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# Assessing Current Instructional Practices In General Biology One (Bio1010) And Arguing For A Model-Centered Curriculum

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

ASSESSING CURRENT INSTRUCTIONAL PRACTICES IN GENERAL  
BIOLOGY ONE (BIO1010) AND ARGUING FOR A MODEL-CENTERED  
CURRICULUM

A dissertation submitted in partial fulfillment of the

requirements for the degree of

DOCTOR OF PHILOSOPHY

in

CURRICULUM AND INSTRUCTION

by

Seth Manthey

2015

To: Dean Delia C. Garcia  
College of Education

This dissertation, written by Seth Manthey, and entitled Assessing Current Instructional Practices in General Biology One (BIO1010) and Arguing for a Model-Centered Curriculum, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

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Mido Chang

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George E. O'Brien

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Eric von Wettberg

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Eric Brewe, Major Professor

Date of Defense: June 17, 2015

The dissertation of Seth Manthey is approved.

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Florida International University, 2015

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Chapter 3 has been reprinted with permission from S. Manthey and E. Brewster, “Towards University Modeling Instruction – Biology: Adapting Curricular Frameworks from Physics to Biology”.

ABSTRACT OF THE DISSERTATION  
ASSESSING CURRENT INSTRUCTIONAL PRACTICES IN GENERAL  
BIOLOGY ONE (BIO1010) AND ARGUING FOR A MODEL-CENTERED  
CURRICULUM

by

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Florida International University, 2015

Miami, Florida

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This collected papers dissertation focused on the argument for the need to adapt and develop a model-centered General Biology I course through the analyses of current instructional practices at a large, public, Hispanic-serving university. This dissertation included a comparison of General Biology I course sections taught in two differing formats, one is a traditional lecture with face-to-face meetings and the other is an online instruction setting. The comparison of these sections was accomplished through the use of a conceptual inventory, student attitude survey, drop-fail-withdraw (DFW) rates, and Social Network Analysis. This comparison found that there was no detectible significant difference between course type for both the conceptual understanding and formation of student-to-student networks. It was also found that there was a significant difference between course type when looking at students' attitudes towards Biology and success in the two course types.

Additionally in a second study the project used a phenomenographic analysis of student interviews that explored the students' use of scientific models when asked

about plant cells and animal cells. It was found that during the analysis of students' ideas that students predominantly used a single model function. The cell types of focus in the second study were two models that were identified, in a third study, through a coded analysis of faculty interviews and textbook analysis. These models are viewed as essential for students to possess an understanding of upon completion of General Biology I.

The model-based course that this study argued for is based on a curricular framework initially developed for use in introductory physics courses. University Modeling Instruction courses in physics (UMI-P) have been linked to improved student conceptual understanding positive attitudinal shifts, and decreased DFW rates. UMI, however, has not been expanded for implementation within the other science disciplines. Drawing from the success of UMI within physics this dissertation focused on the argument for the need for the adaptation and development of UMI for introductory biology.



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## CHAPTER 1 INTRODUCTION

### 1.1. Project Motivation.

For more than a decade, considerable effort has been placed on increasing the number of Science, Technology, Engineering, and Math (STEM) majors and bachelor's degrees awarded within the United States. These efforts are focused on increasing the number of majors/degrees awarded, and also increasing the competitiveness of these majors within the global setting of STEM. The National Research Council (NRC) entered into discussions of how to address these concerns within each of the STEM disciplines (National Research Council, 2007, 2012a). One particular area of emphasis to the National Research Council that serves as an avenue to improve STEM education is through curricular reform efforts.

#### *1.1.1. Curricular Reform in Undergraduate Biology.*

*BIO2010: Transforming Undergraduate Education for Future Research Biologists* (National Research Council, 2003) takes the general discussion regarding improving education in STEM and turns to focus specifically to biology. *BIO2010* outlines curricular changes at both the program and individual class level that are suggested to serve as solutions. Increasing the level and frequency of quantitative analysis is one of the prominent suggestions within *BIO2010*. “Quantitative analysis, modeling, and prediction play increasingly significant day-to-day roles in today’s biomedical research. To prepare for this sea change in activities, biology majors headed for research careers need to be educated in a more quantitative manner (National Research Council, 2003, p. 41).

Embedded within the need for undergraduate biology majors to improve quantitative abilities is the need for them to develop skills in modeling. These modeling skills include understanding modeling as “the process of abstracting certain aspects of reality to include in the simplifications of reality we call models” (p. 43), that “there are trade-offs in modeling – no one model can address all questions. These trade-offs are between generality, precision, and realism” (p. 43), and that “evaluating models depends in part on the purpose for which the model was constructed. Models oriented toward prediction of specific phenomena may require formal statistical validation methods, while models that wish to elucidate general patterns of system response may require corroboration with the available observed patterns” (p. 43).

*Vision and Change in Undergraduate Biology Education: A Call to Action* (Science, 2011), much like *BIO2010*, outlines key areas of importance for improving undergraduate biology. In particular, *Vision and Change*, sets forth both biological concepts – evolution; structure and function; information flow, exchange, and storage; pathways and transformations of energy and matter; and systems – and skills that students should possess upon completion of their undergraduate career. One such skill that *Vision and Change* argues for is that students have the “ability to use modeling and simulations” (Science, 2011, p. 14) as “modeling is a standard tool for biologists” (p. 15). While it may seem that modeling is an area that is only appearing in the literature to shape undergraduate education it has also become an essential aspect of the K-12 curriculum (National Research Council, 2012b).

### ***1.1.2. Increasing Participation in Undergraduate Biology.***

Increasing the number of majors and the number of students earning Bachelor's degrees in the biological sciences is an additional area of emphasis to biology educators. While many of the other STEM disciplines face issues of unequal gender participation, the biological and life sciences do not face this problem with 60% of Bachelor's degrees being earned by women as of 2009 (National Science Foundation, 2012). Much like other STEM disciplines though, interest lies in increasing the participation of historically underrepresented minorities (Hispanic, Black/African American, Native American, and Pacific Islander) in the biological sciences as only 26% of biological sciences majors are from underrepresented minorities. The ethnicity discrepancy is even more apparent when we look at persistence and retention throughout a natural sciences bachelor's degree program. Looking at the retention and persistence in a natural sciences degree program, that is those intending to major versus those completing the major, is where I pay particular attention for the purposes of this dissertation. Using 2012 data from the National Science Foundation it can be seen that there is a retention rate of 93% for both White and Asian (majority) students (National Science Foundation, 2012). That is to say 93% of students from either of these populations who have intended to major in the natural sciences complete the program and earn their bachelor's degree in a natural science. However, when we use this same data source we can see that 63% of Black/African American students persist throughout the degree program and 72% of Hispanic students persist through the program (National Science Foundation, 2012).

### ***1.1.3. Discipline Based Education Research at Florida International University.***

Florida International University (FIU) is a large, urban, research intensive Hispanic-serving institution with a Hispanic population making up 61% of the 2012 enrollment (Florida International University, 2013). The Physics Education Research Group (PERG) at Florida International University (FIU) developed in part to increase the competitiveness and representation of underrepresented students within the physics community. This discipline specific education research group has successfully developed and implemented a curriculum, known as University Modeling Instruction – Physics, that focuses around students’ development and interaction with modeling skills and processes. Through the development, implementation, and refinement of this curriculum the PERG established a place to target the untapped resources of ethnic minority students in the STEM disciplines. While the PERG group is focused on reform efforts benefiting the physics community, FIU as a whole has taken on the task of being a leader in STEM education reform through the creation of the STEM Transformation Institute (Florida International University, 2012), which “focuses on the creation, validation, and implementation of inclusive models of STEM education to support all learners” (p. 5). With the support of the STEM Transformation Institute and the successful physics curriculum to serve as a framework, it was the focus of my study to adapt, develop, implement, and study the efficacy of University Modeling Instruction – Biology to aid in the broadening of participation and competitiveness within biology.



## **1.2. Literature Review and Theoretical Framework.**

In this section I broadly summarize the research relating to Communities of Practice, models, modeling, and University Modeling Instruction. More extensive literature reviews will be incorporated into each chapter.

### ***1.2.1. Communities of Practice***

Communities of Practice from Lave and Wenger is described by Wenger (2011) as “locates learning, not in the head or outside it, but in the relationships between the person and the world, which for human beings is a social person in a social world in this relation of participated” (p. 1). That is to say that learning can be seen as being the individual participating within a particular community. However, according to Wenger participation is not enough, as meaningful learning “requires both participation and reification to be in interplay” (p. 1). It is with both participation and reification that a community develops and new members are acculturated into this learning community. The development of a community also develops a general set of competences. These competences are:

Understanding what matters, what the enterprise of the community is, and how it gives rise to a perspective of the world; being able (and allowed) to engage productively with others in the community; using appropriately the repertoire of resources that the community has accumulated through its history of learning. (Wenger, 2011, p. 2)

While it may seem that by focusing on the community aspect of Communities of Practice the role of the individual is diminished aside from the fact he or she is a member of the community, however, Wenger (2011) emphasizes that the individual identity is

essential to fully understanding what a community of practice means for the individual. Wenger goes as far as saying that identity is “a central element of the theory, just as fundamental and essential as community of practice” (p. 3). The identities of the individual are viewed as an essential aspect of the theory because they are a resource that is able to shape the learning that takes place.

The use of Communities of Practice as a theoretical framework lends itself traditionally to qualitative research, it is important to note that it is the lens by which I interpreted the combined analysis from the conceptual inventory, social network, student attitude, and drop-fail-withdraw results as opposed to each of these results individually. In using all these results to evaluate the differences between face-to-face and online instruction in General Biology I, I followed the guidelines proposed in the What Works Clearinghouse (2008).

### ***1.2.2. Models in Science.***

As identified by both *BIO2010* and *Vision and Change* models and modeling play a significant role in science. This view regarding the importance of models and modeling in science has also been expressed by (Hestenes, 1992; Nersessian, 1992; 1995; Odenbaugh, 2005; Windschitl, Thompson, & Braaten, 2008). Odenbaugh (2005) using examples such as the Lotka-Volterra predator-prey models described by Roughgarden (1979), as cited in Odenbaugh (2005), argues that models serve five functions within theoretical ecology and these functions are: a) explore possibilities, b) investigate more complex systems, c) provide conceptual frameworks, d) generate accurate predictions, and e) generate explanations.

While Odenbaugh claims these five rolls of models are within theoretical ecology, these same five functions of models can be seen when considering *Listeria monocytogenes*. Hamon, Bierne, and Cossart (2006) argue that *L. monocytogenes* is a multifaceted model. While Hamon, Bierne, and Cossart do not define a model in the same way as it is defined in this dissertation, calling *L. monocytogenes* a multifaceted model implies that it a model organism, which has successfully served as the basis for a variety of models that fit with the definition of a model used in this dissertation. It is a model that microbiologists have used to inform how bacteria invade cells, and has shaped the paradigm for studying bacterial adaptations to mammalian hosts. These examples of *L. monocytogenes*' use as a model extend Odenbaugh's (2005) argument beyond theoretical ecology and into microbiology, but the use of models is not limited to the biological sciences.

Nersessian (1992) extends the roles of models to all scientific disciplines, but places particular emphasis on the roll that models play in physics. Using Maxwell as the primary example Nersessian (1992, 1995) argues that through the process of model construction physics was able to advance beyond Newtonian systems and develop laws that explain non-Newtonian systems – that is electromagnetism. Nersessian links model construction to the broader idea of conceptual change within science regardless of discipline. This is to say that “scientific ‘discoveries’ [happen through] a process in which scientists actively construct representations by employing problem-solving procedures” (Nersessian 1992, p. 39). This view that modeling is a cross-disciplinary practice is also reflected by both Hestenes (1992) “the great game of science is modeling the real world” (p. 732) and Passmore, Stewart, and Cartier (2009) “the development,

use, assessment, and revision of models and related explanations play a central role in scientific inquiry” (p. 395). “Constructive modeling” (Nersessian 1995, p. 204), also referred to as model-based inquiry (Windschitl et al., 2008), is an authentic scientific practice that scientists have argued should be incorporated into science courses across the disciplines.

### ***1.2.3. Models in Science Education.***

The implementation of model-based inquiry, “inquiry based on the generation, testing, and revision of scientific models” (Windschitl et al. 2008, p. 2), in the science classroom as a mechanism for student investigation and experimentation differs from the traditional scientific method in multiple ways. Windschitl et al. (2008) argue that the scientific method “misrepresents fundamental intellectual work done by contemporary science” (p. 5). Another key way that model-based inquiry (MBI) differs from the scientific method (TSM) is that in regards to scientific epistemology, TSM prevents students from learning both the disciplinary content and the authentic practice at the same time. Addressing the disconnect between the learning of content and practice as presented in traditional science classrooms employing TSM is one of the strongest features of MBI. Lehrer and Schauble (2006) have described this connection between modeling practice and content, saying, “one cannot engage in the activity of modeling without modeling *something*, and the something (the content and domain) is critical with respect to the questions raised, the inquiry pursued, and the conclusions reached. At the same time, modeling is a practice, not a predigested heap of facts” (p. 383).

A modeling perspective has been used to teach various topics in the sciences ranging from solar systems where the model serves as an analogy allowing for

elementary students to interact with learned content (Lehrer & Schauble, 2006) to evolutionary biology where the model is Darwin's model of natural selection (Passmore & Stewart, 2002). In the evolutionary biology component of a high school biology class, students engaged with case studies that were able to provide data and background readings. These background readings presented students with the explanatory models of evolution - Intelligent Design, Use Inheritance, and Natural Selection. Through reading additional case studies students were able to reason using these three models and eventually were able to understand the explanatory powers of Darwin's model of Natural Selection. While both the elementary classrooms and high school biology have used models and modeling as a key feature of their courses, I argue that it is important for the student not simply presented with the models they are supposed to use, but to instead develop and use the models to better represent the authentic practice of scientific modeling.

#### ***1.2.4. University Modeling Instruction – Physics.***

A curriculum that engages students through the development and use of models exists within the physics setting and is University Modeling Instruction – Physics. This curriculum has been examined in regards to conceptual understanding, students' attitudes, students' odds of success, and the development of student learning communities.

Brewe et al. (2010) explored the conceptual understanding of students enrolled in University Modeling Instruction – Physics, with particular focus on the conceptual scores of underrepresented minorities and by gender. Using the Force Concept Inventory (FCI; Hestenes & Wells, 1992) as a pre- and post- test measure of conceptual understanding Brewe et al. (2010) found that students enrolled in UMI-Physics scored 61.9% correct on

the post FCI versus students in traditional lecture scoring 47.9% correct, a statistically significant difference ( $p < 0.001$ , Cohen's  $d = 0.71$ ) with a large effect  $d = 0.71$  (0.57-0.86, 95% CI on  $d$ ). When these results are broken down by race/ethnicity it shows neutral results in that the gap between represented and underrepresented student populations does not widen. When broken down by gender however, the gap in post FCI scores actually widens.

In addition to positive conceptual understanding results, Brewster et al. (2009) found the first positive results of students' attitudinal shifts for a reformed introductory physics course on the Colorado Learning Attitudes about Science Survey (CLASS-Physics; Adams et al., 2006). This finding has been extended to include multiple classes with multiple instructors (Brewster, Traxler, de la Garza, & Kramer, 2013) The CLASS-Physics survey targets students' attitudinal beliefs and compares them to the beliefs of discipline experts. Brewster et al. (2009) found that UMI-Physics students had significant positive shifts in the overall attitudinal beliefs. It was also found that when broken down by the subcategories of the CLASS-Physics survey UMI-Physics students had positive shifts in four categories.

An additional measure showing the success of the University Modeling Instruction framework comes from the measure of students' odds of success. Using the grades of students enrolled in introductory physics courses at FIU, Brewster et al. (2010) found that the odds of success (receiving a grade of C- or higher) were greater for students enrolled in UMI-Physics versus traditional lecture. Their study found that the odds of success are 6.73 times higher in students participating in University Modeling

Instruction – Physics. These success rates are of particular interest because it is in introductory STEM courses where many students are lost from the major.

Using Social Network Analysis Brewster, Kramer, and O'Brien (2010) attempted to explain why students enrolled in a University Modeling Instruction – Physics class have greater conceptual gains. It was found that students enrolled in sections of University Modeling Instruction – Physics have ten times greater the number of connections within a student network when compared to their peers in traditional lecture format classes. University Modeling Instruction – Physics courses had a post instruction density of 0.1529, while traditional lecture courses only had a post instruction density of 0.0025. Through taking a learning as participation perspective it can be concluded that the differences in the number of connects made within a student network will have an impact on student learning.

### ***1.2.5. University Modeling Instruction Framework.***

With the results based on implementation of University Modeling Instruction – Physics and the perspective that models and modeling are cross-disciplinary in nature, I turn to the development of a University Modeling Instruction – Biology course using the University Modeling Instruction framework. University Modeling Instruction is the amalgamation of three aspects that have been developed with the practice of modeling and models as the primary foci and serve as threads that tie the curricular framework to the practice of scientists. These three aspects are the Modeling Theory of Science, Modeling Theory of Instruction, and Modeling Discourse Management. I will discuss each of these three aspects in the following section.

The Modeling Theory of Science (Halloun, 2006; Hestenes, 1987, 1992, 2006) is the theory that argues that models and modeling are the central focus and activities by which scientists partake, regardless of discipline. That is to say that the scientific endeavor of any discipline moves forward and generates new knowledge through the process of model construction, validation, deployment, and revision. It is in the Modeling Theory of Science where the epistemological assumptions and foundations that shape University Modeling Instruction can be found. The Modeling Theory of Science lays the foundation to shape University Modeling Instruction because models serve as the center of a “conceptual hierarchy, between theory and concept” (Halloun, 2006, p. 21). With models serving as the center of this hierarchy it allows scientists to connect concept to theory through the mediation of “a mechanism that can be used to explain why something in the natural world works the way it does” (Passmore et al., 2009, p. 395).

The Modeling Theory of Instruction (Brewer, 2008) extends the Modeling Theory of Science from the laboratory into the classroom. It suggests that as modeling is the central activity that scientists engage in it is essential that we conduct science classrooms in the same way; around the building, validating, deploying, and revising of models. It asserts that models should be the focus of the content and that the primary activities that students engage in are the components of the modeling cycle (building, validating, deploying, and revision). Beyond emphasizing the importance of models being the focus of both content and activity, the Modeling Theory of Instruction encourages the use of a student-centered pedagogy. By implementing this student-centered pedagogy it creates a community of learners through the high level of student-to-student discourse.



