knowing: The development of self, voice, and mind* (p. 256). New York, NY: Basic Books.

Bernstein, R. J. (1983). *Beyond objectivism and relativism: Science, hermeneutics, and praxis.* . Philadelphia: University of Pennsylvania Press.

Bialek, W., & Botstein, D. (2004). Introductory science and mathematics education for 21st-century biologists. *Science Signalling*, *303*(5659), 788–790. doi:10.1126/science.1095480

Bing, T. J. (2008). *An epistemic framing analysis of upper level physics students' use of mathematics*. University of Maryland. Retrieved from http://www.lib.umd.edu/drum/handle/1903/8528

Bing, T. J., & Redish, E. F. (2009). Analyzing Problem Solving Using Math in Physics: Epistemological framing via warrants. *Phys. Rev. STPER*, *5*(020108), 15. Retrieved from http://prst-per.aps.org/abstract/PRSTPER/v5/i2/e020108

Blumberg, P., & Michael, J. A. (1992). Development of self-directed learning behaviors in a partially teacher-directed problem-based learning curriculum. *Teaching and learning in medicine*, *4*(1), 3–8.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, *26*(3), 369–398.

Bonwell, C., & Eison, J. (1991). *Active learning: Creating excitement in the classroom. ASHE-ERIC Higher Education Reports*. Washington, D.C. Retrieved from www.gwu.edu/~eriche.

Boyes, E., & Stanisstreet, M. (1991). Misconceptions in First-Year Undergraduate Science Students about Energy Sources for Living Organisms. *Journal of Biological Education*, *25*(3), 209–213.

Bredo, E. (1994). Reconstructing educational psychology: Situated cognition and Deweyian pragmatism. *Educational Psychologist*, *29*(1), 23–25.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational researcher*, *18*(1), 32–42. Retrieved from http://edr.sagepub.com/content/18/1/32.short

Bruner, J. S. (1977). *The process of education*. Cambridge: Harvard University Press.

Buehl, M. M., & Alexander, P. A. (2006). Examining the dual nature of epistemological beliefs. *International Journal of Educational Research*, *45*(1-2), 28–42.

Campbell, N. A., & Reece, J. B. (2008). *Biology Eighth Edition* (8th ed.). Benjamin Cummings. Retrieved from http://www.amazon.com/dp/0321536169

Carey, S. (1986). Cognitive science and science education. *American Psychologist*, *41*(10), 1123–1130. doi:10.1037//0003-066X.41.10.1123

Carey, S. (1992). The origin and evolution of everyday concepts (In RN Giere, ed.). In *Cognitive Models of Science* (Vol. 15, pp. 89–128).

Chang, M., Cerna, O., Han, J., & Sàenz, V. (2008). The contradictory roles of institutional status in retaining underrepresented minorities in biomedical and behavioral science majors. *The Review of Higher Education.* Retrieved from http://muse.jhu.edu/journals/rhe/summary/v031/31.4.chang.html

Chi, M. T. . H. (2005). Commonsense Conceptions of Emergent Processes: Why Some Misconceptions Are Robust. *Journal of the Learning Sciences*, *14*(2), 161–199. doi:10.1207/s15327809jls1402_1

Clay, T. W., Fox, J. B., Grünbaum, D., & Jumars, P. A. (2008). How Plankton Swim: An Interdisciplinary Approach for Using Mathematics & Physics To Understand the Biology of the Natural World. *The American Biology Teacher*, *70*(6), 363–370.

Clement, J., Brown, D. E., & Zietsman, A. (1989). Not all preconceptions are misconceptions: finding “anchoring conceptions” for grounding instruction on students’ intuitions. *International Journal of Science Education*, *11*(5), 554–565.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational Researcher*, *23*(7), 13–20. Retrieved from http://edr.sagepub.com/content/23/7/13.short

Cobb, P., Wood, T., & Yackel, E. (1993). Discourse, mathematical thinking, and classroom practice. In *In N. Minick, E. Forman, & A. Stone Education and Mind: Institutional, Social, and Developmental Processes* (pp. 91–119). New York: Oxford University Press.

Cole, M., Gay, J., Glick, J., & Sharp, D. W. . (1971). *The cultural context of learning and thinking*. New York: Basic Books.

Corden, R. (2001). Group discussion and the importance of a shared perspective: learning from collaborative research. *Qualitative Research*, *1*(3), 347. Retrieved from http://qrj.sagepub.com/content/1/3/347.short

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*. St Leonards NSW 2065 Australia: Sage.

Davydov, V. V. (1988). Problems of developmental teaching (part I). *Soviet Education*, *30*(8), 6–97.

Derting, T. L., & Ebert-May, D. (2010). Learner-centered inquiry in undergraduate biology: positive relationships with long-term student achievement. *CBE life sciences education*, *9*(4), 462–72. doi:10.1187/cbe.10-02-0011

diSessa, A. (1993). Towards an epistemology of physics. *Cognition and Instruction*, *10*(2-3), 105–225. Retrieved from http://www.jstor.org/stable/3233725

diSessa, A., Elby, A., & Hammer, D. (2002). J's Epistemological Stance and Strategies. In G. M. Sinatra & P. R. Pintrich (Eds.), *Intentional Conceptual Change*. Mahweh, NJ: Lawrence Erlbaum Associates.