In addition to having a student-centered pedagogy there are a set of in-class discourse tools, which can be classified as Modeling Discourse Management (Desbien, 2002), that help structure the discourse for the development and deployment of models. This set of discourse tools includes Socratic questioning, intentional lack of closure, use of 2' x 3' whiteboards to communicate scientific ideas, small group work, whole class discussions, and a tool known as “seeding” (Desbien, 2002). “Seeding” is the process of introducing a new concept, idea, or question into an intentionally chosen group, and then allowing them to develop their own interpretation of this concept, idea, or question that they will later be asked to present to the whole class (Durdan, Brewe, & Kramer 2011).

An important aspect to consider before developing a model and modeling focused curriculum is the lack of consistent definition of what a model is or what it means to be modeling when exploring the role of models and modeling within science. Hestenes (1987) has defined a model as “a surrogate object, a conceptual representation of a real thing” (p. 4). This definition of Hestenes’ provides a strong foundation to begin defining a scientific model and is one that Halloun has expanded upon by defining a scientific model as “a conceptual system mapped, within the context of a scientific theory, onto a specific pattern in the structure and/or behavior of a set of physical systems as to reliably represent the pattern in question and serve specific functions in its regard” (Halloun, 2006, p. 24). However, I believe this does not provide a complete description of a scientific model for the purposes of these studies thus provide an operational definition of a conceptual model that will serve as the definition of a model throughout the curriculum and the following chapters. I define a scientific conceptual model as a coordinated set of representations (e.g., graphs, equations, diagrams, and/or written descriptions) of a

particular class of phenomena that exist in the shared domain of discourse. Defining a model in such a way allows for a general definition that is aligned with the various definitions found in the literature regarding models. It also provides a limit to the definition as it restricts me from attempting to make conclusions about what is happening inside an individual's head, and instead only speaks of the shared domain, an area we can draw claims from more readily. This definition of a scientific conceptual model is also in line with Vygotsky's definition of "tool" (Cole & John-Steiner, 1978) allowing for an explicit connection between Vygotsky and the constructivist nature of the University Modeling Instruction framework.

### **1.3. Overview of the Dissertation Project.**

This dissertation is organized such that each of the data chapters (Chapters 2 - 5) is written in a research paper format that is either published, currently under review, or is in preparation for submission for publication. By organizing this dissertation in this fashion the specific methods and literature relevant to the study is discussed within each chapter. In this section I provide a description of the studies, thus providing a basic overview of this dissertation. Here I will provide a brief outline of the contents of the following chapters, that is methodology, framework, and purpose - and the details regarding the journal of choice for the respective chapter as well as the format requirements for each.

#### ***1.3.1. Purpose of the Dissertation Project and Research Questions.***

The goal of this research project was to argue for the adaptation and development of a model-centered undergraduate General Biology I curriculum. This research project first made the argument for the importance of taking a model-centered approach towards

a General Biology I curriculum and used this argument as motivation for identifying the essential models of General Biology I. Using this argument for the need for a model-centered curriculum and identified models in Manthey and Brewe (2013) I extended the argument through an exploration of current instructional practices for General Biology I sections, which were a face-to-face traditional lecture and an online section. Additionally, this research project examined student interviews on the topics of plant cells and animal cells, two models identified as part of this study, in order to explore the students' ideas. The focus on general biology is because this introductory course serves as a gateway course that is able to engage underrepresented minorities and provides the opportunity to aid in the development of students' foundational understanding. In particular, the project pushes for the development of a curriculum using the University Modeling Instruction curricular framework, adopted from University Modeling Instruction – Physics. The first phase of my work was to study the efficacy of current General Biology I instructional practices. This was completed by comparing a single section of the lecture aspect of the course with the online section of the course, both course formats were taught by the same instructor. In order to study the efficacy of current instructional practices this phase of my work was framed around the analysis of students' conceptual understanding, attitudes towards biology, retention, and student-student network development.

The second phase of my work was to identify the models that are fundamental to general biology. As part of this work, I describe a University Modeling Instruction – Biology class, and how it is able to contribute to improving undergraduate biology education.

The third phase of this work was an exploration of student ideas regarding plant cells and animal cells upon completion of General Biology I. This investigation looked into students' ideas regarding cellular respiration and photosynthesis, cellular structure, osmosis and diffusion across the membrane, and cellular replication. These areas have been identified as components of the two cell types.

In this dissertation I addressed the following questions:

1) How does the University Modeling Instruction theoretical framework developed for university physics function when applied to the development of University Modeling Instruction – Biology?

2) What are the essential basic models identified by faculty and general biology textbooks for a general biology one course?

3) How do students enrolled in a traditional face-to-face lecture format of General Biology I compare to their peers enrolled in an online format of General Biology I on the Biological Concept Inventory?

4) How do students enrolled in a traditional face-to-face lecture format of General Biology I compare to their peers enrolled in an online format of General Biology I on the Maryland Biology Expectations Survey?

5) How do students enrolled in a traditional face-to-face lecture format of General Biology I compare to their peers enrolled in an online format of General Biology I in terms of the odds of success, measured using retention rates (drop-fail-withdraw)?

6) How do students enrolled in a traditional face-to-face lecture format of General Biology I compare to their peers enrolled in an online format of General Biology I in the development of student-to-student networks?

7) Do students apply the functions of models (describe, explain, predict) in courses without an explicit model focus?

### ***1.3.2. Dissertation Structure, Format and Methodology.***

This doctoral dissertation was written using the Florida International University College of Education's "Collected Papers" format. It is comprised of chapters written only for this dissertation (Chapter 1 and Chapter 5, and a set of related papers that is either published, currently under review, or is in preparation for submission for publication to peer-reviewed journals; journal description to follow. This overall thesis takes on a model/modeling-centered and communities of practice research framework. By using a model/modeling-centered framework I was able to address the calls from the AAAS and NRC regarding a need to engage undergraduate students in the modeling practices of scientists. I was also to draw upon a successful framework from another scientific discipline with the University Modeling Instruction – Physics framework to provide a foundation of a curriculum to argue for. By taking a Communities of Practice framework to guide the interpretation of the efficacy results it provided a theory of learning to structure the interpretation around, as it is the lens through which I view learning takes place. This interpretation of the results in the efficacy study comparing online and face-to-face formats is not shaped off of a single measure but is instead shaped by a multi-measure assessment. It is through these multiple measures of the efficacy that I was able to following the What Works Clearinghouse (Clearinghouse, 2008) standards and guidelines.

Chapter 2 addressed the questions, how do students enrolled in an online section of General Biology I compare to their peers enrolled in traditional lecture general biology

one on the Biology Concept Inventory (research question 3); how do students enrolled in an online section of General Biology I compare to their peers enrolled in traditional lecture general biology one on the Maryland Biology Expectations Survey (research question 4). It also addressed the research questions of how do students enrolled in a traditional face-to-face lecture format of General Biology I compare to their peers enrolled in an online format of General Biology I in terms of the odds of success, measured using retention rates (research question 5); how do students enrolled in a traditional face-to-face lecture format of General Biology I compare to their peers enrolled in an online format of General Biology I in the development of student-to-student networks (research question 6). It reviewed the relevant literature regarding conceptual understanding, attitudinal beliefs within general biology, retention (DFW) and network analysis, provides the theoretical structure of the argument and provides the quantitative results of this analysis. This paper is intended for publication within the Journal of Biological Education, which requires Taylor and Francis Standard Reference Style: Chicago author-date format.

(<http://www.tandfonline.com/action/aboutThisJournal?show=aimsScope&journalCode=rjbe20>)

Chapter 2 of this dissertation is comprised of student conceptual inventory data, student attitudinal belief data, retention rate data, and social network data. These data were collected from two different course types of General Biology I (BSC 1010) available at FIU, traditional lecture and online instruction. In order to collect these data I used the Biology Concepts Instrument (Klymkowsky, Underwood, & Garvin-Doxas, 2010) and the Maryland Biology Expectations Survey (Hall, 2013). Data collection began

during the Fall 2013 semester for both traditional lecture and online instruction sections. In order to collect Social Network data a survey was administered to the students enrolled in all course types that asked questions along the lines of, “Who do you work with to learn biology? Who did you study with for the test? etc.” following the similar procedures to Brewe, Kramer, & O’Brien, (2010) and Brewe, Kramer, & Sawtelle (2012) to explore the development of student learning communities. Enrollment data was collected within the first week of the semester and again at the end of the semester. This data allowed me to measure odds of success for students enrolled in the various sections types and provides an analysis of drop-fail-withdraw (DFW) rates from the sections.

Upon collection of all general biology data for the three-section types, a linear regression analysis was used to generate an equation for predicting BCI score in lecture and Modeling course types using student characteristics (gender, race/ethnicity, pre-test, course type) as predictor variables in predicting student’s post-test scores. To analyze the results from the MBEX, a regression analysis was used to generate an equation for predicting MBEX post-instruction score. To build this equation I used the same predictive variables as in the BCI analysis.

Chapter 3 addressed the role of models and modeling in Biology and identifies the fundamental models in biology. It provided an introduction to University Modeling Instruction, reviewed the relevant literature regarding the use of models in biology education, and provides a framework for the fundamental general models that were identified from analysis of faculty interviews and textbook analysis. This paper has been published in CBE-Life Science Education, which requires Council of Biology Editors Style Manual format.

In Chapter 3 of this dissertation, data was collected from interviews of current biology faculty. These interviews were conducted using a semi-structure format and were conducted to target the identification of the fundamental models of a general biology course. Following the interviews the results were analyzed to generate an outline of the basic models for general biology. To support and build upon the results of the interviews a qualitative analysis of current biology textbooks (Becker, Kleinsmith, Hardin, & Bertoni, 2009; Freeman & Herron, 2007; Raven, Johnson, Mason, Losos, & Singer, 2010; Reece et al., 2011) was conducted. A member-check was conducted to check both the correctness of the interpretation of interview results and the validity of the models identified from the textbook analysis as identified by the researcher (Manthey & Brewé, 2013). Chapter 3 is focused and shaped by research question 1 and research question 2.

Chapter 4 of this dissertation project focuses on the exploration of students' ideas regarding plant cells, animal cells, and the related content. This chapter addressed the research question of what model functions (describe, explain, and predict) do students deploy when discussing plant, animal, and eukaryotic cell models. This chapter also discusses how a model-centered General Biology I course could theoretically help in students developing the ability to deploy all three model functions. It reviews the relevant literature regarding scientific model, model function, and the argument for models in the classroom, provides the methodology for collection the data, analysis of the student interviews, and the argument for how a model-centered course could theoretically aid in the students use of models. This paper is intended for submission to CBE-Life Science Education, which requires Council of Biology Editors Style Manual format.



Chapter 4 of this dissertation draws on student interview data. Students from the current instruction practices were asked to participate in interviews following completion of General Biology I during the Fall 2014 semester. These interviews took a semi-structured format and will be transcribed then analyzed to look for trends and patterns in students' ideas regarding the content of interest. A member check will be conducted to check the correctness of the interpretation of students' ideas. A model(-ing) centered view will be drawn upon during the analysis of students' ideas.

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## **CHAPTER 2 A MULTI-MEASURE COMPARISON BETWEEN WEB-ASSISTED LECTURE BASED AND ONLINE SECTIONS OF GENERAL BIOLOGY I AT A LARGE, PUBLIC, HISPANIC-SERVING UNIVERSITY IN THE USA**

### **2.1 Introduction**

#### **2.1.1. *Growth and Trends in Online Education in USA***

Within the USA there is a significant shift towards providing online educational opportunities to students. These online formats range from online versions of traditional face-to-face courses at a university to massively open online courses, MOOCs. In fact, the growth of online courses has taken the number of students enrolled in at least one online course at a degree-granting postsecondary institution from 1.6 million students in 2002 to over 7.1 million students as of 2012 in the USA alone (Allen and Seaman 2013; Allen and Seaman 2014). These 7.1 million students taking at least one online course represent an all-time high of 33.5% of all students enrolled. With the rapid growth of online education come questions regarding the effectiveness of these courses in comparison to courses that have a face-to-face meeting. Courses that can be categorized as having face-to-face meetings include traditional courses that have 0% of the material delivered online, web-facilitated with 1-29% material delivered online, and hybrid courses with 30-79% material delivered online (Allen and Seaman 2014).

#### **2.1.2. *Perception of Differences***

Much of the research examining the differences between face-to-face courses – those with less than 80% of course content delivered online – and online courses has targeted perceptions and satisfaction of these courses be it from an administrative or a student perspective (Dziuban, Moskal, and Brophy 2007; Swan 2003; Allen and Seaman 2014; Eom, Wen, and Ashill 2006; Richardson and Swan 2003; Moore and Kearsley

2011). From the administrative perspective, 74% of these academic leaders view online courses as equally, if not more, successful than traditional face-to-face sections (Allen and Seaman 2014). There is a sharp division in administrator perceptions between those who work at universities providing online course and those who work at universities that do not provide online courses. The majority, 80%, of those working at universities that provide online courses view them as successful, or more successful than the same course in a traditional lecture format. In universities that do not offer online courses the majority, 72%, view online courses as inferior to face-to-face meeting courses.

Students on the other hand report mixed perceptions of online courses. Summers, Waigandt, and Whittaker (2005) found that students enrolled in an online statistics class were less satisfied with their experiences and the method of delivery when compared to students enrolled in a traditionally taught statistics course. Richardson and Swan (2003) studied factors influencing students' satisfaction with their online courses. Specifically, they explored the concept of social presence—the perception that someone in a mediated interaction is real—of the course instructor. Richardson and Swan found that there was a correlation between social presence and students' perception of satisfaction of the course. This study drew data from a variety of content areas that were taught using online instruction and found that there was a significant correlation between social presence and student satisfaction with the instructor, which was used as a measure of course satisfaction. Eom, Wen, and Ashill (2006) also explored the factors that influence student satisfaction. They found a wide range of predictors for the variance in students' satisfaction with the course for students who had taken at least one online course. These

significant predictors included course structure, self-motivation, interaction, instructor knowledge and facilitation, learning style, and instructor feedback (p. 236).

### ***2.1.3. Researching the Differences (or Lack Thereof)***

Russell (1999) reviewed the literature on differences between fully/mostly online and traditional courses and found that on a variety of measures there was no significant difference, which he titled the “No Significant Difference Phenomenon” (2014). Their review examined 355 different studies that assessed differences between course formats with measurements such as grade comparisons, common question performance, and standardized test scores. Building upon this work Russell has developed a website (<http://www.nosignificantdifference.org/>) that provides access to articles evaluating the efficacy of the different course formats, many of which also found no significant difference between course formats.

Summers, Waigandt, and Whittaker (2005) found no significant differences between course types student content acquisition. These results are in line with those found by Russell, but only consider one of the reported measures from Russell’s work. The other result of this work, as found in previous studies, was that students in the online course were significantly less satisfied with their course than their peers in face-to-face courses. Along these same lines, Anstine and Skidmore (2005) found no significant difference in student performance between students in online and traditional face-to-face course formats for both statistics and managerial economics courses. However, Anstine and Skidmore take their analysis further by performing a regression analysis to hold factors such as student age, if the student has children, level of mathematics, and Graduate Management Admission Test scores constant. They found a significant



difference in student performance between students based on statistics course type, but there remained no significant difference in the managerial economics course. These results indicate that not only should instructional format matter, but also that the interaction between course content and instructional format should be considered.

The aim of this study is to explore the differences in course efficacy for a General Biology I course that is offered in two different instructional formats. Our study has at its foundation the idea that course content and instructional format interact. The first instructional format is a web-assisted lecture based format (WALB), which is defined as having 1-29% of course content delivered online (Allen and Seaman 2013), and the second course format is a fully online course with 100% of course content delivered online. To measure the efficacy of these courses, four different measures were employed to address different aspects of complex learning environments: conceptual understanding, attitudes toward learning, success in the course, and engagement with other students.

## **2.2 Methods**

### **2.2.1. *Setting***

This study was conducted with students enrolled in the first semester (General Biology I) of a two-semester sequence of General Biology at Florida International University, in Miami, FL (US). Florida International University is a large, public, Hispanic-serving university. It ranks 1<sup>st</sup> in the US for awarding Bachelors and Masters degrees to Hispanic students (Florida International University 2013; Cooper 2011).

The data were collected during the Fall semester of the 2013-2014 academic year; this was the first year of implementation of the online format of General Biology I. This course is designed to cover the following content areas: biomolecules and cells,

metabolism and cell cycle, central dogma (DNA -> RNA -> proteins), and evolution. The students enrolled in both formats of the course were required to enroll in the corresponding lab course, which is intended to overlap the lecture materials but is graded independently. The same instructor taught the online and the web-assisted lecture based (WALB) classes.

### 2.2.2. *Participants*

The students enrolled in General Biology I consisted of primarily first-year students, however there were also second- and third-year students also enrolled. The web-assisted lecture based format had a total enrollment of 228 students; the online format had a total enrollment of 75 students. The demographic breakdown of each class type can be found in Table 1. This demographic breakdown includes student's statistical representation status, which looks at a student's race/ethnicity and classifies him or her as either statistically represented or statistically underrepresented. A student's race/ethnicity is classified as being either statistically represented in science population if they identify as White/Caucasian or Asian/Asian American, or it is classified as statistically underrepresented in science population if they identify as Black/African American, Native American, Pacific Islander, or Hispanic.

	<b>Web Assisted Lecture Based</b>	<b>Online</b>
<b>Total</b>	228	75
<b>Gender</b>		
<i>Male</i>	94	28
<i>Female</i>	134	47
<b>Race/Ethnicity</b>		
<i>Statistically Represented</i>	37	11
<i>Statistically Underrepresented</i>	186	62

**Table 1. Demographic breakdown of the Web-Assisted Lecture Based and Online course format total enrollments during the Fall 2013 semester of General Biology I.**

### **2.2.3. *Instructional Format***

The online format of General Biology I was designed to follow the same content sequence as the web-assisted lecture based format. The students were given recorded lectures from the instructor along with online animations and simulations for each of the content areas. Each of the content sections for the online course was made available after students completed the exam associated with the previous material. These exams were offered at the same time as the exams for the WALB section, thus maintaining a similar pace between the two course formats. Although course content was the same, the tasks and grading schemes were slightly different. The grading for lecture consisted primarily of exams (90% of final grade) and weekly quizzes (10% of final grade). The online course included weekly discussions (30% of final grade) as well as exams (60% of final grade) and weekly quizzes (10% of final grade).