Dubin, R., & Taveggia, T. C. (1968). *The Teaching-Learning Paradox: A Comparative Analysis of College Teaching Methods.* Eugene, Oregon: Univerisity of Oregon Press. Retrieved from http://eric.ed.gov/ERICWebPortal/recordDetail?accno=ED026966

Duschl, R. A. (1992). *Philosophy of Science, Cognitive Psychology, and Educational Theory and Practice* (p. 287). SUNY Press.

Dweck, C. (2000). *Self-theories: Their role in motivation, personality, and development*. Psychology Press.

Ebert-May, D., Batzli, J., & Lim, H. (2003). Disciplinary research strategies for assessment of learning. *Bioscience*, *53*(12), 1221–1228. Retrieved from http://www.jstor.org/stable/10.1641/0006-3568(2003)053[1221:DRSFAO]2.0.CO;2

Ebert-May, D., Brewer, C., & Allred, S. (1997). Innovation in large lectures: Teaching for active learning. *Bioscience*, *47*(9), 601–607. Retrieved from http://www.jstor.org/stable/1313166

Ebert-May, D., & Hodder, J. (2008). *Pathways to scientific teaching*. Sinauer Associates. Retrieved from https://www.msu.edu/course/plb/802/frontiers/pdfs/ebertmay_2004_1.pdf

Eisobu, G. O., & Soyibo, K. (1995). Effects of concept and vee mapping under three learning models on students' cognitive achievement in ecology and genetics. *Journal of Research in Science Teaching*, *32*, 971–995.

Elby, A. (1999). Another reason that physics students learn by rote. *American Journal of Physics*, *67*(S1), S52–S57. Retrieved from http://link.aip.org/link/?AJPIAS/67/S52/1

Elby, A. (2001). Helping physics students learn how to learn. *American Journal of Physics*, *69*(S1), S54. doi:10.1119/1.1377283

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education*, *85*(5), 554–567.

Elby, A., Scherr, R., McCaskey, T., Hodges, R., Redish, E. F., & Hammer, D. (2007). *Maryland Tutorials in Physics Sense-making*. College Park, MD: Funded by NSF DUE-0341447.

Engeström, Y. (1999). *Activity theory and individual and social transformation*. (R. Miettinen & R. Punamäki, Eds.)*Perspectives on Activity Theory* (pp. 19–38). Cambridge University Press.

Freeman, S. (2008). *Biological Science* (3rd ed.). Benjamin Cummings.

Garvin-Doxas, K., Klymkowsky, M., & Elrod, S. (2007). Building, using, and maximizing the impact of concept inventories in the biological sciences: report on a National Science Foundation sponsored conference on the construction of concept inventories in the biological sciences. *CBE-Life Sciences Education*, *6*(4), 277–282. Retrieved from http://lifescied.org/cgi/content/abstract/6/4/277

Garvin-Doxas, K., & Klymkowsky, M. W. (2008). Understanding randomness and its impact on student learning: lessons learned from building the Biology Concept Inventory (BCI). *CBE-Life Sciences Education*, *7*(2), 227–233. Retrieved from http://lifescied.org/cgi/content/abstract/7/2/227

Glasersfeld, E. von (1989). Cognition, construction of knowledge, and teaching. *Synthese*, *80*(1), 121–140. doi:10.1007/BF00869951

Glasersfeld, E. von (1989). Constructivism in education. In T. Husen & N. Postlewaite (Eds.), *In International Encyclopedia of Education* . Retrieved from http://www.citeulike.org/group/6308/article/3832814

Goffman, I. (1997). *Frame Analysis: An essay on the organization of experience*. Northeastern U. Press.

Goodwin, H. A., & Davis, B. L. (2005). Teaching undergraduates at the interface of chemistry and biology: challenges and opportunities. *Nature Chemical Biology*, *1*, 176–179.

Gredler, M. E. (1997). *Learning and instruction: Theory into practice* (3rd ed.). Upper Saddle River, NJ: Prentice-Hall.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American psychologist*, *53*(1), 5. Retrieved from http://psycnet.apa.org/journals/amp/53/1/5/

Greeno, J. G., Collins, A., & Resnick, L. B. (1996). Cognition and learning. In D. Berliner & R. Calfee (Eds.), *Handbook of Educational Psychology* (Vol. 1968, pp. 15–46). New York, NY, US: Macmillan.

Gresser, P. (2006). *A study of social interaction and teamwork in reformed physics laboratories*. Retrieved from http://drum.lib.umd.edu/handle/1903/3362

Grossman, P., & McDonald, M. (2008). Back to the future: Directions for research in teaching and teacher education. *American Educational Research Journal*, *45*(1), 184. Retrieved from http://aer.sagepub.com/content/45/1/184.short

Grove, N., & Bretz, S. (2007). CHEMX: An instrument to assess students' cognitive expectations for learning chemistry. *Journal of Chemical Educationhemical education*, *84*(9), 1524–1529. Retrieved from http://www.users.muohio.edu/bretzsl/Bretz.JCE.2007(1).pdf

Hake, R. R. (1998). Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*, 64–74. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.46.6997&rep=rep1&type=pdf

Hall, K.L. (2010). Student Attitudes Towards Using Physics in Biology. *AAPT annual meeting.* Washington, DC.

Hall, K.L., Watkins, J. E., Coffey, J. E., Cooke, T. J., & Redish, E. F. (2011). Examining the Impact of Student Expectations on Undergraduate Biology Education Reform. In *AERA National Meeting-Spring 2011*.

Halloun, I. (1997). Views about science and physics achievement: The VASS story. In *AIP Conference Proceedings* (Vol. 399, p. 605). Retrieved from http://link.aip.org/link/?APCPCS/399/605/1

Hammer, D. (1989). Two approaches to learning physics. *The Physics Teacher*, *27*(9), 664–670. Retrieved from http://www.mtsd.k12.nj.us/645938927141035/lib/645938927141035/_files/Hammer_paper.pdf

Hammer, D. (1994). Epistemological beliefs in introductory physics. *Cognition and Instruction*, *12*(2), 151–183.

Hammer, D. (1996a). More than misconceptions: Multiple perspectives on student knowledge and reasoning, and an appropriate role for education research. *American Journal of Physics*, *64*(10), 1316–1325. doi:10.1119/1.18376

Hammer, D. (1996b). Misconceptions or p-prims: How may alternative perspectives of cognitive structure influence instructional perceptions and intentions? *Journal of the Learning Sciences*, *5*(2), 97–127. doi:10.1207/s15327809jls0502_1

Hammer, D. (2000). Student Resources for Learning Introductory Physics. *American Journal of Physics*, *68*(S1), S52–S59.

Hammer, D., & Elby, A. (2002). On the form of a personal epistemology (in B. K. Hofer & P. R. Pintrich eds.), *Personal Epistemology: The Psychology of Beliefs About Knowledge and Knowing* (pp. 169–190). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.114.7178&rep=rep1&type=pdf

Hammer, D., & Elby, A. (2003). Tapping students' epistemological resources. *Journal of the Learning Sciences*, *12*(1), 53–91.

Hammer, D., Elby, A., Scherr, R. E., & Redish, E. F. (2004). Resources, framing, and transfer (In J. Mestre ed.). In J. Mestre (Ed.), *Transfer of Learning from a Modern Multidisciplinary Perspective* (pp. 89–120). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.76.9210&rep=rep1&type=pdf

Hammer, D., & Smith, A. (1996). Misconceptions or p-prims: How may alternative perspectives of cognitive structure influence instructional perceptions and intentions? *Journal of the Learning Sciences*, *5*(2), 97–127. doi:10.1207/s15327809jls0502_1

Handelsman, J., Miller, S., & Pfund, C. (2006). *Scientific Teaching*. WH Freeman & Co.

Hofer, B. K. (2006). Domain specificity of personal epistemology: Resolved questions, persistent issues, new models. *International Journal of Educational Research*, *45*(1-2), 85–95. Retrieved from http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VDF-4M4KK7V-1&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=30cafef56055c549a49376946df7c964

Hofer, B. K, & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learningHofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to l. *Review of Educational Research*, *67*(1), 88–140. Retrieved from http://rer.sagepub.com/cgi/content/abstract/67/1/88

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *CONTEMPORARY EDUCATIONAL PSYCHOLOGY*, *25*(4), 378–405. doi:10.1006/ceps.1999.1026

Hofer, B. K., & Pintrich, P. R. (2012). *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing*. Routledge. Retrieved from http://www.questia.com/PM.qst?a=o&se=gglsc&d=107259510

Hofer, Barbara K., & Pintrich, P. R. (1997). The Development of Epistemological Theories: Beliefs About Knowledge and Knowing and Their Relation to Learning. *Review of Educational Research*, *67*(1), 88–140. doi:10.3102/00346543067001088

Hofer, B, K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review*, Volume 13, Issue 4, pp 353-383. Retrieved from http://www.springerlink.com/index/R6R6241GP87047K6.pdf

Hoskins, S. G., Lopatto, D., & Stevens, L. M. (2011). The C.R.E.A.T.E. approach to primary literature shifts undergraduates' self-assessed ability to read and analyze journal articles, attitudes about science, and epistemological beliefs. *CBE life sciences education*, *10*(4), 368–78. doi:10.1187/cbe.11-03-0027

Hulleman, C. S., & Harackiewicz, J. M. (2009). Promoting interest and performance in high school science classes. *Science*, *326*(5958), 1410.

Inhelder, B., & Piaget, J. (1999). *The growth of logical thinking from childhood to adolescence* (Vol. 22). Routledge.

Jimenez-Aleixandre, M., Rodriguez, A., & Duschl, R. (2000). “ Doing the lesson” or“ doing science”: Argument in high school genetics. *Science Education*, *84*(6), 757–792. Retrieved from http://praza.com/xornal/uploads/23605363-SciEd-Doing-the-lesson-or-doing-science-argument-in-high-school-genetics.pdf

Kanter, D. E., Lee, V. R., & Sherin, B. L. (working paper). Changing conceptual ecologies: A case study of learning in a task-structured science curriculum.