### **2.2.4. *Data sources and collection***

In order to address the complex nature of student learning environments, the study was designed to make measurements of several aspects considered important to understanding student learning. These aspects include students' content understanding, students' epistemological expectations, the success rate of students in the course, and the formation of student-to-student collaborative study networks.

#### **2.2.4.1. *Conceptual Understanding - Biological Concepts***

##### ***Instrument (BCI)***

One of the instruments selected for assessment of both General Biology I course formats was the Biological Concepts Instrument (BCI; Klymkowsky, Underwood, and Garvin-Doxas 2010). The BCI is a 29 multiple-choice question survey that covers a

breadth of topics standard to a General Biology I course. Administration of the BCI was conducted through the web-assisted portion of the lecture-format course to allow for common administration between the two course formats. It was given as an optional extra credit incentive to the students and was administered as a pre- and post-course assessment. Students were matched on their pre-/post-instruction scores based on a student identification number. The matched number of responses, those students taking both the pre- and post- course assessment, was 63 and 32 for the lecture based and online course formats, respectively. For the breakdown of total and matched responses, see Table 2.

	<b>Web Assisted Lecture Based</b>	<b>Online</b>
<b>Total</b>		
Pre	9.48 (N=124)	9.90 (N=51)
Post	11.77 (N=102)	11.91 (N=55)
<b>Matched</b>		
Pre	9.36 (N=63)	11.18 (N=32)
Post	12.19 (N=63)	12.81 (N=32)

**Table 2. Student Pre- and Post- instruction scores on the Biological Concepts Instrument out of a 29 total points. Scores reported by course type and by all student responses (students taking either the Pre- or Post-instruction survey) and matched student responses (students taking both the Pre- and Post-instruction survey).**

#### **2.2.4.2.**      *Epistemological Expectations - Maryland Biology*

##### *Expectations Survey (MBEX)*

The research team selected the Maryland Biology Expectations Survey (MBEX; Hall 2013) as an additional survey to examine course format differences. The MBEX was designed to measure students' epistemological expectations about Biology courses in general and thus is not constrained by the course content. Student epistemological

expectations measured by the MBEX include views on whether biology is a collection of isolated facts or a series of interconnected principles, and whether biology has connections to real world experiences. The MBEX is a 32-question Likert-scaled survey, including a filtering question that requires students to select the specified answer for the results to be considered valid. Like the BCI, the MBEX was administered online to create a common administration process between the two instructional groups. It was given as an optional extra credit incentive to the students, was administered as a pre- and post-course assessment, and students were matched on their pre-/post-instruction scores based on a student identification number. The matched number of responses, those students who took both the pre- and post-instruction survey (and correctly responded to the filtering question), were 58 and 30 for the lecture based and online instructional formats respectively. For the breakdown of total and matched responses see Table 3.

	<b>Web Assisted Lecture Based</b>	<b>Online</b>
<b>Total</b>		
Pre	84.18 (N=113)	91.82 (N=41)
Post	82.02 (N=85)	87.25 (N=47)
<b>Matched</b>		
Pre	84.07 (N=58)	91.84 (N=30)
Post	81.42 (N=58)	90.68 (N=30)

**Table 3. Student Pre- and Post- instruction scores on the Maryland Biology Expectations Survey out of 155 total points. Scores reported by course type and by all student responses (students taking either the Pre- or Post-instruction survey) and matched and valid student responses (students taking both the Pre- and Post-instruction survey and answering a filtering question correctly).**

#### **2.2.4.3. Student Success - Drop, Fail, or Withdraw**

The third measure of course differences selected by the research team was Drop, Fail, or Withdraw (DFW) rates, also referred to as student success rates. For the purposes

of this study a mark of Fail is considered earning a grade of C- or below on a standard A – F scale. This data was collected at the end of the semester by conducting a query of student grades from the university database. The end of semester query also included the records of students who had dropped or withdrawn from the course throughout the semester and thus contained the full sample of students from each course type.

#### **2.2.4.4.**            *Formation of Student Networks - Social Network Analysis*

Social Network Analysis for this study explores the formation of student-to-student study groups. Data was collected through the administration of a survey to the students enrolled in all course types. This survey was comprised of two questions, but for the purposes of this study we focus on the following question, “who do you work with to learn biology?” Similar studies by Brewster, Kramer, and O’Brien (2010) and Brewster, Kramer, and Sawtelle (2012) have used this type of question to explore the development of the student learning communities. This measure of student learning communities is important to consider because it is argued that “by design, the success of many online courses is dependent upon the nature of student-to-student and student-to-faculty interactions” (Picciano 2002). Measurement of student learning communities also provides the ability to ask questions about the opportunities for students to form peer groups as a pedagogical element of their course (Grunspan, Wiggins, and Goodreau 2014). Understanding the formation of student peer groups is important because it has been linked to retention and persistence (Allen and Seaman 2013; Brewster, Kramer, and Sawtelle 2012; Allen and Seaman 2014), participation (Allen and Seaman 2014; Goertzen, Brewster, and Kramer 2011), and exam performance (Dziuban, Moskal, and

Brophy 2007; Grunspan, Wiggins, and Goodreau 2014; Swan 2003; Allen and Seaman 2014; Eom, Wen, and Ashill 2006; Richardson and Swan 2003; Moore and Kearsley 2011). The network survey was administered three times as extra credit opportunities throughout the semester as a pre-, mid-, and post-assessment through the web-assisted portion of the lecture-based course. For the purposes of this study we only focus on the mid-semester survey as a comparison of the two different course formats because the participation rate was higher on this survey. These varying response rates be due to survey fatigue, as described by Allen and Seaman (2014) and Grunspan, Wiggins, and Goodreau (2014), affected the results of the pre- and post-assessment network survey results. In the web-assisted lecture based format there were 115 respondents who named a total of 155 out of the possible 228 students as study partners. In the online format of General Biology I there were 53 respondents who named a total of 60 out of the possible 75 students.

#### **2.2.4.5.**        *Statistical tests and analysis*

For this study we present the results of the matched data, i.e. students who took both the pre- and post-instruction assessments, for the BCI and MBEX results. However, *t*-tests were conducted to test for significant differences between the scores on pre-instruction and post-instruction in a comparison of all responses versus only the matched responses.

Regression analysis and model building allow us to compare the BCI and MBEX between the two different course formats for the matched student responses. Regression analysis and model building allow the use of multiple predictive and/or control variables. These variables can include a student's pre-instruction score and student demographic

information, such as gender and statistical representation status. For the regression analysis, a threshold of  $p < 0.05$  was used to consider if either the model or the factors which loaded into the model were significant. For both the BCI and MBEX  $t$ -tests were conducted on each course format to check for significant shifts on each measure from pre-instructor scores to post-instruction scores.

In order to test for the significance of DFW rates, odds ratio tests (Summers, Waigandt, and Whittaker 2005; Szumilas 2010) were conducted. Odds ratios for the purposes of this study were calculated by determining the ratio of students earning a grade equal to or above a certain threshold to those receiving a grade lower than the threshold. As part of this study, the odds ratios (hereafter referred to as “odds of success”) were calculated to compare across course types, gender, statistical representation status, and the interaction between course type and the student demographics.

The Social Network Analysis mid-semester survey results from the two different course formats were analyzed and compared through a calculation of degree centrality (Richardson and Swan 2003; Grunspan, Wiggins, and Goodreau 2014). Degree centrality is best described as the total number of connections each student (node) has in the network. Connections are determined by Student A either listing that he or she has learned biology with Student B or by Student B listing that he or she has learned biology with Student A (or both listing each other). For the purposes of this study directionality of the connection (indegree/outdegree) were not considered. Additionally, to analyze the Social Network Analysis survey results, we calculated the cumulative degree distribution (CDF) of study partners. Cumulative degree distribution calculates the probability that



Student A, from either course type, would have a certain number ( $k$ ) of study partners from the corresponding format, this is also referred to as  $k$ -cores. The CDF gives information about, e.g., whether the total number of connections in a network is dominated by a few high-degree students, or more equally spread around among many moderately-connected students. These two analyses allow for us to make direct comparisons of the two different course networks.

## **2.3 Results And Interpretation**

### **2.3.1. *All Scores versus Matched Scores***

As part of this study we compared the differences between all responses (pre- and post- instruction) and only those responses that had matching responses (students took both the pre- and post- instruction assessment) for both the BCI and MBEX. Looking at the overall number of students taking either the pre- or post- instructional assessment, we had a response rate of less than 50% for the WALB section and approximately 70% for the online section on both assessments. These response rates drop to 25% for the web-assisted lecture based course and 13% for the online course when considering matched students only. The web-assisted lecture based course had 124 BCI responses and 113 valid MBEX responses on the pre-instruction assessment and the online course had 51 responses on the pre-instruction assessment. The web-assisted lecture based course had 102 BCI responses and 85 valid student MBEX responses on the post-instruction assessment and the online course had 55-student responses on the post-instruction assessment.

<b>Web Assisted Lecture Based</b>	<b>All Responses</b>	<b>Matched Responses</b>	<b><i>p</i>-value</b>	<b>Lower 95% CI</b>	<b>Upper 95% CI</b>
Pre	9.48 (N=124)	9.36 (N=63)	0.119	-1.31	1.55
Post	11.77 (N=102)	12.19 (N=63)	0.6541	-2.219	1.3789
<b>Online</b>	<b>All Responses</b>	<b>Matched Responses</b>	<b><i>p</i>-value</b>	<b>Lower 95% CI</b>	<b>Upper 95% CI</b>
Pre	9.90 (N=51)	11.18 (N=32)	0.3343	-3.918	1.3476
Post	11.91 (N=55)	12.81 (N=32)	0.5671	-4.025	2.2201
<b>Maryland Biology Expectations Survey (MBEX)</b>					
<b>Web Assisted Lecture Based</b>	<b>All Responses</b>	<b>Matched Responses</b>	<b><i>p</i>-value</b>	<b>Lower 95% CI</b>	<b>Upper 95% CI</b>
Pre	84.18 (N=113)	84.07 (N=58)	0.9402	-2.735	2.939
Post	82.02 (N=85)	81.42 (N=58)	0.7035	-2.517	3.7207
<b>Online</b>	<b>All Responses</b>	<b>Matched Responses</b>	<b><i>p</i>-value</b>	<b>Lower 95% CI</b>	<b>Upper 95% CI</b>
Pre	91.82 (N=41)	91.84 (N=30)	0.996	-5.6953	5.6663
Post	87.25 (N=47)	90.68 (N=30)	0.3213	-10.28	3.4156

**Table 4. *t*-test comparison of means between all student responses and matched student responses on both the Biological Concepts Instrument and the Maryland Biology Expectations Survey. Results show no significant statistical difference between all student responses and matched student responses on both the BCI and MBEX.**

When only considering matched students the web-assisted lecture based section had 63-student scores and 58 valid student scores; the online section had 32-student scores and 30 valid student scores for the BCI and MBEX, respectively.

The results of the *t*-test comparison for the BCI across all scores versus matched only scores show no significant difference as seen in Table 4.

The *t*-test comparison for the MBEX shows no significant difference between all students who took the pre-instruction assessment and the pre-score of those who took both the pre- and post- instruction assessment for either course format, that is, WALB-

PreAll versus WALB-PreMatched had a  $p$ -value = 0.9402. The complete results of this comparison can be seen in Table 4. Accordingly, we find support to extend the matched results to the remainder of students in the respective sections.

### **2.3.2. Student Conceptual Understanding - Biological Concepts Instrument (BCI)**

The web-assisted lecture based class had 63 matched student scores, whereas the online course had 32 matched student scores. The mean pre-instruction scores were 31% and 38% for the WALB and online courses, respectively. The post-instruction scores were 41% for WALB and 45% for the online courses. The course-based shifts from pre- to post- instruction yield effect sizes (Cohen's  $d$ ; Eom, Wen, and Ashill 2006; Cohen 1992) of 0.58 and 0.25 respectively. Additionally, when looking at the scores pre- and post-instructions for student race/ethnicity representational status we see that statistically represented students ( $N=12$ ) went from a pre-score of 36% correct to a post-score of 46% correct whereas statistically underrepresented students ( $N=77$ ) go from 33% correct to 42% correct. Conducting a similar comparison for student gender we see that males ( $N=30$ ) shifted from 31% to 43% correct and females ( $N=65$ ) shifted from 35% correct to 42% correct. In order to better test these ranges in students' scores based off of their demographics and course types we built the regression models to predict student BCI post-scores using pre-score, course type, student gender, and student statistical representation status, the best model (Model 3 in Table 5) produced a  $R^2 = 0.4012$ , and a Cohen's  $f^2 = 0.67$ . In this model course type was coded as Lecture/Online, student gender as Female/Male, and student race/ethnicity representational status as Rep/URep.

	<b>Model 1</b> R <sup>2</sup> = 0.299	<b>Model 2</b> R <sup>2</sup> = 0.3009	<b>Model 3</b> R <sup>2</sup> = 0.4012
<b>Factors</b>			
Intercept	6.19***	6.2831	5.1217**
Pre-instruction	0.62219***	0.6308***	0.7821***
Course Type ( <i>Online</i> )	-	-0.5275	-0.3903
Gender ( <i>Male</i> )	-	-	0.9304
Race/Ethnicity	-	-	-0.5599
Representation ( <i>Statistically Underrepresented</i> )			
*** p≈0      **p<0.001      *p<0.05      (p<0. 1)			

**Table 5. Regression models predicting student Post-instruction score on the Biological Concepts Instrument. Models are built using Pre-instruction score, Course type, student Gender, and student Race/Ethnicity. Results show that Pre-instruction score is the only statistically significant factor in explaining the variance in student Post-Instruction BCI score.**

We can conclude from this analysis that 40% of the variance in student post-score on the BCI can be explained by the factors included. More specifically, the significant factors in Model 3 were student pre-score (and the intercept). Interactions between factors, for example the interaction between course type and gender, contributed only non-significant increases in R<sup>2</sup> value. The shifts for the WALB course from pre-instruction to post-instruction scores were found to be statistically significant, while the shifts for the online course were not found to be statistically significant.

### ***2.3.3. Student Epistemological Attitudes - Maryland Biology Expectations Survey (MBEX)***

The web-assisted lecture based course had 58 matched and valid (those who answered the filtering question correctly) student scores, and the online course had 30 matched and valid student scores. The mean pre-score for the WALB course was 54% favorable and 60% favorable for the online section. The mean post-score for the WALB course was 53% favorable and 59% favorable for the online section. The course-based

shifts from pre- to post- instruction yield effect sizes (Cohen’s *d*) of -0.30 and -0.08 respectively. Similar to examining the BCI results we explored the descriptive statistics for student demographics and their pre- and post-instruction MBEX scores. We found that statistically represented students (N=18) scored 58% favorable on the pre and 54% favorable on the post, while statistically underrepresented students (N=77) scored 55% favorable pre and 54% favorable on the post. Regarding the shifts in MBEX score for both male and female students we found that female scores shifted from 56% favorable to 55% favorable; male students had MBEX scores that shifted from 56% favorable to 53% favorable.

	<b>Model 1</b> R <sup>2</sup> = 0.5221	<b>Model 2</b> R <sup>2</sup> = 0.539	<b>Model 3</b> R <sup>2</sup> = 0.5641
<b>Factors</b>			
Intercept	14.78582*	18.8317*	19.494*
Pre-instruction	0.80851***	0.74784***	0.75503***
Course Type ( <i>Online</i> )	-	(-3.58469)	4.1419*
Gender ( <i>Male</i> )	-	-	(-3.34353)
Race/Ethnicity Representation ( <i>Statistically Represented</i> )	-	-	-3.30047
*** p≈0      **p<0.001      *p<0.05      (p<0. 1)			

**Table 6. Regression models predicting student Post-instruction score on the Maryland Biology Expectations Survey. Models are built using Pre-instruction score, Course type, student Gender, and student Race/Ethnicity. Results show that Pre-instruction score and Course type are the statistically significant factors in explaining the variance in student Post-Instruction MBEX score. The results show that the students enrolled in the online course scored higher on average than the WALB course.**

When building the regression models to predict student post-score using student pre-score, course type, gender, and statistical representation status, using the codes of Lecture/Online for course type, Female/Male for student gender, and student

race/ethnicity representation status as 0 for underrepresented and 1 for represented. Using this coding scheme we found that the best model (Model 2 in Table 6) produced a  $R^2 = 0.539$ , with Cohen's  $f^2 = 1.16$ . Model 2 used pre-score and course type as predictive factors, with only the intercept and pre-score meeting the threshold for significance at a  $p$ -value = 0.05. Model 3 was also tested ( $R^2 = 0.564$ , Cohen's  $f^2 = 1.29$ ) and found to have a non-significant difference ( $p$ -value = 0.09) in  $R^2$  from that of Model 2 and also showed significance in the ability to describe that variance in student post-instruction MBEX results. While following Occam's razor would suggest that the simpler of the two models (Model 2) is sufficient for the purposes of this study, using Model 3 allows us to answer additional questions of significance regarding gender and statistical representation status. Model 3 is comprised of the intercept, pre-score, course type, student gender, and statistical representation status. Of these factors involved in Model 3, significance at a  $p$ -value = 0.05 was found in the intercept, pre-score, and course type. These significant factors indicate that, for example, for every one point a student scored favorable on the pre-instruction MBEX survey, their post score would be 0.755 points higher.

However, when we check the assumptions of the model regarding the homogeneity of variance for the course type predictors we find that it violates the assumption that the two groups were not significantly different to begin ( $p$ -value = 0.005 using Levene's Test for Homogeneity).

### 2.3.4. Student Success - Drop, Fail, or Withdraw

Odds of success ratios comparing the online course and web-assisted lecture based course found 57 out of 75 successful students and 134 out of 228 successful students, respectively. Compared to the WALB, the odds of being successful in the online course were significantly higher, with an odds ratio of 2.22 with a 95% confidence interval of 4.015 – 1.229.