Kelly, G. J., Carlsen, W. S., & Cunningham, C. M. (1993). Science education in sociocultural context: Perspectives from the sociology of science. *Science Education*, *77*(2), 207–220. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/sce.3730770208/abstract

Khodor, J., Halme, D. G., & Walker, G. C. (2004). A hierarchical biology concept framework: a tool for course design. *CBE-Life Sciences Education*, *3*(2), 111–121. Retrieved from http://lifescied.org/cgi/content/abstract/3/2/111

King, P. M., & Kitchener, K. S. (1994). *Developing Reflective Judgment: Understanding and Promoting Intellectual Growth and Critical Thinking in Adolescents and Adults. Jossey-Bass Higher and Adult Education Series and Jossey-Bass Social and Behavioral Science Series.* Jossey-Bass, 350 Sansome Street, San Francisco, CA 94104-1310

Klymkowsky, M. W, & Garvin-Doxas, K. (2008). Recognizing student misconceptions through ed’s tools and the biology concept inventory. *PLoS Biol*, *6*(1), e3. Retrieved from http://www.plosbiology.org/article/info:doi/10.1371/journal.pbio.0060003

Labov, J. B., Reid, A. H., & Yamamoto, K. R. (2010). *From the National Academies Integrated Biology and Undergraduate Science Education: A New Biology*

*Education for the Twenty-First Century?* (Vol. 9, pp. 10–16). Washington, D.C. doi:10.1187/cbe.09

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Laws, P., Sokoloff, D., & Thornton, R. (1999). Promoting active learning using the results of physics education research. *UniServe Science News*, *13*, 14–18. Retrieved from http://sydney.edu.au/science/uniserve_science/newsletter/vol13/vol13.pdf#page=14

Lemke, J. L. (2001). Articulating communities: Sociocultural perspectives on science education. *Journal of research in science teaching*, *38*(3), 296–316. Retrieved from http://www.colorado.edu/physics/phys4810/phys4810_fa06/4810_readings/Lemke_reading2.pdf

Lippmann, R. F. (2003). *Students' understanding of measurement and uncertainty in the physics laboratory: Social construction, underlying concepts, and quantitative analysis*. Retrieved from http://adsabs.harvard.edu/abs/2003PhDT.......190L

Lising, L., & Elby, A. (2005). The impact of epistemology on learning: A case study from introductory physics. *American Journal of Physics*, *73*, 372. Retrieved from http://ajp.aapt.org/resource/1/ajpias/v73/i4/p372_s1

Louca, L., Elby, A., Hammer, D., & Kagey, T. (2004). Epistemological resources: Applying a new epistemological framework to science instruction. *Educational Psychologist*, *39*(1), 57–68.

M. Schommer. (1990). The effects of beliefs about the nature of knowledge in comprehension. *Journal of Educational Psychology*, *82*(3), 498 – 504.

Magolda, B. (1992). *Knowing and reasoning in college: Gender-related patterns in students' intellectual development. Knowing and Reasoning in College: Gender-related* …. San Francisco: Jossey-Bass. Retrieved from http://scholar.google.com/scholar?hl=en&q=Baxter+Magolda,+1992&btnG=&as_sdt=1,9&as_sdtp=#0

Maple, S., & Stage, F. (1991). Influences on the choice of math/science major by gender and ethnicity. *American Educational Research Journal*. Retrieved from http://aer.sagepub.com/content/28/1/37.short

Matsumura, L. C., Slater, S. C., & Crosson, A. (2008). Classroom climate, rigorous instruction and curriculum, and students' interactions in urban middle schools. *The Elementary School Journal*, *108*(4), 293–312. Retrieved from http://scholar.google.com/scholar?hl=en&q=Matsumara,+Slater+&+Crosson,+2008+education&btnG=Search&as_sdt=0,9&as_ylo=&as_vis=0#0

Matthews, K. E., Adams, P., & Goos, M. (2010). Using the Principles of BIO2010 to Develop an Introductory , Interdisciplinary Course for Biology Students. *CBE - Life Sciences Education*, *9*, 290 –297. doi:10.1187/cbe.10

Mayer, R. E. (2004). Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. *The American psychologist*, *59*(1), 14–9. doi:10.1037/0003-066X.59.1.14

McCaskey, T. (2009). *Comparing and Contrasting Different Methods for Probing Student Epistemology and Epistemological Development in Introductory Physics*. University of Maryland.

McClanahan, E. B., & McClanahan, L. L. (2002). Active learning in a non-majors biology class: lessons learned. *College Teaching*, 92–96. Retrieved from http://www.jstor.org/stable/27559095

McCloskey, M. (1983). Naive theories of motion. In D. Gentner & A. Stevens (Eds.), *Mental Models* (pp. 299–324). Retrieved from http://books.google.com/books?hl=en&lr=lang_en&id=QFI0SvbieOcC&oi=fnd&pg=PA299&dq=M.+McCloskey,+?Naive+theories+of+motion&ots=rSm_OCZtMJ&sig=WciObiPj-HJwcl2ZuThcCABd1m4

McCray, R. A., Dehaan, R. L., & Schuck, J. A. (2003). *Improving Undergraduate Instruction in Science, Technology, Engineering, and Mathematics: Report of a Workshop*. Washington, D.C.: The National Academies Press.

McMahon, M. (1997). Social Constructivism and the World Wide Web - A Paradigm for Learning. In *Paper Presented at the ASCILITE Conference.* Perth, Australia.

Mehan, H., & Wood, H. (1975). *The reality of ethnomethodology.* New York: John Wiley.

Michael, J. A. (2006). Where's the evidence that active learning works? *Advances in physiology education*, *30*(4), 159–167. doi:10.1152/advan.00053.2006

Michael, J. A. (2007). Faculty perceptions about barriers to active learning. *College Teaching*, *55*(2), 42–47.

Michael, J. A., & Modell, H. I. (2003). *Active learning in secondary and college science classrooms: a working model for helping the learner to learn*. Lawrence Erlbaum.

Michael, J. A., Wenderoth, M. P., Modell, H. I., Cliff, W., Horwitz, B., McHale, P., Whitescarver, S. (2003). Undergraduates' understanding of cardiovascular phenomena. *Advan. Physiol. Edu.*, *26*(2), 72–84. Retrieved from http://advan.physiology.org/cgi/content/abstract/26/2/72

Miller, J. E., & Cheetham, R. D. (1990). Teaching freshmen to think-active learning in introductory biology. *Bioscience*, *40*(5), 388–391. Retrieved from http://www.jstor.org/stable/1311217

Minick, N. (1989). *L. S. Vygotsky anti Soviet activity theory: Perspectives on the relationship between mind and society.* . Newton, MA: Literacies Institute: Educational Development Center, Inc.

Most, S., Scholl, B., Clifford, E. ., & Simons, D. (2005). What you see is what you set: sustained inattentional blindness and the capture of awareness. *Psychological review*, *Vol 112*(1), 217–242. Retrieved from http://psycnet.apa.org/psycinfo/2004-22409-009

NAS. (1990). *Fulfilling the Promise: Biology Education in the Nation's Schools*. Washington, D.C.: The National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=1533

NAS. (1991). *Moving Beyond Myths:Revitalizing Undergraduate Mathematics*. Washington, D.C.: The National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=1782

NAS. (1992). *Research and Education Reform:Roles for the Office of Educational Research and Improvement*. Washington, D.C.: The National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=1973

National Commission on Excellence in Education. (1983). *A Nation at Risk: The Imperative for educational reform*. Washington, D.C. Retrieved from http://www2.ed.gov/pubs/NatAtRisk/index.html

National Research Council. (1996). *From Analysis to Action: Undergraduate education in science, mathematics, engineering, and technology*. Washington, D.C. Retrieved from http://www.nationalacademies.org/publications/

National Research Council. (1997). *Science Teaching Reconsidered: A handbook*. Washington, D.C. Retrieved from http://www.nationalacademies.org/publications/

National Research Council. (1999). *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology*. Washington, D.C. Retrieved from http://www.nationalacademies.org/publications/

National Research Council. (2000). *How People Learn: Brain, Mind, Experience and School*. Washington, DC.

National Research Council. (2003). *Bio 2010: Transforming Undergraduate Education for Future Research Biologists*. Washington, DC.

National Research Council. (2009). *A New Biology for the 21st Century: Ensuring the United States leads the coming biology revolution*. Washington, D.C. Retrieved from http://www.nap.edu/catalog.php?record_id=12764

National Science Board. (1986). *Undergraduate Science, Mathematics, and Engineering Education: Role for the National Science Foundation and Recommendations for Action by Other Sectors to Strengthen Collegiate Education and Pursue Excellence in the Next Geberation of U.S. Leadership in S*. Washington, D.C.

National Science Foundation. (1996). *Shaping the Future: New expectations for undergraduate education in science, mathematics, engineering, and technology*. Arlington, Va.

Nehm, R. H., & Reilly, L. (2007). Biology majors' knowledge and misconceptions of natural selection. *BioScience*, *57*(3), 263–272. Retrieved from http://www.bioone.org/doi/abs/10.1641/B570311

Newman, D., Griffin, P., & Cole, M. (1989). *The Construction Zone: Working for cognitive change in school*. Cambridge: Cambridge University Press.

Niaz, M., Aguilera, D., Maza, A., & Liendo, G. (2002). Arguments, contradictions, resistances, and conceptual change in students' understanding of atomic structure. *Science Education*, *86*(4), 505–525. Retrieved from http://www3.interscience.wiley.com/journal/94518609/abstract

Norman, G. R., & Schmidt, H. G. (2000). Effectiveness of problem-based learning curricula: theory, practice and paper darts. *Medical Education*, *34*(9), 721–728. Retrieved from http://www3.interscience.wiley.com/journal/119185509/abstract

NRC. (2012). *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*. (S. Singer, N. Nielsen, & H. Schweingruber, Eds.) (p. 261). National Academies Press.

Nystrand, M. (2006). Research on the role of classroom discourse as it affects reading comprehension. *Research in the Teaching of English*, *40*(4), 392–412. Retrieved from http://www.jstor.org/stable/40171709

O'Connell, D. (2008). An Inquiry-based Approach to Teaching Photosynthesis & Cellular Respiration. *The American Biology Teacher*, *70*(6), 350–356. Retrieved from http://www.bioone.org/doi/abs/10.1662/0002-7685(2008)70[350:AIATTP]2.0.CO;2

O'loughlin, M. (1992). Rethinking science education: Beyond Piagetian constructivism toward a sociocultural model of teaching and learning. *Journal of Research in Science Teaching*, *29*(8), 791–820. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/tea.3660290805/abstract

Palmer, B., & Marra, R. (2004). College student epistemological perspectives across knowledge domains: A proposed grounded theory. *Higher Education*, *47*(3), 311–335. Retrieved from http://www.springerlink.com/index/qnh9611039623517.pdf

Pellegrino, J. W. (2006). *Rethinking and Redesigning Curriculum, Instruction and Assessment: What Contemporary Research and Theory Suggests*. *National Center on Education and the Economy*.