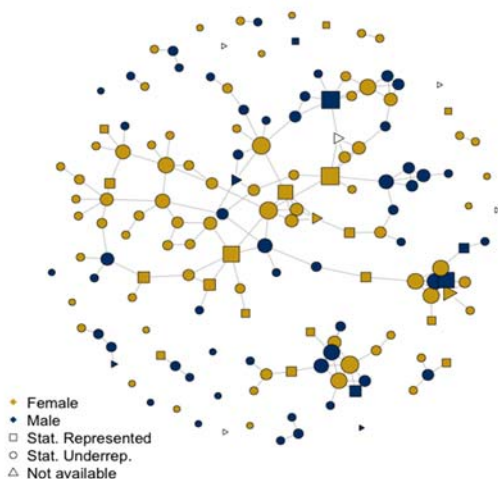
	<b>Odds Ratio</b>	<b>95% Confidence Interval</b>
<b>Online vs. Web Assisted Lecture Based*</b>	<b>2.221*</b>	<b>1.229 – 4.015*</b>
Male vs. Female (All Formats)	0.948	0.589 – 1.525
Statistically Represented vs. Statistically Underrepresented (All Formats)	0.8846	0.469 – 1.66
Male vs. Female (Online)	1.758	0.55 – 5.606
Male vs. Female (WALB)	0.845	0.495 – 1.44
Statistically Represented vs. Statistically Underrepresented (Online)	3.478	0.412 – 29.354
Statistically Represented vs. Statistically Underrepresented (WALB)	0.713	0.351 – 1.447

**Table 7. Odds ratio results comparing the odds of success based on course type and student demographics. The results show that the odds of success were only significantly different when comparing the two different course types, with the odds of being successful 2.22 times higher than the odds of being successful in the WALB course.**

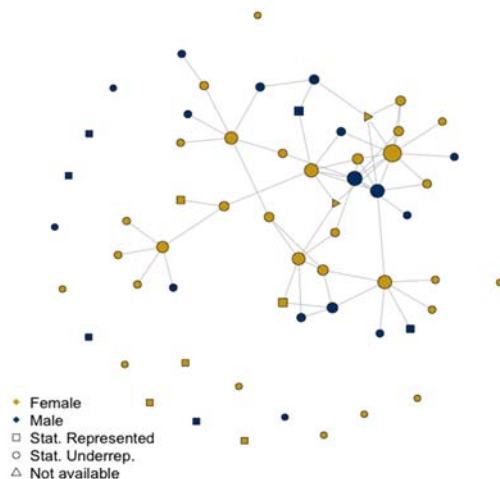
There were no significant differences when comparing overall differences in gender success, statistical representation differences in success, or course specific success for either of the demographic disaggregation (Table 7).

### 2.3.5. Formation of Student Networks - Social Network Analysis

The mid-semester survey of students study partners had a total of 115 respondents in the WALB section and 53 respondents in the online section, response rates of 50% and 70% respectively. This response rate is appropriate for an ungraded optional survey (Russell 2014; Grunspan, Wiggins, and Goodreau 2014). Within each of these courses, a total of 155 and 60 individuals were named (either taking the survey themselves, or selected as connections by people who did). This translates into 155 out of a possible 228 nodes “present” in the WALB course and 60 out of a possible 75 nodes for the online course (Figures 1 and 2). The degree centrality—the number of reported connections a



**Figure 1 Sociogram for the Web-Assisted Lecture Based Section of General Biology I**

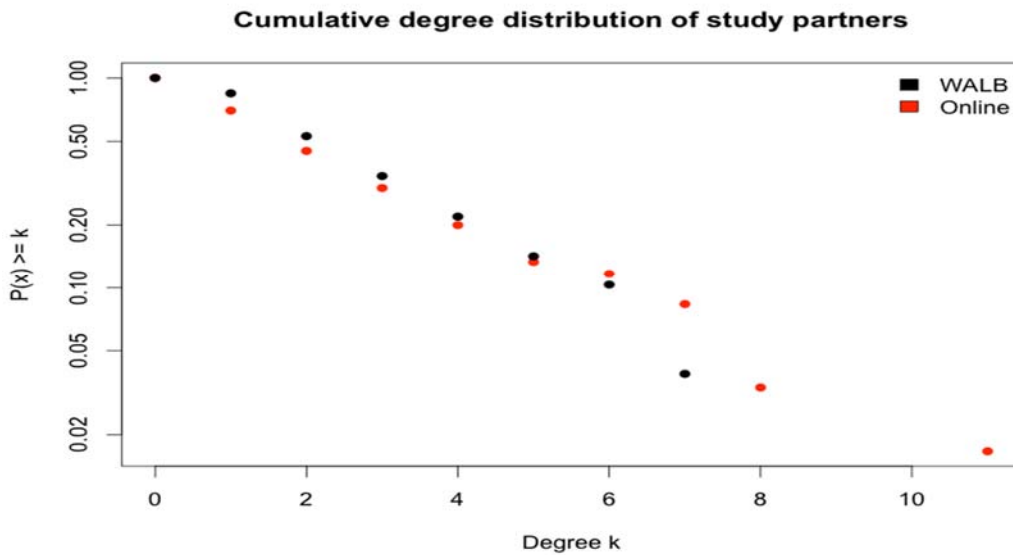


**Figure 2 Sociogram for the Online Section of General Biology I**

student has—averages 3 study partners for the WALB section and 2 for the online section. However, an average difference of one study partner may be due to the differences in class size alone. Therefore, we calculated the probability of having  $k$  study partners, also referred to as the probability of degree distribution. It was found that there were no significant differences in these probabilities in the range of  $k=0$  to  $k=6$  (Figure



3). The probability of students reporting that they had at least zero study partners ( $k=0$ ) was 100% for either course type, by definition. The probability dropped dramatically, to 50%, when we looked at students naming at least two of their peers as learning community members who they worked with to learn biology. At  $k=6$  the probability drops to ~12% for either course type.



**Figure 3 Cumulative degree distribution of the two course formats of General Biology I. The vertical axis is a measure of probability and the horizontal axis is the number of study partners. Results show that both course types are similar in terms of the probability of having up to 6 study partners or less.**

For the WALB course, this means that out of the 228 students enrolled, only 28 students selected having at least 6 members of their learning community. For the online course, only 9 out of the possible 75 students selected at least 6 study partners.

## 2.4 Discussion

Online education as a replacement to in-person courses has seen considerable growth in university settings across the US. As online courses proliferate, a simultaneously growing body of work explores the perceptions held by administration,

faculty, and students regarding online education. However, there seems to be a lack of measured student outcomes in such course types, especially when we look at biology education. With the aim of filling this gap in the literature, we investigated differences between students enrolled in an online section of General Biology I and a web-assisted lecture based section of General Biology I, both taught by the same instructor. The measurements conducted were on student conceptual understanding, epistemological expectations, DFW rates, and the formation of student-to-student networks. With these combined measurements, we can begin to capture the complexity of the students' learning environments, be they physical or digital.

#### **2.4.1. *Student Conceptual Understanding (BCI)***

We found no significant differences between the course formats when comparing students' post-instruction scores on the BCI and controlling for pre-instruction score. There was a significant gain found in the web-assisted lecture based course format and no significant gain detected in the online section. However, when we analyzed these results using regression analysis to control for the students' pre-instruction scores and account for the differences in population between the two courses formats, there is no significant difference in terms of gains between the course types. When disaggregating these results to look at student characteristics, we also found no significant difference in the post-instruction BCI score between male and female students, or between statistically represented and statistically underrepresented students in either course type. These results show a lack of difference between students of varying demographics while enrolled in either course format, suggesting that either course type is equally likely to have the same impact on student conceptual understanding of General Biology I concepts. These results,

combined with a lack of differences between both gender and statistical representation status, contradict the results of Summers, Waigandt, and Whittaker (2005) and Eddy, Brownell, and Wenderoth (2014), which found gender disparity within the similar context of introductory biology courses. It is also important to note that there is a possible explanatory mechanism for the lack of difference between gender and representation status. This explanatory mechanism may be instructor's gender (female) and statistical representation (statistically underrepresented), and the role it plays in student conceptual understanding (Anstine and Skidmore 2005; Price 2010; Bettinger and Long 2005). One way to explore this mechanism is by conducting a cross-instructor study looking at all sections of the General Biology I course, regardless of format, at this large-Hispanic serving university. In comparing the results of this study to those of Eddy et al. (2014), it is important to consider the differing contexts between the study sites. The student population surveyed by Eddy et al. (2014) was drawn from a university of majority statistically represented students, while this study surveyed students at a majority statistically underrepresented university.

#### ***2.4.2. Formation of Student Networks (SNA)***

This study also found that there was no significant difference between the course types when it came to the development of student-student networks/study partnerships. This result is one that we found counterintuitive, as we expected the students enrolled in the online format to be significantly more isolated than the students enrolled in the WALB section. The presence of a student community has long-term consequences, as explored in research by Tinto (1997), showing that the formation of a community of

students and the participation within these communities has been linked to persistence through a major and retention through a course in general. Thus it might be argued that the students of either course format are equally as likely to be retained throughout the course. Our results indicate that both course formats are equally successful in providing students opportunities to form a learning community. However, it is possible that these study groups formed during the mandatory in-person laboratory taken by all students, regardless of course format type. This effect could be investigated by factoring in co-enrollment of the listed study partners in the same laboratory sections. However, this course enrollment information was not made available to the research team. Nonetheless, it seems highly unlikely that students only form networks during lab sessions and do not form new networks in their online or WALB sections.

#### **2.4.3. *Student Success (DFW)***

This study did find a significant difference in the odds of success, that is the odds of receiving a passing grade (C or better) rather than failing (C- or worse), dropping, or withdrawing, between the two course formats. We found that online course students were two times as likely to be successful in their General Biology I course. When broken down by gender and ethnic representation, no significant differences between the course types emerged based on gender, statistical representation status, or interaction of these two student demographic factors. One possible explanation for the difference in student success between the two different course types is that there are different demographics between the two student populations that were not considered, such as years in college or student age. These factors would be important to consider for this analysis, because many of the students enrolled in the web-assisted lectured based format were in their first year

of college and thus adjusting to the multifaceted differences between high school courses/coursework and university level courses/coursework. Student age is also important to consider, because older students may be more successful in an online course (Allen and Seaman 2013; Anstine and Skidmore 2005).

Another important factor that may influence these results is the existence of pre-course student differences. These pre-course differences were observed in our BCI and MBEX results, and controlled for using regression analysis. However, we were unable to control for these pre-course differences using an odds-of-success analysis, and thus this could be an additional influencing factor on finding that the online course students are more likely to succeed in General Biology I.

#### **2.4.4. *Student Epistemological Attitudes (MBEX)***

The Maryland Biology Expectations Survey (MBEX) also showed significant differences between the two different course types in this study. The results of the regression analysis found that both Model 2 (Intercept, Pre-score, and Course format) and Model 3 (Intercept, Pre-Score, Course format, student gender, and student representational status) were significant predictors of students' post-instruction scores. However, it is important to note that once the additional factors (gender and statistical representation status) were included in Model 3, the course type shifted from non-significant to a significant predictor of student outcomes. This result suggests that there is something more on the student-level that is not factored into the analysis, but also shows that there is a significant difference between course types in predicting student post-instruction MBEX scores. These statistically significant differences between the two course types, as indicated by regression Models 2 and 3, are likely due to the fact the

assumption of homogeneity of variance is violated for course type. Taking this into consideration it is also important to consider that we also detected a significant difference between course format when examining the odds of success.

This significant difference between the course types is also evident in the shift of MBEX scores for each course type. The web-assisted lecture based course has a significant negative shift; students have epistemological expectations that shift away from the favorable. The online course has no significant difference between students' pre-instruction and post-instruction MBEX scores. However, when studying student epistemological expectation and attitudinal survey scores, it is important to consider the fact that a non-significant shift between pre- and post- instruction scores is often viewed as a positive result. We emphasize this fact because it is often the case that students' epistemological expectations of science courses and content decreases as the progress through a course (Brewer, Traxler, de la Garza, and Kramer. 2013; Cooper 2011; Brewer, Kramer, and O'Brien 2009; Hall 2013).

Collecting four different measures – spanning conceptual, attitudinal/epistemological, social, and overall outcomes – allows us to begin to measure the complexity of a classroom. In our study, we see that the course types are not distinguishable on two of the four measures (BCI and SNA), but that there are significant differences between the course types on two of the other measures (MBEX and DFW). While the course type differences on MBEX may violate homogeneity, it does suggest that we look deeper into differences between these two course types because the differences are likely linked to student level factors not considered in this study, such as age, years in college, and/or full-time or part-time enrollment (Klymkowsky, Underwood,

and Garvin-Doxas 2010; Paulsen and Wells 1998). A major question stemming from the significant differences found in this study is: if we were to factor in these other student demographics, would this explain enough of the variance in these significant measures to shift the significant differences found between the course types to a non-significant difference? One promising possibility for addressing this question is through the use of propensity score matching (Hall 2013; Dehejia and Wahba 1998; Caliendo and Kopeinig 2005).

#### ***2.4.5. Educational Implications***

Our study has found that the course types were generally equivalent for the outcome measures that we selected. However, one difference occurred in a measurement closely tied to the course – odds of earning a grade of C or higher. These differences, as previously discussed, may be due to pre-course differences between the two student populations, or differences in un-measured student demographic characteristics such as age. One additional factor that may have influenced the difference in odds of success is a change in the clarity of expectations. When a student enrolls in an online course, there is likely a certain set of expectations about how to be successful in the course he or she understands at the moment of enrollment, but in a course that has a more traditional face-to-face meeting these expectations can vary dramatically, such as the traditional sage-on-stage in contrast to an active learning environment using think-pair-share. Providing students with a clearer set of expectations of how to be successful in face-to-face courses before students enroll may help establish no statistically significant difference in the odds of getting a C or better between instructional formats.

In describing these two course types as essentially equally effective, the additional factor of course size must be considered. Our section here, 75 students, although large for an online course, it is considered a small section compared to face-to-face class size (228 students). This smaller size allowed opportunities for higher instructor involvement and interaction with the students. This could lead to the instructor having a high social presence, which has been seen to influence students experiences in online courses (Brewer, Kramer, and O'Brien 2010; Richardson and Swan 2003; Brewer, Kramer, and Sawtelle 2012). These results also beg the question of what course sizes these results might extend to—both in absolute numbers, and in ratio to a WALB course. Is the limit at equal sizes to the WALB class, or at a scale more like that of MOOCs?

Finally, both courses showed no significant difference between them on the BCI and probability of degree distribution using Social Network Analysis. However, it is still important to address these aspects of the course. Regarding the formation of student-to-student learning groups, it is likely beneficial for the students to have a higher probability of having a network consisting of more than 2 peers. It would be productive to consider how to encourage the formation of a larger peer learning community in our courses. As students interact with a greater number of peers, they are given more opportunities to engage with and discuss course materials in a learning community (Picciano 2002; Tinto 1997; Brewer, Kramer, and O'Brien 2010; Goertzen, Brewer, and Kramer 2011; Brewer, Sawtelle, Kramer, O'Brien, Rodriguez, and Pamela 2010). Participation in community, already a factor of known importance in face-to-face university student success, may change form but will remain equally important as online courses and MOOCs change the educational landscape.



When we look at the conceptual understanding, these courses had an average of 41% and 45% correct on the post-instruction BCI for the web-assisted lecture based course and the online course, respectively. These scores, however, are still less than 50% of the items correct on the BCI. At this point, we might question if either of these course formats are the most productive when it comes to content learning gains in students. Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, and Wenderother (2014) have found that lecture based courses, which we found are not significantly different than online based courses, are likely to be less productive than reformed instructional practices regarding student content knowledge gains. What these reformed instructional practices and course formats look like specifically is still open for debate. But it is one that will hopefully see increased odds of success; greater conceptual understanding gains and positive epistemological expectation shifts; and a higher probability of students forming larger student-student networks.

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## **CHAPTER 3 TOWARDS UNIVERSITY MODELING INSTRUCTION – BIOLOGY: ADAPTING CURRICULAR FRAMEWORKS FROM PHYSICS TO BIOLOGY**

### **3.1 Abstract**

University Modeling Instruction (UMI) is an approach to curriculum and pedagogy that focuses instruction on engaging students in building, validating, and deploying scientific models. Modeling Instruction has been successfully implemented in both high school and university physics courses. Studies within the physics education research (PER) community have identified UMI’s positive impacts on learning gains, equity, attitudinal shifts, and self-efficacy. While the success of this pedagogical approach has been recognized within the physics community, the use of models and modeling practices is still being developed for biology. Drawing from the existing research on UMI in physics, we describe the theoretical foundations of UMI and how UMI can be adapted to include an emphasis on models and modeling for undergraduate introductory biology courses. In particular, we discuss our ongoing work to develop a framework for the first semester of a two-semester introductory biology course sequence by identifying the essential basic models for an introductory biology course sequence.

### **3.2 Introduction**

The American Association for the Advancement of Science (AAAS) has issued a call for the reform of undergraduate biology and has identified six student competencies as essential to this reform (AAAS, 2011). One of these competencies is for students to gain skills at developing, implementing, and evaluating scientific models, because “modeling is a standard tool for biologists” (AAAS, 2011).

Not only has the AAAS made an explicit call for the inclusion of modeling abilities and skills as one of the core competencies, but the National Academy of Sciences (NAS) has made it one of the scientific practices that comprise *A Framework for K–12 Science Education* (National Research Council [NRC], 2012). The framework even goes as far as to say “curricula will need to stress the role of models explicitly and provide students with modeling tools . . . so that students come to value this core practice and develop a level of facility in constructing and applying appropriate models” (p. 59).

Even before AAAS and the NAS made model development and use a core competency and practice for biology students, there was considerable research by biology educators on models and modeling (Stewart *et al.*, 2005; Lehrer and Schauble, 2006; Windschitl *et al.*, 2008; Odenbaugh, 2009; Passmore *et al.*, 2009; Schwarz *et al.*, 2009; Svoboda, 2010; Svoboda and Passmore, 2011). However, there is no consensus on what models are, what constitutes the practice of modeling, and how to develop modeling skill while also delivering content.

Students’ development and use of models has been well-researched in other fields of science, particularly within physics (Hestenes, 1987; Schauble *et al.*, 1991; Wells *et al.*, 1995; Desbien, 2002; Halloun, 2006; Brewster, 2008). It is from this work that we shape our argument for the adaptation of a pedagogical and curricular framework known as UMI to biology.

The aim of this paper is to discuss how models and modeling have been described within the different scientific disciplines, introduce the components of UMI, and provide examples of a basic model from the UMI viewpoint. We will then provide a

framework to structure the curriculum around the essential basic biological models for the application of UMI to first-semester introductory biology.

### **3.3 Background on Models and Modeling Within Biology Education**

Biology education research has investigated the use of models and the process of modeling in biology. However, this work tends to lack explanation of how to implement the pedagogical technique and descriptions of the organizing biological models needed for introductory university courses.