Perry, W. F. (1970). *Forms of Intellectual and Ethical Development in the College Years*. Holt, Rinehart, & Wilson.

Piaget, J. (1999a). *The psychology of intelligence* (Vol. 26). Routledge.

Piaget, J. (1999b). *The construction of reality in the child* (Vol. 20). Psychology Press.

Piaget, J., & Cook, M. T. (1952). *The origins of intelligence in children.* New York, NY, US: WW Norton & Co. Retrieved from http://psycnet.apa.org/psycinfo/2007-10742-000/

Piaget, J., & Inhelder, B. (1969). *The psychology of the child* (Vol. 5001). Basic Books.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science education*, *66*(2), 211–227. Retrieved from http://ci.unlv.edu/files/Week6_Posner_et_al_Optional.pdf

Prawat, R. S., & Floden, R. E. (1994). Philosophical perspectives on constructivist views of learning. *Educational Psychologist*, *29*(1), 37–48. Retrieved from http://www.tandfonline.com/doi/abs/10.1207/s15326985ep2901_4

Prince, M. (2004). Does active learning work? A review of the research. *JOURNAL OF ENGINEERING EDUCATION-WASHINGTON-*, *93*(3), 223–232.

Putnam, H. (1987). *The many faces of realism.* LaSalle, IL: Open Court.

Raven, P. H., Johnson, G. B., Losos, J. B., Mason, K. A., & Singer, S. R. (2000). *Biology* (8th ed.). McGraw-Hill.

Rawson, R. E., & Quinlan, K. M. (2002). Evaluation of a computer-based approach to teaching acid/base physiology. *Advances in physiology education*, *26*(2), 85–97. Retrieved from http://advan.physiology.org/cgi/content/abstract/26/2/85

Redish, E. F. (2003). *Teaching physics: with the physics suite*. Hoboken, NJ : John Wiley & Sons. Retrieved from http://www2.physics.umd.edu/~redish/Book/toc.pdf

Redish, E. F. (2009). A Theoretical Framework for Physics Education Research: Modeling Student Thinking. *American Journal of Physics*, *77*(7), 629–642.

Redish, E. F., & Hammer, D. (2009). Reinventing college physics for biologists: Explicating an epistemological curriculum. *American Journal of Physics*, *77*(7), 629. doi:10.1119/1.3119150

Redish, Edward F., & Hammer, D. (2009). Reinventing college physics for biologists: Explicating an epistemological curriculum. *American Journal of Physics*, *77*(7), 629–642. doi:10.1119/1.3119150

Redish, Edward F., Saul, J. M., & Steinberg, R. N. (1998). Student expectations in introductory physics. *American Journal of Physics*, *66*(3), 212–224. doi:10.1119/1.18847

Reiner, M., & Gilbert, J. (2000). Epistemological resources for thought experimentation in science learning. *International Journal of Science Education*, *22*(5), 489–506.

Reingold, I. D. (2005). Organic first: A biology-friendly chemistry curriculum. *CBE-Life Sciences Education*, *4*(4), 281–283. Retrieved from http://lifescied.org/cgi/content/full/4/4/281

Reznitskaya, A., Anderson, R. C., & Kuo, L. J. (2007). Teaching and learning argumentation. *The Elementary School Journal*, *107*(5), 449–472. Retrieved from http://www.jstor.org/stable/10.1086/518623?journalCode=esj

Reznitskaya, A., Kuo, L. J., Clark, A. M., Miller, B., Jadallah, M., Anderson, R. C., & Nguyen-Jahiel, K. (2009). Collaborative reasoning: a dialogic approach to group discussions. *Cambridge Journal of Education*, *39*(1), 29–48. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/03057640802701952

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context.* Oxford: Oxford University Press.

Rorty, R. (1978). *Philosophy and the mirror of nature.* Princeton: Princeton University Press.

Roth, W-M., & Roychoudhury, A. (1994). Physics students' epistemologies and views about knowing and learning. *Journal of Research in Science Teaching*, *31*, 5–30.

Roth, Wolff-Michael, & Roychoudhury, A. (1994). Physics students' epistemologies and views about knowing and learning. *Journal of Research in Science Teaching*, *31*(1), 5–30. doi:10.1002/tea.3660310104

Russ, R. S., Scherr, R. E., Hammer, D., & Mikeska, J. (2008). Recognizing mechanistic reasoning in student scientific inquiry: A framework for discourse analysis developed from philosophy of science. *Science Education*, *92*(3). Retrieved from http://www2.physics.umd.edu/~rescherr/Mech.pdf

Ryan, M. P. (1984). Monitoring text comprehension: Individual differences in epistemological standards. *Journal of Educational Psychology*, *76*(2), 248.

Scherr, R. E., & Hammer, D. (2008). Student behavior and epistemological framing: examples from collaborative active-learning activities in physics. In *Cognition and Instruction* (Vol. 27, pp. 147–174). Retrieved from http://portal.acm.org/citation.cfm?id=1599871.1599909

Schoenfeld, A.H. (1987). *Cognitive science and mathematics education*. Lawrence Erlbaum.

Schoenfeld, A.H. (1988). Problem solving in context (s). *The teaching and assessing of mathematical problem solving*, *3*, 82–92.

Schoenfeld, A. H. (1988). When Good Teaching Leads to Bad Results: The Disasters of "Well-Taught" Mathematics Courses. *Educational Psychologist*, *23*(2), 145–166. doi:10.1207/s15326985ep2302_5

Schommer, M. (1993). Comparisons of beliefs about the nature of knowledge and learning among postsecondary students. *Research in Higher Education*, *34*(3), 355–370. Retrieved from http://www.springerlink.com/index/j52h2664g38lq9g0.pdf

Schommer, M., & Calvert, C. (1997). The development of epistemological beliefs among secondary students: A longitudinal study. *Journal of Educational Psychology*, *89*(1), 37–40. Retrieved from http://psycnet.apa.org/?fa=main.doiLanding&doi=10.1037/0022-0663.89.1.37

Schommer, M., Crouse, A., & Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology*, *Vol 84*(4), 435–443. Retrieved from http://psycnet.apa.org/journals/edu/84/4/435/

Semsar, K., Knight, J. K., Birol, G., & Smith, M. K. (2011). The Colorado Learning Attitudes about Science Survey (CLASS) for use in Biology. *CBE-life sciences education*, *10*(3), 268–278. doi:10.1187/cbe.10-10-0133

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Boulder, Colo.: Westview Press .

Shor, I. (1992). *Empowering education: critical teaching for social change.* Chicago: University of Chicago Press. Retrieved from http://eric.ed.gov/ERICWebPortal/search/detailmini.jsp?_nfpb=true&_&ERICExtSearch_SearchValue_0=ED359303&ERICExtSearch_SearchType_0=no&accno=ED359303

Skinner, K. M., & Hoback, W. W. (2003). Web-based, active learning experiences for biology students. *Bioscene*, *29*(1), 23–29. Retrieved from http://amcbt.indstate.edu/volume_29/v29-1p23-29.pdf

Smith, A. C., Stewart, R., Shields, P., Hayes-Klosteridis, J., Robinson, P., & Yuan, R. (2005). Introductory biology courses: a framework to support active learning in large enrollment introductory science courses. *Life Sciences Education*, *4*(2), 143. Retrieved from http://www.lifescied.org/cgi/content/abstract/4/2/143

Smith, J. P., DiSessa, A. A., & Roschelle, J. (1993). Misconceptions Reconceived: A Constructivist Analysis of Knowledge in Transition. *The Journal of the Learning Sciences*, *3*(2), 115–163.

Smith, T. I., & Wittmann, M. C. (2008). Applying a resources framework to analysis of the Force and Motion Conceptual Evaluation. *Phys. Rev. ST Phys. Educ. Res.*, *4*(020101).

Sokoloff, D. R., & Thornton, R. K. (1997). Using interactive lecture demonstrations to create an active learning environment. *The Physics Teacher*, *35*(6), 340–347. doi:10.1119/1.2344715

Southerland, S. A., Abrams, E., Cummins, C. L., & Anzelmo, J. (2001). Understanding Students' Explanations of Biological Phenomena: Conceptual Frameworks or P-Prims? *Science Education*, *85*, 328–348.

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta-Analysis. *Review of Educational Research*, *69*(1), 21–51. doi:10.3102/00346543069001021

Stanley, L. (1990). *Feminist praxis: Research, theory, and epistemology in feminist sociology*. Routledge.

Steen, L. A. (2005). Math & Bio 2010: Linking Undergraduate Disciplines. Retrieved from http://www.maa.org/mtc/projectreport.html

Steffe, L. (1999). *Prospects for alternative epistemologies in education*. (L. E. Associates, Ed.)*Constructivism in Education.* Hillsdale, NJ: Sage Publications Ltd.

Strike, K. A., & Posner, G. J. (1992). A Revisionist Theory of Conceptual Change. In R. A. Duschl & R. J. Hamilton (Eds.), *Philosophy of Science, Cognitive Psychology, and Educational Theory and Practice* (pp. 147–176). Albany: SUNY Press.

Summer institute to improve university science teaching. (2009). *Science*. Retrieved from http://www.sciencemag.org/content/324/5926/470.short

Tannen, D. (1993a). *Framing in discourse*. Oxford University Press New York.

Tannen, D. (1993b). What's in a Frame? Surface Evidence for Underlying Expectations. In *Framing in Discourse* (pp. 14–56).

Tobias, S. (1992). *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't*. Research Corporation. Retrieved from http://eric.ed.gov/ERICWebPortal/custom/portlets/recordDetails/detailmini.jsp?_nfpb=true&_&ERICExtSearch_SearchValue_0=ED357975&ERICExtSearch_SearchType_0=no&accno=ED357975

Tobias, S. (1990). *They're not dumb, they're different: stalking the second tier*. *The Author Would Like to Thank Dr*. Tuscon, Az.

Tobias, S. (2000). From Innovation to Change: Forging a Physics Education Reform Agenda for the 21st Century. *American Journal of Physics*, *68*(2), 103–104.