#### ***3.3.1. Arguing for the Use of Models***

Researchers have called for models to be used in science courses, because this more closely aligns with authentic scientific practice. Windschitl *et al.* (2008) argue for the use of what they call “model-based inquiry” (p. 2) to become the new focus of science courses, as opposed to the traditional scientific method. Using the biology classroom as the context for their argument, they state that the traditional scientific method “emphasizes the testing of predictions rather than ideas, focuses learners on material activity at the expense of deep subject matter understanding, and lacks epistemic framing relevant to the discipline” (p. 1). Windschitl and colleagues contend that “model-based inquiry” is superior to the traditional scientific method, because it allows students to engage in an authentic practice of scientists, which is the “development of coherent and comprehensive explanations through the testing of models” (p. 5). Passmore *et al.* (2009) argue that models should be used in science courses, because models are the central practice of all scientific disciplines: “The development, use, assessment, and revision of models and related explanations play a



central role in scientific inquiry and should be a prominent feature of students' science education" (p. 395).

### **3.3.2. *Functional Role of Models***

Models are a prominent component of all scientific disciplines, although their roles vary across disciplines and within the discipline of biology. Passmore *et al.* (2009) state that a model gathers "theoretical objects and the processes they undergo and thus serves as a mechanism that can be used to explain why something in the natural world works the way it does" (p. 395). That is to say, models explain scientific theories.

Odenbaugh (2005), while agreeing with Passmore and colleagues, believes that models serve to do much more. He argues that they allow the biological community to explore possibilities, investigate more complex systems, provide conceptual frameworks, create accurate predictions, and generate explanations (Odenbaugh, 2005). Odenbaugh says the models allow scientists to explain and reason within specifics that may have previously been unknown, and Svoboda and Passmore (2011) add that models "facilitate the communication of ideas" (p. 2). Thus, scientists use models to discuss, modify, manipulate, and expand their understanding. Odenbaugh's argument that models allow scientists to investigate more complex systems is one that we view as fundamental. Biological systems range from internal cellular systems to whole ecological systems. These systems comprise many intertwined components. To develop models of these complex systems, scientists must identify simplifying assumptions, while attending to the relevant components. This process reduces the scale students and scientists must use in order to effectively reason about these complex systems.

To demonstrate the functional role of models within biology, we now present a contextualized argument using *Listeria monocytogenes* as a multipurpose specific model. *L. monocytogenes*, the Gram-positive bacterium responsible for diseases such as meningitis, septicemia, and gastroenteritis, has been used as a model organism—a specific model—for cellular biologists to describe many complex phenomena. One of the complex phenomena that *L. monocytogenes* has been used to model is that of the invasion of macrophages. Through the development of this *L. monocytogenes*-specific model of macrophage invasion, researchers have been able to generalize to a basic pathogenic bacteria model for these complex phenomena (Hamon *et al.*, 2006).

The use of a *L. monocytogenes*-specific model has allowed researchers to “suggest the need for [further] empirical studies” (Svoboda and Passmore, 2011, p. 2). For example, while modeling the phenomenon of the listeriolysin O pore-forming mechanism, researchers found that this toxin exhibits optimal activity at a lower pH than other pore-forming toxins, which suggests a direction for future studies (Hamon *et al.*, 2006).

Thus, modeling is a beneficial practice for students, because it is an authentic practice of biology. Several questions remain concerning the use of modeling in the classroom: What are the basic models in an introductory biology class? How do we systematically engage students in the construction, validation, deployment, and modification of these models? It is our aim to provide answers to these questions.

### **3.3.3. *Models and Modeling in the Classroom***

Moving from the field and into the classroom, Lehrer and Schauble (2006) describe the act of modeling in the classroom, saying, “one cannot engage in the activity

of modeling without modeling *something*, and the something (the content and domain) is critical with respect to the questions raised, the inquiry pursued, and the conclusions reached. At the same time, modeling is a practice, not a predigested heap of facts” (Lehrer and Schauble, 2006, p. 383). The specific model of *L. monocytogenes* discussed above demonstrates the value of modeling *something*. If the researchers had explored the macrophagic invasion mechanisms or pore-forming toxins phenomena without using *L. monocytogenes* as the specific model, the information they learned would simply have become a generic list of facts, rather than a contextualized, validated, and applied model separate from the phenomenon.

While we agree with Lehrer and Schauble (2006) regarding the importance of modeling *something*, they also argue that models function as analogies (p. 372). These analogies allow students to have a representation of phenomena, such as the solar system, that are otherwise too large to easily understand. We argue that, for Lehrer and Schauble, models function as a way for students to interact with learned content and not as a way for students to both learn and engage with the content. However, we believe their perspective needs to be expanded to include having students use and develop models. By using and developing models, students are not only exploring content but also developing a deeper and richer understanding of the phenomena. We think that students also learn through modeling the foundational knowledge elements and their structure, as valued within a discipline.

These arguments on the function and benefit of models and modeling in biology show the importance of identifying the models within introductory biology. The identification of these models would allow the full development of a two- semester

introductory biology sequence. The difficulties of developing model-based courses can be alleviated by drawing upon research from the physics education community on their use of models in physics classrooms.

### **3.4 Modeling Within the Physics Classroom Context**

There is much overlap between scientific disciplines on the practice of using models. However, there are differences between the disciplines in employing models as the curricular focus. Hestenes (1987, 1992) describes models as being one of the integral parts of scientific knowledge. He defines a scientific model as “a surrogate object, a conceptual representation of a real thing” (Hestenes, 1987, p. 4) and a physics model as a mathematical model. This is one of the major differences between biology and physics models. We reject these strict definitions of scientific and physics models and expand these definitions of models, particularly scientific models, to better function for biology. Halloun (2006) defines a scientific model as “a conceptual system mapped, within the context of a scientific theory, onto a specific pattern in the structure and/or behavior of a set of physical systems as to reliably represent the pattern in question and serve specific functions in its regard” (p. 24). While this definition of a scientific model is more in line with modeling in biological systems, it is insufficient to shape how models can be used in a classroom. With this in mind, we define a scientific conceptual model as a coordinated set of representations (e.g., graphs, equations, diagrams, and/or written descriptions) of a particular class of phenomena that exist in the shared domain of discourse. In addition, we contend that students should first model specific situations by constructing *specific* models and then abstract out to *basic* models (Nersessian, 1995, 2002). Basic models are models that cover all fundamental conceptions, but that are not

tied to specific phenomena or systems. In the example of *L. monocytogenes*, a specific model of how *L. monocytogenes* invades cells was first constructed. This was later generalized to a more basic model of pathogenic bacteria. Basic models are both descriptive and explanatory, while being general enough to apply to multiple similar phenomena (Halloun, 2006). The procedural knowledge that Hestenes refers to as the scientific method can be incorporated into the biology classroom through the process of developing specific models that are then abstracted out to more basic models (Hestenes, 1987).

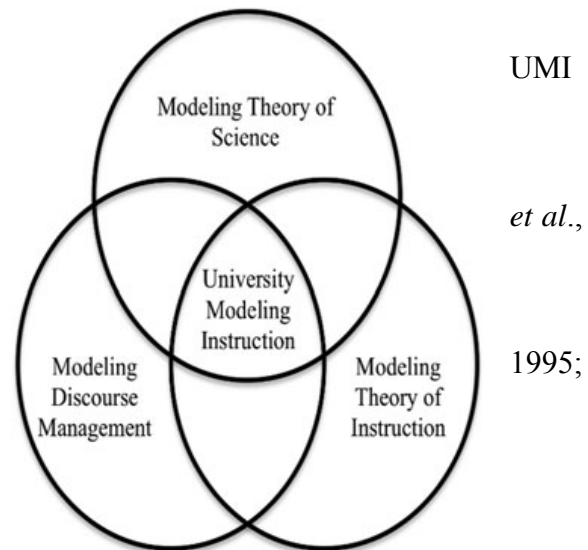
Windschitl *et al.* (2008) also aver that modeling and model-based reasoning can, and in fact should, serve as the new norm within science classrooms. UMI is a curricular framework that establishes

modeling as the science classroom norm.

is composed of three aspects: modeling theory of science (Hestenes, 1987; Wells 1995; Halloun, 2006), modeling theory of instruction (Hestenes, 1987; Wells *et al.*, Brewe, 2008), and modeling discourse

management (Desbien, 2002; Durden *et al.* 2011). We draw on University Modeling

Instruction — Physics (UMI-Physics) to scaffold the development of UMI in biology, and we provide an overview of these theoretical foundations in the following section.



**Figure 1 UMI is considered the nexus of modeling theory of science, modeling theory of instruction, and modeling discourse management**

### **3.5 University Modeling Instruction**

UMI represents the juncture of the modeling theory of science, the modeling theory of instruction, and modeling discourse management, as seen in Figure 1. We will now describe each of these three components in further detail.

#### **3.5.1. *Modeling Theory of Science***

The modeling theory of science is the basic premise that scientific paradigms, such as biology, progress through an ongoing process of model construction, validation, deployment, and revision (Halloun, 2006). This basic premise also states that disciplinary knowledge is generated through this same on- going process. Thus, UMI rests on the epistemological foundation established by the modeling theory of science. In the modeling theory of science, a scientific theory is a set or family of models and a “set of particular rules and theoretical statements that govern model construction and deployment and that relate models to one another” (Halloun, 2006, p. 17). This perspective places models in the middle of a hierarchical structure, below laws and theories but above concepts, and argues that models are the way in which scientists understand and conceptualize science (Hestenes, 1987). This middle level between theories and concepts allows models to serve a critical function within science; they act as the bricks and mortar of a theory and are the basis for how scientists argue. Therefore, they serve as the ideal level for the development of student of understanding of both concept and theory.

#### **3.5.2. *Modeling Theory of Instruction***

The modeling theory of instruction serves as a framework for the application of the modeling theory of science to the classroom. The modeling theory of instruction asserts that building, validating, deploying, and revising models is the central activity of

scientists, and students therefore should be engaged in a similar pursuit. Models should be the focus of the content and modeling should be the primary activity in which students are engaged throughout a science course. The modeling theory of instruction suggests a pedagogy that is student-centered, and it intentionally creates a community of learning through student-to-student communications. This pedagogy also explicitly asks students to create, validate, deploy, and revise these scientific models. The process of creating and developing models “focuses on qualitative and quantitative model development and testing” (Brewer, 2008, p. 1155) and follows a specific path called the modeling cycle that Brewer describes as “introduction and representation, coordination of representations, application, abstraction and generalization, and refinement” (Brewer, 2008, p. 1156).

### ***3.5.3. Modeling Discourse Management***

While both the modeling theory of science and the modeling theory of instruction may together establish a classroom that engages students in authentic scientific practice, we believe that it is also important to structure the discourse to support the development of models and the process of modeling. Modeling discourse management shapes in-class discourse by providing instructors with a set of discourse management tools to guide students so that authentic science discourse occurs. These discourse management tools range from the intentional lack of closure, which can cause “students to wrestle with the issues outside class and return with new ideas to share” (Desbien, 2002, p. 84) to Socratic questioning. Other modeling discourse management tools are small-group work, whole-class discussions, and “seeding” (Desbien, 2002, p. 83). Seeding is the introduction of a new concept, idea, or question into an intentionally chosen small group that allows them to

create their own interpretation of the concept, idea, or question (Durden *et al.*, 2011). The small group then presents the created interpretation to the whole class. Classroom discussion is generated, because students, rather than the instructor, present the idea, and this leads to a resolution.

#### **3.5.4. Research on UMI-Physics**

UMI has been developed and researched in the PER community, whose research has explored the effects of UMI on the gender and ethnicity gaps (Brewer *et al.* 2010), students' attitudes about science (Brewer *et al.*, 2009), and students' self- efficacy (Sawtelle *et al.*, 2010). These research results are one of the motivating factors in adapting UMI to biology.

Using the Force Concept Inventory (FCI; Hestenes and Wells, 1992), Brewer *et al.* (2010) explored the odds of success effects that UMI-Physics had on the ethnicity and gender gaps that exist within the physics discipline. They also investigated the performance differences between students in traditional lecture courses versus those enrolled in UMI- Physics. The results were that students in UMI-Physics out-performed students on the post instruction FCI (61.9% vs. 47.9%, respectively,  $p < 0.001$ ). In addition, UMI-Physics students had higher (6.73-fold) odds of success (a grade of C– or higher) than those in traditional lecture. However, these positive results become mixed when broken down to examine gender and ethnicity. UMI-Physics did not widen the ethnicity gap in FCI scores, the ethnicity gap in odds of success, or the gender gap for odds of success, but it did widen the gender gap for FCI score (Brewer *et al.*, 2010).

UMI-Physics classes not only have predominantly positive results with regard to conceptual understanding of physics topics (Brewer *et al.*, 2010), but they also have the



first published positive results for reformed introductory physics courses on the Colorado Learning Attitudes about Science Survey (CLASS-Phys; Brewe *et al.*, 2009). This survey targets students' attitudinal beliefs and compares them with expert attitudinal beliefs, such as "viewing physics as a coherent, connected group of topics and seeing problem solving as a conceptually grounded search through the knowledge base, rather than as a hunt for equations" (Adams *et al.*, 2006; Brewe *et al.*, 2009, p. 013102-1). It was found that UMI-Physics had significant positive shifts overall and positive shifts in four of the subcategories that make up the CLASS-Phys (Brewe *et al.*, 2009).

Self-efficacy, one's confidence in one's ability to perform a task, is another area that has been explored within the context of UMI-Physics. Traditional lecture classrooms had negative impacts on the self-efficacy of all students, a result in contrast with that of UMI-Physics, which had neutral impacts when evaluating all students. However, when the results were broken down by gender, the study shows distinct differences between the components of self-efficacy interactions with gender (Sawtelle *et al.*, 2010). Using the results of Brewe *et al.* (2009, 2010) and Sawtelle *et al.* (2010), we argue that the UMI framework of UMI-Physics should be used to adapt and reform undergraduate biology courses.

### **3.6 University Modeling Instruction—Biology**

#### **3.6.1. *Adapting University Modeling Instruction to Biology***

One of the major challenges faced in adapting a UMI framework from physics to biology lies in the need to adapt model-centered epistemology to authentically represent the discipline of emphasis. This is due to the fact that physics is a discipline with clearly defined and distinguishable laws and theories, while biological theories and laws

are difficult to distinguish. To adapt the model-centered epistemology for biology, we are adapting the middle-out hierarchical structure described by Halloun (2006). This structure places models at the basic level—the middle—of the “conceptual hierarchy, between theory and concept” (p. 21). We propose adapting this hierarchy by replacing theory with what we will refer to as theoretical structure. This change allows us to account for the elements that comprise the ontological and epistemological assumptions—the things, relationships, and mechanisms that make up the model of situation—across the disciplinary boundaries that are serving to shape the middle-out hierarchical structure of models and modeling.

Representations used in constructing the model must also be altered when adapting UMI from physics to biology. Representations play a vital role within the modeling process, as it is through the addition and refinement of these representations that a model’s robustness is developed. In UMI, as in science, the representations used within the model must coordinate with one another, which is what allows models to explain phenomena.

In adapting UMI to biology, we have chosen to feature some of the cross-disciplinary representations from UMI-Physics in conjunction with biology-specific representations from both primary literature and representative textbooks. However, for the purposes of this paper, we will focus on these cross-cutting representations. These cross-cutting representations not only cross the boundaries for UMI, but also are those that allow us to define a common theme that ties together scientific disciplines.

An example of a UMI representation that can be used across disciplinary boundaries is the energy pie chart. Energy pie charts are representations used to describe the storage

and transfer of energy within a given system, such as the system of a ball dropping to the ground or energy transfer from coral zooxanthellae to the coral polyps and continuing throughout the food web in a coral reef biome. The incorporation and use of the energy pie chart representational tool allows for students to describe the substance-like flow of energy within a specific ecosystem. For a further discussion on the use of energy pie charts, see Brewe (2011). This representational tool is able to cross-cut from the introductory physics models to the introductory biology models; featuring it in both types of courses shows energy to be a common thread in both disciplines.

### 3.6.2. *Content Organization*

Much like the organization of UMI-Physics as described by Brewe (2008), UMI-Biology (UMI-Bio) organizes its content for introductory biology around a small number

University Modeling Instruction	Standard Course
Models are constructs that are built in accordance to theoretical structures, biological principles, and constraints	Biological principles are given as a set of facts and applied to understand phenomena
Models are built by the application of representational tools, which can then be used to solve problems	
Models are temporal and must be validated, refined, and applied	Content is permanent; validation has already taken place
Basic models are applied to specific biological phenomena	Theoretical structures and biological principles apply to specific situations
Modeling is a process that is learned through participation within a community of practice	Understanding is a game that requires tricks and is learned by memorizing large numbers of definitions and facts
Models are distinct from phenomenal they represent and can include causal, descriptive, and predictive elements	Content is not separate from the phenomena

**Table 8 Comparison of content in UMI-Bio and a more standard biology course – Adapted from Brewe (2008)**

of basic models. This is beneficial, because “the organization matches expert knowledge organization in which a few fundamental principles are viewed as requisite for a very broad understanding” (Brewer, 2008, p. 1156). Not only does this organization reflect expert knowledge organization, but it also allows students to see this small number of basic models as a manageable amount of knowledge to understand. This is unlike a traditional two-semester sequence of introductory biology that focuses on covering 20-plus chapters containing a large number of principles, concepts, and topics. Further differences between UMI-Bio and a traditional introductory biology course can be seen in Table 8, modified from Brewer (2008).

### ***3.6.3. Short Theoretical Vignette of UMI-Bio***

Another way to envision UMI-Bio is through a short description of an idealized class activity in which a plant cell model is discovered to be inadequate to explain phenomena and an animal cellular model is introduced. Prior to the class, students will have worked extensively with prokaryotic cells, plant cells, cell stains, and light microscopes, and should have an understanding of scale, structure and function, and energy pathways. Students will first be asked to create descriptive models of a new cell type presented to them on a prepared microscope slide. Students can use the basic prokaryotic or plant cellular models as a template, but will quickly find that neither of these models can be applied to the current phenomena, as the scale and many of the structural elements are different. Working in small groups, students would then collect observations to begin developing and refining their new descriptive cell model. While the students collect data, the instructor would ask one group why either of the basic models developed so far in the class (prokaryotic or plant cell model) do not apply to this current

cell phenomenon. Students are likely to respond with “This is not a prokaryotic cell” or “It is not stained the same as a plant cell.” Once *the students* have introduced these ideas, the instructor would encourage them to pursue these ideas by asking what other organisms they believe this cell could be. This would lead to a discussion about organism types, with commonsense questions, such as, “What other organisms exist on this planet?” The need to consider other organisms would cause the instructor to introduce an animal cellular model. As a result of this interaction, the instructor will have seeded the group with the concept of an animal cell model. During the whole-class discussion, this group will be asked to introduce the general animal cell model to the whole class. This would allow for students as a whole class to build a more robust theoretical structure of cellular biology, with minimal input from the instructor.