Tuminaro, J. (2003). *A cognitive framework for analyzing and describing introductory students' use and understanding of mathematics in physics*. University of Maryland. Retrieved from http://www.physics.umd.edu/perg/Dissertations/Tuminaro

Tuminaro, J., & Redish, E. F. (2007). Elements of a cognitive model of physics problem solving: Epistemic games. *Physical Review Special Topics-Physics Education Research*, *3*(2), 20101. Retrieved from http://prst-per.aps.org/abstract/PRSTPER/v3/i2/e020101

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, *211*(4481), 453–458. Retrieved from http://www.brainvitge.org/papers/tverski_kahneman.pdf

Udovic, D., Morris, D., Dickman, A., Postlethwait, J., & Wetherwax, P. (2002). Workshop Biology: Demonstrating the effectiveness of active learning in an introductory biology course. *Bioscience*, *52*(3), 272–281. Retrieved from http://caliber.ucpress.net/doi/full/10.1641/0006-3568(2002)052[0272:WBDTEO]2.0.CO;2?select23=Choose

VanTassel-Baska, J., Bass, G., Ries, R., Poland, D., & Avery, L. D. (1998). A National Study of Science Curriculum Effectiveness With High Ability Students. *Gifted Child Quarterly*, *42*(4), 200–211. doi:10.1177/001698629804200404

Von Glasersfeld, E. (1983). Learning as a constructive activity. *Proceedings of the 5th Annual Meeting of the North American Group of Psy-chology in Mathematics Education*, *1*, 41— 101. Retrieved from http://anti-matters.org/articles/73/public/73-66-1-PB.pdf

Von Glasersfeld, E. (1992). Questions and answers about radical constructivism. In M. K. Pearsall (Ed.), *Scope, Sequence, and Coordination of School Science.* National Science Teachers Association. Retrieved from http://www.citeulike.org/group/8921/article/4046686

Von Glasersfeld, E. (1996). *Radical constructivism: A way of knowing and learning* (Vol. 6). Routledge.

Vosniadou, S. (1992). Knowledge Acquisition and Conceptual Change. *Applied Psychology-an International Review-Psychologie Appliquee-Revue Internationale*, *41*(4), 347–357.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and instruction*, *4*(1), 45–69. Retrieved from http://www.cs.phs.uoa.gr/en/staff/32. vosniadou 1994.pdf

Vygotsky, L. (1978). *Mind in society*. Cambridge, MA: Harvard University Press. Retrieved from http://www.citeulike.org/group/1912/article/563607

Vygotsky, L., Hanfmann, E. E., & Vakar, G. E. (1962). *Thought and language.* Cambridge, MA: MIT press. Retrieved from http://doi.apa.org/psycinfo/2006-10268-000

Vygotsky, L. S. (1979). Consciousness as a problem in the psychology of behavior. . *Soviet Psychology*, *17*(4), 3–35.

Walker, J., & Cotner, S. (2008). A delicate balance: integrating active learning into a large lecture course. *CBE-Life Sciences Education*, *7*(4), 361–367. Retrieved from http://vvww.lifescied.org/content/7/4/361.short

Walker, J. D., Cotner, S. H., Baepler, P. M., & Decker, M. D. (2008). A Delicate Balance: Integrating Active Learning into a Large Lecture Course. *CBE - Life Sciences Education*, *7*, 361–367. doi:10.1187/cbe.08

Walton, K. L. . (2008). Use of case studies and data analysis to improve critical thinking skills in a one-semester anatomy & physiology course. *The FASEB Journal*, *22*(1_MeetingAbstracts), 767–6. Retrieved from http://www.fasebj.org/cgi/content/meeting_abstract/22/1_MeetingAbstracts/767.6

Walton, K. L. ., & Rybarczyk, B. J. (2009). Assessing biology students' critical thinking abilities using a skills-based classification model. *The FASEB Journal*, *23*(1_MeetingAbstracts), 632–11. Retrieved from http://www.fasebj.org/cgi/content/meeting_abstract/23/1_MeetingAbstracts/632.11

Watkins, J., & Elby, A. (2013-in press). Context-dependence of students' views about the role of equations in understanding biology. *CBE-Life Sciences Education*.

Watkins, J., Hall, K. L., Redish, E. F., & Cooke, T. J. (2010). Understanding How Students Use Physical Ideas in Introductory Biology Courses. In *Proceedings of the Physics Education Research Conference* (pp. 333–336.).

Wells, C. G. (1999). *Dialogic inquiry: Towards a sociocultural practice and theory of education*. Cambridge Univ Press.

Williams, K. S., Ebert-May, D., Luckie, D., & Hodder, J. (2004). Ecological controversy: analysis to synthesis. *Frontiers in Ecology and the Environment*, *2*(10), 546–547. Retrieved from http://www.esajournals.org/doi/abs/10.1890/1540-9295(2004)002[0546:ECATS]2.0.CO;2

Wittmann, M. C. (2002). The Object Coordination Class Applied to Wavepulses: Analysing Student Reasoning in Wave Physics. *Int. J. Sci. Ed*, *24*(1), 97–118.

Younie, S., & Leask, M. (2001). Communal constructivist theory: information and communications technology pedagogy and internationalization of the curriculum. *Journal of Information Technology for Teacher Education*, *10*(1,2), 117–134.