#### **3.6.4. *Identifying Basic Models in Biology—Methods***

Identifying the basic models within introductory biology required a metalevel analysis of the content of introductory biology. While models have been described in various ways within biology, there are few descriptions that are aligned with the definition of a basic model provided by Halloun (2006). With this in mind, we undertook a three-part model and theoretical structure identification effort involving exploratory interviews with experts in the domain and a review of two representative introductory biology textbooks, returning with a member check of our proposed basic models. The first part of the process was exploratory interviews with two biology professors, Charles and Gregor (all names are pseudonyms). Charles holds a PhD in population biology and conducts research that focuses on conservation and restoration and evolutionary and tropical biology. Gregor, a PhD in ecology and evolution, is

currently focusing on plant conservation genomics and evolutionary ecology. Both Charles and Gregor are members of large research universities. These interviews were conducted to elicit the participants' expectations about models and theoretical structures they expect their students to understand after completing an introductory biology course sequence.

The interviews were conducted using a semistructured interview format, as described by Rubin and Rubin (2004). Each of the interviews lasted approximately 1 h. These interviews were then transcribed and analyzed to identify areas of theoretical structure, basic models, or areas that needed further refinement through review of representative textbooks.

Following our analysis of the interviews, a review of representative textbooks was conducted to further develop, refine, and support proposed theoretical structures and basic models identified in the interviews. If an additional basic model was identified during the textbook review, it was added to the identified models noted for further consideration in the curricular sequence. The reviewed textbooks included widely used and accepted textbooks from biology courses (Raven *et al.*, 2011; Reece *et al.*, 2011). These combined results were presented to biology faculty for additional feedback and can be

found in Table 9.

General Biology I (Semester One)		
Theoretical Structure <i>(Ontological Assumptions)</i>	Basic Model(s)	Specific Model Example(s)
<b>Cellular Biology</b> <i>Structure and Function</i> <i>Pathways of Energy and Matter</i>	Prokaryotic Cell Plant Cell Animal Cell	E. coli & S. aureus Elodea cell Human cheek cell
<b>Genetics</b> <i>Evolution</i> <i>Information Flow, Exchange, and Storage</i> <i>Mutation</i> <i>Reproduction and Replication</i>	Meiosis and Mitosis Transcription & Translation Evolution	Ascaris Mitosis & Lily Meiosis AIDS Virus Rock pocket mouse

**Table 9 Essential model-centered hierarchies for the first semester of a two-semester general biology UMI-Bio sequence**

These combined results after the interview and textbook analysis were presented to biology faculty and to the interview participants for additional feedback. The combined results can be found in Table 9. The interview participants were presented with these results to allow for a member-checking process during which they were encouraged to verify correct interpretations, correct any incorrect interpretations, and expand on any quotes they felt necessary.

#### **3.6.4.1. Interview Results**

During the analysis of the interview transcripts, we were able to identify multiple basic models and theoretical structures that participants viewed as essential components of an introductory biology course. One of the models that emerged from both interviews was a basic model of transcription and translation. This model emerged from Charles's statement that the process of DNA becoming RNA and then becoming proteins is even

“[the] central paradigm of molecular biology.” He continued on to say that one could “teach from the ‘central dogma’ and then take examples of how RNA is turned back into DNA” by reverse transcription. Gregor echoed the importance of this model, saying, “[you can] get them to model [transcription and translation], go the reverse direction with reverse transcriptase, RNA to DNA.”

We identified a model of evolution as a focal aspect of an introductory biology course, according to both participants. Gregor said that, “evolution is its own model,” while Charles discussed the historical nature of models within the study of evolution. On our member check, Gregor expanded his statement regarding evolution’s role as a model to say that, “evolution by natural selection has a long history as a central model for explaining several phenomena that were challenges to non-evolutionary paradigms that preceded Darwin.” Further evidence of evolution as a basic model was biology’s goals of understanding “what creates, maintains, and leads to the loss of genetic variation with populations” (Charles) and “trying to predict changes in allele frequency over time” (Gregor). In addition, during member check, Gregor mentioned that it is important to consider how evolution has been phrased through various models over time.

### **3.6.4.2.** *Textbook Review Results*

We saw the need to draw upon resources beyond the interviews and thus reviewed appropriate biological texts so that we could identify robust models for the intended two-semester introductory course sequence. This sequence can be found in Table 9.

To expand upon the central dogma and the importance of transcription and translation as identified by both participants, we examined both Reece *et al.* (2011) and



Raven *et al.* (2011). In Reece *et al.*, this model and phenomenon is the focus of an entire chapter (chap. 17), in which it is further broken into the processes of DNA becoming RNA through transcription and RNA becoming protein through translation. Raven *et al.* focus on this model in chapter 15, and include a distinction between prokaryotic transcription and eukaryotic transcription, an important element to consider while developing our curriculum. In both textbooks, the discussions of the transcription and translation phenomena are connected with a discussion of reverse transcriptase processes in retroviruses.

Refining the transcription and translation basic model to include the phenomena of retroviruses, such as the AIDS virus, allows students to see the application of this model to a major phenomenon of disciplinary importance. The curriculum is also aimed at having students learn that transcription can also be reversed, taking RNA to DNA, though the use of reverse transcriptase, thus expanding the functionality of the basic model.

We identified an important representation within the model of evolution. As discussed previously, representations are essential to a robust of a model. During our review of Raven *et al.* (2011) and Reece *et al.* (2011), we identified the Hardy-Weinberg principle and its associated equation as adding to the robustness of the model of evolution. This principle states: “in a large population with no selection and random mating, the proportion of alleles does not change through the generations” (Raven *et al.*, 2011, p. 401). This representational tool provides students with a way to quantitatively describe and predict the genetic variance and frequencies, which are essential abilities of the basic evolutionary model. Both Charles and Gregor discussed the importance of evolution and the Hardy-Weinberg principle/equation.

During our review of textbooks, we identified additional theoretical structures and basic models that did not arise from the interviews. One of the theoretical structures was cellular biology. This was justified by the principles of cell theory, which states that, “all organisms are composed of cells, life’s basic units” (Raven *et al.*, 2011, p. 12). Moreover, “the cell theory, one of the basic ideas in biology, is the foundation for understanding the reproduction and growth of all organisms” (Raven *et al.*, 2011, p. 12). Cell theory helped us identify the basic model of mitosis and meiosis, which is included because “all cells arise only from preexisting cells” (Raven *et al.*, 2011, p. 12).

While it is important to identify the theoretical structures and basic models for a UMI course, it is necessary to consider how to organize the content. Drawing upon these identified theoretical structures and basic models, we now propose a course framework for the first semester of a two-semester introductory biology sequence and outline a modeling cycle for each of the basic models.

### **3.6.5. Framework for the First-Semester Curricular Content of UMI-Bio**

Here, as well as in Table 9 above, we present the results of our ongoing work on identification of the theoretical structures, basic models, and specific models within introductory biology. We view these elements of a model-centered biology epistemology as essential components of introductory biology, and they are a synthesis of results of our interviews of biology faculty and textbook analysis. We present these results as the framework for the content of the first semester of an introductory biology sequence.

The first theoretical structure that is essential for students to encounter is cellular biology, which comprises the ontological assumptions of structure and function and pathways and transformation of energy and matter, as described in *Vision and Change*

(AAAS, 2011). This theoretical structure is composed of the basic model of a prokaryotic cell, which allows for a refined model in future classes to distinguish between an archaea cell model and a bacterial cell model. Additional models in the cellular biology theoretical structure are the plant and animal cells. Students will first engage with the prokaryotic cell model by building a specific model of an *Escherichia coli* cell. This specific model will introduce students to cellular structure, scale, and energy obtainment.

Following the construction of this *E. coli*-specific model, students will explore other bacterial and archaea species, looking at these same phenomena of scale, energy obtainment, and structure. The aim is for students to be deploying and revising their model until a point is reached at which they are able to generalize these specific models to a basic model of a prokaryotic cell. Students will then be presented with a plant cell and asked to deploy their prokaryotic cell model. However, the students' basic model of a prokaryotic cell cannot explain the cellular structure or scale, and the modeling cycle must begin anew for the development of a basic plant cellular model. This basic cellular model, as well as the animal cell model, again focuses students on the structure, scale, and energy obtainment of these basic cell types. The same process of model development, model deployment, and model revision is repeated for the animal cell as described in the vignette above. The descriptive representations of cell structure for each of these cellular biology models came from the text-book review, specifically from Raven *et al.* (2011, pp. 67–68) and Reece *et al.* (2011, pp. 100–101).

The theoretical structure of cellular biology is concluded when students have developed three robust basic models that describe three of the major categories of life-

forms. Students should be able to deploy these models to describe, predict, and explain the basic cell types and to compare and contrast these basic models. The model-centered hierarchical structure for this theoretical structure can be found in Table 9.

Genetics is the second theoretical structure students will encounter during the first semester of introductory biology. The genetics theoretical structure comprises the basic models of transcription and translation, mitosis and meiosis, and evolution. This structure also focuses on the ontological elements of information flow, exchange, and storage; evolution; mutation; and reproduction and replication.

To begin, the curriculum will have students learn the basic model of mitosis and meiosis by developing specific models of the stages of yeast cells and cell division, as well as these same stages in lily anther and ovulatory cells, as seen in Table 9. In developing these specific models, students will interact with the ontological elements of information flow and exchange, and evolution. In particular, evolution raises the ideas of the “three mechanisms that contribute to the genetic variation arising from sexual reproduction: independent assortment of chromosomes, crossing over, and random fertilization” (Raven *et al.*, 2011, p. 257). Through the development of these models, the curriculum will guide students toward the need to develop a basic model for transcription and translation.

As part of the genetics theoretical structure, students will also develop a basic model of evolution. To do this, students will develop a specific model for the rock pocket mouse (*Chaetodipus intermedius*) evolutionary phenomenon. The rock pocket mouse has evolved via genetic mutation and natural selection pressures and is found in two distinctly different colors that match its native habitat: tan, the color of sand, or dark gray, the color of

volcanic rock. Rock pocket mouse evolution is one of the most straightforward examples of evolutionary phenomena; it allows students to develop a model of evolution that includes but is not limited to the Hardy-Weinberg principle, genotypic mutation, and phenotypic trait expression. Once a basic model of evolution is developed, students will deploy this model to explore cheetah genetic diversity, and evolution in Darwin's classic example of finches.

The full sequence and list of theoretical structures, basic models, and examples of specific models for each of the basic models are found in Table 9.

### **3.7 Conclusions**

In response to the call for increased attention to students' ability to model (AAAS, 2011; NRC, 2012), we have presented an argument regarding the importance of models and modeling within biology. We aver that modeling is the essential way in which scientists reason, argue, and structure their knowledge, and that the process of modeling is the central activity of scientists.

Because modeling is a central activity of scientists, it is essential for our students—our future scientists—to engage in the activity of modeling. To provide students with something to model, we have presented a curricular framework for the first semester of a two-semester sequence of introductory biology. This framework, the product of faculty interviews and textbook review, presents the foundations of the theoretical structures, basic models, and specific models that are to shape the first semester. It aims to engage students in developing and deploying several essential basic biological models. This format adapts the model-centered epistemology described by Halloun (2006) and is shaped around the four theoretical structures of cell biology,

genetics, organismal biology, and ecology. The curricular framework presented here is adapted from a currently implemented and successful curricular framework from physics known as UMI-Physics.

### **3.8 Future Directions**

We plan to continue the identification, explanation, and development of the essential basic introductory biology models identified here, as well as those for the second semester of introductory biology. We also intend to further validate these proposed biology models through additional inter-views and surveys of biology faculty and to further develop the course materials for UMI-Bio. On further development of these course materials, the efficacy of the curriculum will be tested by exploring both conceptual understanding changes and attitudinal belief shifts in students. We also want to extend this work by further exploration of the synergy and coherence between the themes and content in UMI for physics and biology. This will include the development of interdisciplinary representations, similar to the example of energy pie charts, which should aid conceptual transfer across disciplines. Exploring the interdisciplinary nature of representations establishes a link between the disciplines for students' understanding of energy conservation and transfer. In addition, it is consistent with the field of biology, which has become more interdisciplinary.

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## CHAPTER 4 TEACHING SCIENTIFIC MODELS: COMPARING RECOMMENDATIONS AND CLASSROOM PRACTICE THRU A PHENOMENOGRAPHIC LENS

### 4.1 Introduction

For more than a decade there has been a push from policy makers to reform the curricular and pedagogical practices that comprise the undergraduate biology major curricula (Brenner, 2003; National Research Council, 2003). As part of this reform effort there is a focus on integrating the epistemological practices of scientists, specifically the use of scientific models and modeling. *Vision and Change in Undergraduate Biology Education: A Call to Action* (Science, 2011) recommends that the “ability to use modeling and simulations” is a necessary skill students should have upon completion of an undergraduate degree because “modeling is a standard tool for biologists”. Not only have models and modeling been one of the central focuses of undergraduate biology education reform, but as seen in the *Discipline Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering* (National Research Council, 2012) they play a part in the larger call to reform the curricula and pedagogy for all scientific disciplines.

Models and modeling have gained such standing within these national reform efforts because they have been described as a major component in the advancement of science. Nersessian’s work (1992, 1995) on conceptual change pays particular attention to Maxwell and his process of model use to move physics from being able to only explain Newtonian mechanics and to being able to explain phenomena that behave in a non-Newtonian manner. That is to say his process of advancing physics was through “actively

[constructing] representations by employing a problem-solving procedure”, which is one of the primary components of model building. Passmore, Gouvea, and Giere (2014) show that scientific models play a role in conceptual change amongst scientists as well, arguing that “models play a central role in scientific sense-making”. They even go as far to say that there is a “clear sense that models are at the center of the day-to-day work of science; they are the functional units of scientific thought”.

Odenbaugh (2005) draws upon the Lotka-Volterra predator-prey models to describe ways in which scientists can apply models and modeling to their discipline as a way to show how scientists use models and that models are at the center of scientific work. These model/modeling applications include the abilities to: a) explore possibilities, b) investigate more complex systems, c) provide a conceptual framework, d) generate accurate predictions, and e) generate explanations. He continues to point out that within the field of theoretical ecology there are many critics of a model-based approach. This is because these critics believe that in order for a model to be successful they must be able to provide mathematically accurate predictions. Odenbaugh (2005) disagrees, arguing that even models that are not fully accurate in their predictions are still useful. He argues that their utility comes from their ability to fulfill the other functions of models – to describe and/or explain phenomena. This notion that models function strictly to provide mathematical predictions, accurate or inaccurate, is one that we will draw upon later when looking at model use within the classroom.

The differences between model/modeling uses in the classroom as compared to the model/modeling practices of scientists are important to consider. While many of these differences may not be easy to identify, it is essential that we help students’ practices to

develop to reflect the practices of scientists. Therefore it is important for us to focus on the process by which we aid students in achieving this practice. Much of the work on scientific models/modeling within the classroom is set within a learning environment that has an explicit focus on scientific models, and model building (Brewer, 2008; Svoboda & Passmore, 2010; Windschitl, Thompson, & Braaten, 2008). Previously, we have argued for the development of a General Biology I course with an explicit model-centered focus (Manthey & Brewer, 2013) that follows a Modeling approach successful in physics. However while reviewing this previous work, we found ourselves returning to the question – do students still use models when it is not an explicit focus of their course?

This paper argues that students are using scientific models and that they are already applying the functions of scientific models – describe, explain, predict aspects of the natural world (P. S. Oh & Oh, 2011) – despite lacking specific emphasis on the teaching of scientific models. We illustrate this point by presenting interviews with students enrolled in General Biology I about their ideas regarding plant, animal, and general eukaryotic cells, which are exemplars of scientific models that exist within this first undergraduate course. We further our argument to say that while students are already applying some of the functions of scientific models when models are not an explicit part of the instruction, students are primarily taking advantage of only one of the functions – describe. However, if models are the functional unit of science practice, it is important for students to apply the additional functions of models early in their academic careers. Using the same models of plant, animal, and eukaryotic cells, we argue that a curriculum should be designed so that students are utilizing at minimum two of the three functions, in this case describing and explaining, to these models when asked about their ideas.

## **4.2 Background**

### ***4.2.1. What are scientific models?***

Scientific conceptual models are “coordinated sets of representations (e.g., graphs, equations, diagrams, and/or written descriptions) of a particular class of phenomena that exist in the shared domain of discourse” (Manthey & Brewe, 2013, p 208). These conceptual models are used by scientists to describe, explain, and predict aspects of the phenomenon of focus (P. S. Oh & Oh, 2011). Halloun (2006) argues that models are so central to scientific practice that they are the connection between theory and concept within a conceptual hierarchy. Scientific models can take two forms, each with their own level of generalizability; the first is referred to as a specific model. A specific model is that of a specific situation and serves as a starting point for the development of a basic scientific conceptual model. A basic conceptual model is the second form of models. It is the generalized form of the specific model, is useful across multiple situations, and encompass the overall concept while remaining situation nonspecific (Manthey & Brewe, 2013; Nersessian, 1995). It can be said that scientific models are multifaceted in that they are both comprised *of* something as well as *for* something (Passmore & Stewart, 2002). While the idea of a model *of* something may seem relatively straightforward, the idea of a model *for* something, we believe, garners further discussion.

### ***4.2.2. What are the purposes of scientific models?***

Scientific models have a variety of functions. These functions range from providing a way for scientists to interact with more complex phenomena that would prove otherwise difficult to manipulate – such as Watson and Crick’s model of the DNA

molecule – to generating predictions of a given phenomenon (Odenbaugh, 2005). Not only are models used by scientists to advance their work, but models are also used to communicate the ideas about the phenomenon of focus (Krell, zu Belzen, & Krüger, 2012). For the purposes of this paper, we have defined the functions of scientific models as being to provide a description, explanation, and prediction of a phenomenon (Halloun, 2006; Manthey & Brewe, 2013; P. S. Oh & Oh, 2011).

The descriptive function of a model can be seen through the use of representations, be they visual or verbal. These representations can include diagrams, drawings, 3-D objects, verbal descriptions, and/or written words. These representations allow scientists to engage with those complex phenomena, particularly with those that are too large (solar systems), too small (animal cells), or nontangible (electromagnetic forces; Odenbaugh, 2005). Oh and Oh (2011) argue that the descriptive function of models is to provide “answers to the ontological question of what exists”. While a simple description of what exists is valuable, it is important to note that a representation alone is not enough. Passmore, Gouvea, and Giere (2014) argue that a representation *of* something is not enough and that each representation used, such as the 3-D representation of DNA, has to be used *for* something, particularly “*for* developing a deeper understanding”.

Using these representations of something fulfills the descriptive function of scientific models, whereas when we have representations for something we begin to address the explanatory function of scientific models. As Oh and Oh (2011) describe, this functions as the “answers to the causal question of why things happen”. They also claim that way one scientists draw upon models is to provide explanations through the use of analogy. For example in an ecological model of a coastal marine ecosystem, we are able

to develop a descriptive explanation using food webs to illustrate the structure of the system, which can include descriptions of energy, biomass, and/or indirect effects. This same food web, however, can also be used to formulate causal explanations for *why* there would be a sudden increase in the population of sea urchins, decrease in sea kelp, and decrease in sea otter, when a new law regarding the protection of orcas was passed. While most may not have had experience with this ecosystem and/or particular food web, it is analogous to a variety of terrestrial food webs that scientists are able to draw upon to explain the particular phenomena of population fluctuation.

The third model function of focus in this paper is that of the ability of a model to have predictive power. Odenbaugh (2005) points out that many authors argue that within the field of ecology it is essential for models to provide accurate predictions about the phenomenon of focus. These accurate predictions include “using the model to make and test predictions, solve intellectual problems and test ideas” (Treagust, Chittleborough, & Mamiala, 2004). Brewe (2008) argues that instructionally, the true predictive power of models comes at the point quantitative tools are added to the representation toolbox. These quantitative tools include equations that can be manipulated to allow for measureable predictions regarding the manipulation of various aspects of the phenomena. For example, in the Lotka-Volterra model it is not until we include the equation and begin manipulating the number of predators in the system that we can make predictions regarding the dynamics of the predator-prey system. Further discussion regarding the range of functional role or purpose of scientific models can be seen in the work of Oh and Oh (2011), Krell et al. (2012), Grünkorn, Belzen, and Krüger, (2014), and Treagust, Chittleborough, and Mamiala, (2002).

It is evident that there exists a considerable amount of research regarding what models are and what the purposes of models are. Much of this work in fact has been completed in learning environments and classrooms that were designed to have a model and/or modeling centered curriculum (Brewer et al., 2010; Brewer, Traxler, la Garza, & Kramer, 2013; Chiel, McManus, & Shaw, 2010; Svoboda & Passmore, 2010). Passmore and Stewart's (2002) work looking at approaches to teaching evolutionary biology within a high school. They found that through the use of a modeling approach to teaching evolution by natural selection there is "enormous potential to deepen and broaden students understanding". These potentials can be achieved when curricula are designed with a goal of model building in mind. Grünkorn et al. (2014), Krell et al. (2012), and Treagust et al. (2002) have examined student understanding of the roles of models. Treagust et al. (2002) found that "a large majority of [the] students understood the descriptive role of models" (p. 366), but there was room to improve student understanding regarding the prediction making role of models. Despite all of this work exploring on models, modeling, the purposes of models, and student understanding of these purposes, our question remains – do students use models when it is not an explicit focus of their course, and if so are they drawing upon the multi-functionality of scientific models? To aid in answering this question we conducted a phenomenological study exploring student's scientific conceptual models of plant cells, animal cells, and eukaryotic cells and their ability to apply the functions – to describe, explain, predict – to these models.



## **4.3 Methods and Data**

### ***4.3.1. Analysis Framework***

For this work I conducted a preliminary qualitative study using a phenomenographic, approach, as described by Marton (1981), to help answer our research question of interest. Phenomenography is a qualitative research method aimed at providing an “experiential description” (Marton, 1981) through analysis of several individuals’ shared experience. In order to establish this experiential description of a shared experience, the researcher conducted individual interviews lasting approximately one hour each with three students that were enrolled in a flipped format General Biology I course. A flipped course is intentionally designed so that the majority of the course work is done outside of a formal meeting time. For this course this coursework included reading the assigned textbook, watching video lectures, taking online quizzes, and completing group assignments. Also for this course there was a required in-person meeting section that met once per week for 75-minutes. During these sessions students worked in teams of six to complete activities ranging from quizzes to simulations of various cellular processes.

The interviews that comprise this study focused on students’ ideas about three of the essential models – plant cell, animal cell, and eukaryotic cell – which undergraduate students should be able to utilize upon completion of General Biology I as identified in our previous work (Manthey & Brewé, 2013). These interviews asked participant questions aimed at eliciting their ideas about the cell types such as, “What do you know about plant cells?” and “What can you tell me about animal cells?” These questions were chosen with the intent of leaving them open ended, following the suggestions of

(Limberg, 2008) and allow for students to provide any and all of their ideas, knowledge, and understanding about each of the cellular model types. For our analysis of these interviews our goal was to “identify the qualitatively different ways in which different people experience, conceptualize, perceive, and understand” (Richardson, 1999) the phenomenon of cellular models upon the participants’ completion of the unit in General Biology I.

To analyze these data, the interviews were transcribed and photographs of student drawings were collected. Following phenomenographic methodology (Limberg, 2008) the transcripts were examined to identify “quotes that provide an understanding of how the participants experienced the phenomenon” (Creswell, 2012). We then organized these quotes into broader thematic categories. These categories allow for us to provide a description of how the participants interact with and experience the phenomenon. In order to examine how the participants experienced the phenomenon of interest, statements showing evidence of students’ model use were focused on. However, before we can provide a complete account of the participants’ experiences with cellular models, we must first provide a description of both the course and the participants of the study.

#### ***4.3.2. Course Context***

This study was conducted at Florida International University (FIU), a large, urban, public Hispanic-serving university. This university is ranked number one in terms of awarding Bachelors and Masters degrees to Hispanics (Cooper, 2011). The student population has a demographic break down of 61% Hispanic, 13% Black, 15% White, 4% Asian or Pacific Islander, and 7% other (Florida International University, 2013). It also is a commuter school, with 91% of all students residing in the three counties closest to

campus. The course had recently had a shift in pedagogical practice, which was part of a university-wide effort to reform the introductory courses, often considered gateway courses, across the STEM disciplines.

The participants in this study were drawn from one section of General Biology I. At this university General Biology I covers biomolecules and cells, metabolism and cell cycle, central dogma (DNA → RNA → proteins), and evolution. As part of the university-wide reform effort this course had been converted to follow a “flipped” course design, as previously discussed. During the formal weekly meeting sessions, which for each of the four separate sections of approximately 96 students, was 75 minutes in length, students worked in groups of 6 to complete in-class quizzes and activities.

#### ***4.3.3. Participants***

Three individuals were recruited from General Biology I, the first course in the Biological Sciences Bachelor’s of Science degree. All three participants were enrolled in one of four sections of this course that were taught using a flipped-course design model. All participants were enrolled as freshman, however two of the three had completed their Associates degree during a dual enrollment program with their respective high schools. All names are pseudonyms.

Maria, a biology major, is one of the two students interviewed who entered the course with her Associates degree. She intends to apply to and enroll in medical school upon completion of her undergraduate degree. Maria is also a typical representative example of a student drawn from the population of the institution, as she self-identifies as Hispanic and was raised in the area. At the time of the interview, she had previously

completed two biology courses – her high school level biology and a university-level introduction to biology course as part of her AA degree.

The second participant that had completed an Associates degree is Alex. Alex, who self-identifies his ethnic group as Black, is enrolled as a biomedical engineering major. He, like Maria, intends on applying to medical school upon the completion of his degree. It is worth noting that he chose biomedical engineering opposed to a standard biology degree or pre-med degree as it allowed him to have an established plan B of becoming a biomedical engineer. While completing his Associates degree he elected to not enroll in any biology courses and instead completed both Chemistry and Physics, so while his background in science is strong, he was taking a Biology course beyond the high school level for the first time.

Thomas, who identifies his ethnicity as Hispanic, was the third participant in the study. He hoped for his major to be “ecology, earth science, or something like that”. Thomas is a returning student to his undergraduate studies, and his last biology course work was in high school, 20 years ago.

#### ***4.3.4. Interviews***

Each interview was conducted on a one-on-one basis and lasted approximately one hour. The interviews were video recorded to capture the moments during which the participants were providing drawings of each of the cellular models of focus. During these semi-structured interviews each participant was asked similar questions, such as “What do you know about plant cells?” and “What can you tell me about animal cells?” These questions were chosen with the intent of leaving them open ended, following the suggestions of (Limberg, 2008) and allow for students to provide any and all of their

ideas, knowledge, and understanding about each of the cellular model types. If follow-up questions were needed to help gain further detail following a student response, they were asked. During these interviews a small portable whiteboard and markers were made available to students if they chose to use it. Each interview was conducted during the semester students were enrolled in the course and after each of the participants had completed the section of the course on cellular structure, processes, and functions.

Following the interviews a transcript was prepared. These transcripts were read and the research team identified statements of significance such as, “plant cells are like a rectangle-ish I’d say something like that because of the cell wall...” (Alex). Statements, such as this, were selected as significant because they displayed evidence that students were experiencing the phenomenon of focus for this work. The identified statements from each other the three participants were then gathered together and we attempted to develop thematic categories that were present across all the participants through, as Limberg (2008) describes, “an abductive type of analysis, moving between empirical data [interviews] and theoretical concepts [model use] to let one illuminate and contribute to the other”. It is these identified thematic categories that illuminate the students’ experience of the phenomenon under study, scientific model use.

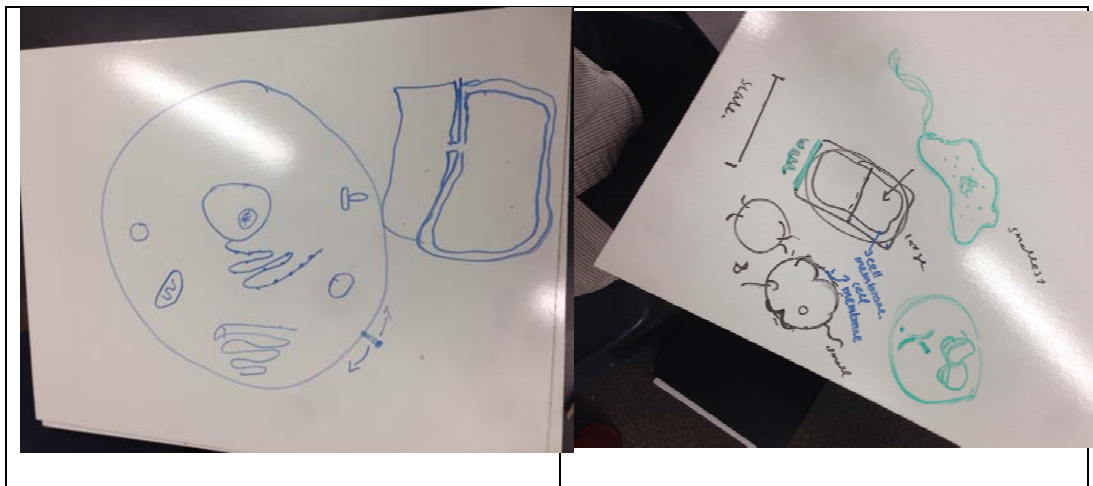
#### **4.4 Results and Discussion**

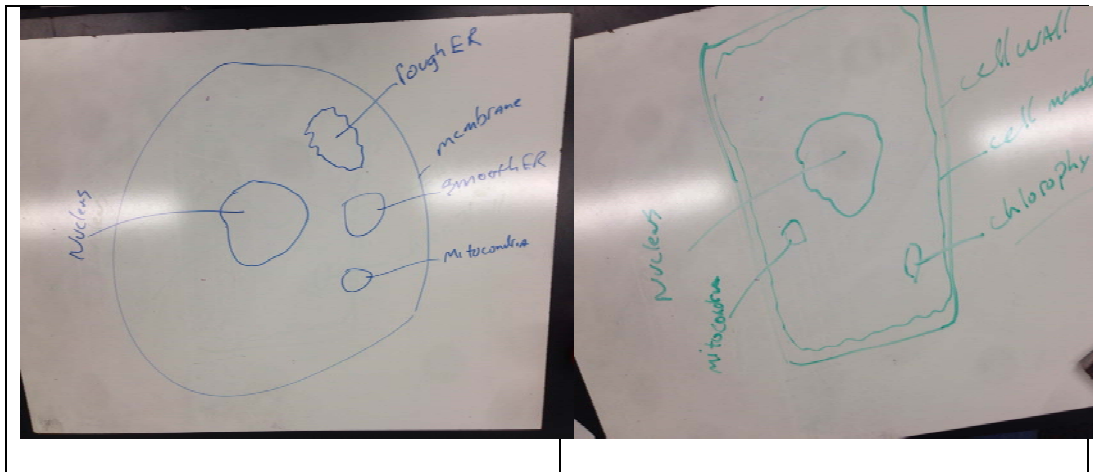
We now present the results of our preliminary phenomenographic analysis of the student interviews. These results show that there is a commonality across participants in how and what they understand about plant, animal, and eukaryotic cells following their completion of the cellular biology unit of General Biology I. Following the phenomenology methodology described by Creswell (2012), as previously discussed, we

first identified statements of significance from students regarding our phenomenon of focus. Subsequently, we categorized the statements into two common themes: describe and explain. It is these themes and their key exemplars that we now present.

#### ***4.4.1. Theme One - Describe***

One of the major themes we identified through our analysis was that students often simply listed features and facts about the cell types. We found that this theme closely paralleled the descriptive model function. This is evident through students primarily providing both verbal and drawn representations of each cellular type. Each of the participants took advantage of the available whiteboards to provide a drawing of both plant and animal cells as seen in Figure 1.





**Figure 1 (Clockwise). a) Alex’s drawings of a plant cell and of an animal cell; b) Maria’s drawings of a plant, animal, prokaryotic, and eukaryotic cell; c) Thomas’s drawing of a plant cell; and d) Thomas’s drawing of an animal cell.**

While each student was working on providing a drawing of the cell of focus, they were also providing a verbal representation for each. For example, in all three instances when providing a drawing of a plant cell, the participants stated that these cells are rectangular in shape due to the existence of the cellular wall. Thomas, while beginning his drawing of a plant cell, “roughly rectangular with that being the cell wall...”; Alex, “plant cells are like a rectangle-ish I’d say something like that because of the cell wall...”; and Maria, “So plant cells are like, they’re like rectangular right, because they have a cell wall.”

This pattern of providing both a verbal representation and drawn representation continued throughout the interviews. However, there do exist portions of the interviews where the participants provided descriptive aspects without providing (or adding to) a drawn representation. When discussing a comparison between plant and animal cells, Maria goes on to describe a list of organelles both have in common. “They share a bunch of organelles like the mitochondria, nucleus, like they both have nucleuses. They are like

membrane bound. They have the ER [endoplasmic reticulum], the golgi apparatus, the lysosomes and stuff like that... they have the same organelles.” Thomas also provided lists of cellular organelles, but in this instance he was referring to and labeling organelles he had previously drawn. The majority of the significant statements we identified fit into the first theme of lists and facts regarding descriptive elements of the cells. However, we were able to identify a second theme.

#### ***4.4.2. Theme Two - Explain***

During the interviews when participants were asked the intentionally open prompts like, “what can you tell me about plant cells”, they primarily provided descriptive features of the cell as previously discussed. However, there were a few statements made by the students that we grouped together as a second thematic category. These statements when analyzed together formed a theme that again paralleled one of the three primary model functions. This second theme is one where students explained the function of the cellular components they had listed previously.

In multiple instances it was not until prompted by the interviewer to explain the purpose of a specific descriptive aspect, organelles for example, of the cell did the participants begin to deploy the explanatory power of their model. When providing details regarding the features of plant cells, Maria said “they have chloroplasts. They have mitochondria.” However, she didn’t provide any explanation of the function of these organelles without the interviewer prompting, “okay so they have mitochondria and chloroplasts, the purposes of those are?” It was at this point that Maria began discussing their role as energy producers for the cells. This explanation of mitochondria and chloroplasts existing inside plant cells for energetic purposes came up later when



comparing the cellular models of plant and animal cells. “Animal cells, so mitochondria have to have something come in. Plant cells they have chloroplasts to produce the sugars for the mitochondria to use.” This statement from Maria shows that this second theme identified by the research team paralleled one of the three primary model functions – to provide explanations. As a reminder, the explanatory model function that is paralleled by this second theme is that explanations answer the question of why things happen (P. S. Oh & Oh, 2011) and that they allow the model to not just be *of* something but instead *for* something (Passmore et al., 2014). Maria is applying the explanatory feature of the models because she is able to have a model *for* something by being able to explain the functions of the organelles within these cell types.

While in the majority of the cases students did not deploy the explanatory function of models until promoted by the interviewer, all three participants provided an explanation of the cellular walls function without needing a prompt. Maria states that the cell wall exists for the purpose of maintaining “the structure so that the cell doesn’t just, like, do its own thing”. Thomas provided a similar explanation regarding the purpose of a cell wall in plant cells in that they are present to provide structural integrity to for the cell, particularly in response to environmental pressures. “Cell wall on the outside of the plant cell keeps it from lysing, but they can still crenate. That was the other one, crenation, and all of the water leaves and it all shrinks up.” In fact when Alex provided an explanation for the purpose of cell walls he actually was discussing the same phenomenon as Thomas, “we water plants a lot because when a [plant] cell is inside a hypotonic solution it will swell up. Usually, if it was an animal cell it would burst, but plant cells actually need to be in a hypotonic solution”. Alex also references that cell walls provide a “sturdy

structure” to support both the single cell and the whole organism. As seen from the student statements above, there were moments during the interview where students deployed the explanation function of models, however these moments were infrequent and often required prompting. We identified the two major themes discussed above, both of which paralleled two of the three model functions – describe and explain. Noticing this pattern we looked at the statements that we identified as significant and found that one statement reflected the third model function of prediction.

#### ***4.4.3. Model Function – Predict***

While we did not find enough evidence to identify a third common theme across all student participants, we did identify one of significant statement as continuing the pattern of paralleling the three functions of models. This one key exemplar identified was of a student deploying the third function of model to predict. However, it was only when significantly prompted and then prompted again with follow up questions that Maria drew upon the predictive function of scientific models in to help “solve [an] intellectual problem” (Treagust, Chittleborough, & Mamiala, 2004).

**Interviewer:** Think of conditions where, like, plants can’t survive and how that relates back to the features of the cell

**Maria:** Where they can’t survive, I guess somewhere where there is no light and water

**Interviewer:** So no light. No water.

**Maria:** So like in a room where there is no light and no water or outer space, maybe. I mean there is light but there is no water.

**Interviewer:** Or oxygen..

**Maria:** Yeah, or oxygen..

**Interviewer:** And so those all relate back to what feature of the plant cell then?

**Maria:** To the chloroplast. Because the chloroplast because plants they take small components, so like O<sub>2</sub>, H<sub>2</sub>O,

and like CO<sub>2</sub> and they make it into a large component like glucose where as compared to animal cells we get glucose and we're breaking it down into the smaller components. So then yeah, they need those smaller components to be able to like function.

As can be seen from this series of prompts, it required the interviewer asking Maria directly to relate environments suitable to plants to the features of a plant cell she had previously described. Even once Maria did apply the predictive power of the cellular model, it could be argued that she only was applying this at the most basic level. As previously discussed, Brewe (2008) argues that instructionally the power of the predictive function comes from the inclusion of quantitative elements. In this case, Maria could have provided a quantitative element through a discussion of ATP production under various conditions (normal, no light, no water, etc.). From this combination of being able to only identify a single statement of significance regarding predictive model function, need for significant prompting during the interview, and lack of quantitative element when predicting, we argue there is a lack of emphasis on the predictive power of models.

#### **4.5 Reforming Curriculum for a Model-Centered Focus**

From our preliminary phenomenographic analysis of student interviews, it is evident that these students have developed models of plant, animal, and eukaryotic cells upon completing the unit of General Biology I on cellular biology. However, when the students deployed their models in the interviews they typically were only using one of the basic functions of models, to provide description. While these results may be a product of the phenomenon of focus – cellular features, functions, and structure – and the initial questions asked during the interviews – “What do you know about plant cells?” and

“What can you tell me about animal cells?” – we believe that if both the curriculum and pedagogy take a more explicit focus on model development and use, students would apply the various functions of models more evenly.

One of the primary aims of an explicit model focus in the General Biology I courses would be to have students complete the course with models that allow them to describe, explain, and predict in the same manner as practicing scientists. There are instances and specific content areas within General Biology I, such as cells, where there needs to be a distinction between the scientific practice model functions and the school science model functions. That is to say there are instances when it is instructionally advantageous to have students interact with models that only draw upon two of the three model functions. These models are to serve as scaffolds from which students, as they advance in their science careers, are able to draw upon to aid in the development and use of models that complete all three model functions. For example, if students have developed eukaryotic cellular models that describe the features of the cell and provide an explanation for why the features exist and how the mechanisms work then they will be able to apply them to phenomena in the future. One example of a phenomenon where this could be applied is being able to predict what would happen to a cell if the cellular membrane proteins, such as the sodium-potassium pump, suddenly allowed a different ratio across the membrane. This specific model of the sodium-potassium pump phenomenon does first require the foundational descriptive and explanatory model of cells.

#### **4.6 Conclusion**

In this study we have argued that even without an explicit focus on models and modeling students, when interviewed, still deploy some of the functions of model use. Seeing that students are deploying the functions of models it can also be claimed that students are, in fact, developing the practice of using scientific models. We argue, however, that there would be additional benefits to following the recommendations of both the National Research Council (2012) and the AAAS (2011) to having an explicit focus on developing model and modeling based competencies in the next generation of scientists. Not only is it recommended to have an explicit focus, but also it has been found that physics students have greater conceptual understanding in courses and programs that have this explicit focus (Brewer et al., 2010; Passmore & Stewart, 2002; Svoboda & Passmore, 2010).

#### **4.7 Acknowledgements**

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## CHAPTER 5 CONCLUSIONS

In this chapter I provide a summary of the findings from the previously discussed chapters in reference to the research questions of which this dissertation lays its foundation, explore the implications of these findings, and discuss the future directions of this work.

### 5.1. Summary of Findings

This dissertation focused on developing a data and theory driven argument for the need to reform traditional General Biology I courses to one that takes an explicit model-centered focus. The studies that developed this argument are three-fold: first, a multi-measure quantitative analysis of current instructional practices of the introductory course General Biology I at a large, public, Hispanic-serving university (Chapter 2). The second study employed qualitative methods and identified models that faculty and current textbooks found essential for General Biology I (Chapter 3). A third study explored students' use of models, as models are an essential scientific practice, developed during a course that does not take a model-centered focus (Chapter 4). Not only did these linked studies focus on the central argument for this dissertation, but they also established a framework for asking and answering bigger questions about reformed biology curriculum. These studies provided the framework for the development of a model-centered biology curriculum. Here, I provide a summation of the major findings of the studies that comprise this dissertation and lay the framework for future work, as organized by research question.

### **5.1.1. Current Instructional Practices in General Biology I – Online and Lecture Formats**

- 1) How do students enrolled in a traditional face-to-face lecture format of General Biology I compare to their peers enrolled in an online format of General Biology I on the Biological Concept Inventory?*

Previous work that studied reformed STEM courses specifically, a model-centered curriculum in physics (Brewer, Sawtelle, Kramer, O'Brien, et al., 2010) has found at the same university where the investigations included in this dissertation was carried out, that students enrolled in this model-centered course had significantly greater conceptual gains when compared to those in traditional lecture format courses.

Conceptual gains serve as one of the key measures on all reform efforts; therefore, if I am going to argue for the need to reform General Biology I it was important to establish a baseline of the conceptual gains of current instructional practices for this course.

Chapter 2 of this dissertation completed this evaluation of course efficacy. In Chapter 2 I evaluated and compared current instructional practices through a comparison of the online and web-assisted lecture based formats of General Biology I at a large, public, Hispanic-serving university. This study of current instructional practices allowed me to establish a baseline for all future work on reformed General Biology I curriculum developed at this university. One way I studied current instructional practices was through the use of the Biological Concepts Inventory (BCI; Klymkowsky, Underwood, & Garvin-Doxas, 2010) to collect data regarding student's conceptual understanding. To analyze this data, which was collect pre- and post- instruction, I used statistical model building thru linear regression analysis. I found from this analysis that there were no significant predictors of the variance of student post-instruction BCI score beyond the

pre-instruction BCI score, which was able to explain 40% of the variance in student post-instruction BCI score. Other factors that were considered in this regression analysis were student gender, course type, and representational status. I found no significant difference between students in either course format, either gender, or between statistically represented and statistically underrepresented populations in regards to conceptual understanding. I also found that in both course types on the post-instruction BCI assessment student scores were lower than 50% correct. With these type of conceptual inventory gains and scores it is evident that there are areas that we can improve instructionally that would benefit students' conceptual understanding. One way of instructional reform is through the development and implementation of a model-centered curriculum as argued for throughout this work. Implementing a curriculum of this type would provide the opportunity to improve upon these scores. However, I found it important to not only measure conceptual understanding and instead apply a multiple measure analysis to study the instructional practices due to the complex nature of a learning environment.

2) *How do students enrolled in a traditional face-to-face lecture format of General Biology I compare to their peers enrolled in an online format of General Biology I on the Maryland Biology Expectations Survey?*

Part of understanding the complex nature of a learning environment is asking questions regarding students' epistemological expectations. To answer these questions I used the Maryland Biology Expectations Survey (MBEX; Hall, 2013) as a pre- and post-instruction measure of students' epistemological attitudes about biology. On this measure students were found to have post-instruction MBEX score that was 53% and 59% favorable in the web-assisted lecture based and online formats, respectively, which were

shifts of no statistical significance from their pre-instruction scores. While statistically neutral shifts for each course type from pre- to post- instruction attitudinal scores are a good result to find because it is common to see negative shifts in student attitudes in STEM courses (Adams et al., 2006; Brewe, Kramer, & O'Brien, 2009).

Considering it positive to see that we have a non-significant impact on students' attitudinal beliefs when we examine their MBEX scores, it is worth discussing the method of instruction. Our results showed that there was a significant difference between course types when it came to explaining the variance in students' post-instruction MBEX score. However, these results did violate the assumption of homogeneity of variance using a Levene's Test, showing that these student groups were significantly different to begin with. These results do suggest though that there may be factors that predict student post-instruction score that are imbedded within course format differences, such as student age or understanding of the discipline. I would argue that we, as educators, could continue to improve our instruction so that we move from having neutral shifts towards having positive attitudinal shifts from pre- to post- instruction. This is essential because it aids in students becoming central members in the Community of Practice (Wenger, 1999). In biology education it is important to help students develop attitudes about science more in line with those of experts. One way to do this is through the development and implementation of a model-centered curriculum based off of University Modeling Instruction. This framework has been successful across multiple semesters and multiple instructors in introductory physics courses to have positive shifts in students' attitudes towards science (Brewer, Traxler, la Garza, & Kramer, 2013).

These results discussed for both conceptual understanding and attitudinal shifts are not the only significant differences between an online course, and a more traditional instructional format course. Odds-of-success is another area where I found a significant difference between course formats furthering the argument that instructional format is important. In fact, previous work suggests that there is likely a difference between a traditional format course and a model-centered course. Students from Modeling Instruction – Physics have been found to have high odds of success than their peers in traditional format classes (Brewer, Sawtelle, Kramer, O’Brien, et al., 2010), thus my interest in establishing a baseline for future comparisons in the introductory biology course context.

3) *How do students enrolled in a traditional face-to-face lecture format of General Biology I compare to their peers enrolled in an online format of General Biology I in terms of the odds of success, measured using retention rates (drop-fail-withdraw)?*

Using student course grades as a proxy measure for student success, I conducted an odds ratio analysis. For this analysis I compared the odds of students receiving a grade of C or better, a success, versus the odds of students receiving a grade of C- or lower, dropping, or withdrawing from the course, a nonsuccess. For the analysis I compared course formats, gender, representation status, and any interaction between course format and student demographics. I found that the only odds ratio comparison to show a statistically significant difference in the odds of success was the comparison between the odds of being successful in the online course and the odds of being successful in the web-assisted lecture based course. I found that students were approximately two times as likely to be successful when enrolled in the online format of General Biology I.

4) *How do students enrolled in a traditional face-to-face lecture format of General Biology I compare to their peers enrolled in an online format of General Biology I in the development of student-to-student networks?*

Additionally, I looked at the formation of student-student peer networks as another measure by which to compare the two current instructional practices. These study networks have been linked to student retention and persistence (Tinto, 1997) and also provides opportunities for students to become more central members within their community of practicing future biologists. Using surveys of students that asked, “Who do you study with to learn biology?” at a mid-semester point, I used social network analysis to analyze student responses. I used these student responses to measure degree centrality for both of the course types. I did find that there was a difference in degree centrality between the two course formats, however, this may be due simply to the fact that there were 2.5x as many responses in the web-assisted lecture based format than the online format. Taking this into account I calculated the probability of degree distribution, which calculates the probability of students having a certain number of study partners. I found that when calculating the probability of degree distribution there was no significant difference between course types in students having anywhere from 1 to 6 study partners.

With such a low probability of having more than two study partners from the mid-semester survey of both course types it is worth arguing for reforming current instructional practices. I again argue for the development of a course that follows the University Modeling Instruction framework. Brewé et al. (Brewé, Kramer, & O’Brien, 2010; Brewé, Kramer, & Sawtelle, 2012) found that the introductory physics courses that followed this framework had students forming larger peer-to-peer study networks.

It is with these combined results of current instructional practice that I see significant room for improvement thru curricular and pedagogical form efforts, as discussed throughout my review of these results. It has been argued by Freeman et al. (2014) that we, as educators, are in fact doing a disservice to our students and should move entirely towards active learning (reformed) courses. The argue that if our classroom studies were anything like clinical trails that we would be obligated to cease instruction through traditional formats due to their overwhelmingly poor results in comparison to active learning across the STEM disciplines. It is these next sections that I provide a summary of my proposed approach to provide an active learning, evidence-based, reform curricular format. This format is one that places scientific models and modeling at its primary core.

### **5.1.2. The Structure of a Model-Centered General Biology I Course**

5) *What are the essential basic models identified by faculty and general biology textbooks for a general biology one course?*

While this work was unable to measure the efficacy of a model-centered Biology course, I was able to identify models specific to General Biology I to help the development of a model-centered biology I course in study two. In addition, as part of this dissertation I explored how students use scientific models in study three, discussed later, with the aim of furthering the argument for a model-centered Biology course. This model-centered course would follow the evidence based University Modeling Instruction framework developed and found to be successful in introductory physics across multiple measures. However, this is not the only reason it is advantageous to develop a curriculum around this framework. The University Modeling Instruction framework also coincides

with the recommendations of the American Association for the Advancement of Science (Science, 2011) and the National Research Council (National Research Council, 2003; 2012) to reform the undergraduate biology curricula and pedagogical practices nationwide. These national calls suggest that one of the central focuses of all reformed STEM curriculums include students developing their skills in model use and modeling practices. It is with this in mind that I propose the framework of a curriculum for General Biology I to serve as the structure to develop curricular materials for a University Modeling Instruction – Biology course around. This proposed structural framework serves as Chapter 3 of this dissertation.

As part of this curriculum, which relies on scientific models to serve as an organizing frame, I turned to answering the question about what are the essential models students should understand upon completion of General Biology I in study two. To answer this question I interviewed biology faculty and analyzed current textbooks from which I was able to identify six essential models for General Biology I. These models are prokaryotic cells, plant cells, animal cells, mitosis and meiosis, transcription and translation, and evolution. The identification of these six essential models serves as the foundational element to develop a model and modeling centered course. These six models alone are not enough to argue for the development of a course. Drawing upon previous work that describes a curricular and pedagogical framework for an introductory physics course (Brewer, 2008; Desbien, 2002; Halloun, 2006; Hestenes, 1987), I described the adaptation process of this successful curriculum from physics to biology.

- 6) *How does the University Modeling Instruction theoretical framework developed for university physics function when applied to the development of University Modeling Instruction – Biology?*



There are disciplinary differences between physics and biology, but despite that modeling and scientific models lay at the foundation of both disciplines. In study two, I found that when trying to adapt this curricular framework across disciplines challenges arose due to differences in epistemological and ontological differences, such as in biology it is challenging to distinguish between theories and laws whereas in physics these are clearly distinct. Additionally, in adapting this framework I found that it was important to consider the representational tools that were to be used in model construction. In order to help unify student's epistemologies of science as connected across the disciplines, I argue that various representations can be used across disciplines under a University Modeling Instruction framework. One of these representations that can go across disciplines is energy pie charts, as it they can be used as representations in the cellular models of General Biology I and the kinematic models of introductory physics.

### **5.1.3. Students' Use of Models**

7) *Do students apply the functions of models (describe, explain, predict) in courses without an explicit model focus?*

Not only is the identification of models and designing a framework important for this argument, but exploring students use of models when models are not part of the explicit focus of the course were used to strengthen this argument. As model and modeling serve as a central scientific practice (Nersessian, 1999; Odenbaugh, 2005; P. S. Oh & Oh, 2011; Passmore, Gouvea, & Giere, 2014; Science, 2011) it is important to explore if instructional practices that do not focus on models are aiding students in their development of one of the AAAS's core competencies. In order to explore students use

of models I conducted interviews with three students enrolled in General Biology I. These interviews focused on student's ideas about plant, animal, and eukaryotic cells, which I had previously identified as essential models of General Biology I. From this analysis I was able to identify that when discussing these cell types students were not drawing upon all the functions of models. I found that student's predominately were using the descriptive function of scientific models when discussing plant, animal, and eukaryotic cells. There were instances when students did use either the explanatory or predictive function of models, but these instances were limited.

Since modeling is focused on the development, deployment, and revision of scientific models to provide descriptions, explanations, and predications of phenomena it is important that curriculum allow for this. As argued in Chapter 4 of this dissertation, I have encouraged that biology educators make the modeling practices and use of scientific models much more explicit in biology courses, and I argue that following the University Modeling Instruction framework to develop a General Biology I curriculum would do this very thing. A central feature of the University Modeling Instruction framework is the modeling cycle (Brewer, 2008) and it is through this cycle where students abilities to utilize three of the primary functions – describe, explain, and predict – can be developed.

The University Modeling Instruction framework, based off of the evidence provided in the introductory physics context, is an ideal candidate to base the development of reformed biology curriculum around. In this dissertation I have shown that there is much room for improvement of current instructional practices for General Biology I at a large, urban, public, Hispanic-serving university. I have also laid out the

structural backbone of a curriculum that would follow the University Modeling Instruction framework.

## **5.2 Implications of This Research**

### **5.2.1. Implications for Biology Instructors**

Having described and discussed the major findings of this research, I now turn my focus towards a discussion of the implications of this research for biology instructors. These results provide evidence that as instructors we have been successful providing multiple course formats that are of equal efficacy for the formation of student social networks and conceptual understanding. While the results of this work do show differences between course formats on two measures, epistemological expectations and odds of success, these results show for all measures and course formats there are no significant differences based on student gender or student race/ethnicity representational status. These results are important for instructors because in regards to increasing the participation of underrepresented populations, the instructor of focus for this research at the large, public, Hispanic-serving university has done no statistically significant harm towards underrepresented students ability to continue to participate as members of the biology community of practice.

The results found in this dissertation suggest that there are areas to improve the instructional practices within General Biology I. As previously discussed students in both course formats scored <50% correct on the post BCI, had neutral epistemological attitude shifts, and had a low probability of having more than two study partners. These three results indicate specific areas that we, as instructors, can improve upon. One way of improving these results is through curricular reform efforts, a point that Freeman et al.

(2014) have argued through a meta-analysis comparing lecture-based courses to active learning course formats. Additionally, the results of this study suggest that instructors can explicitly focus their reformed curriculum on models to aid in students deploying more than just one function of scientific models.

These results of this study not only argue for the need to develop reform based undergraduate General Biology I curricula, but they also provide a framework that instructors can use to address the suggestions of Freeman et al. (2014), as well as the nationwide calls for reform (National Research Council, 2012; Science, 2011). This framework not only provides a way to implement many of these suggestions it is based off of an evidence-based framework that has been developed for physics. In physics this framework has been found to increase student's conceptual understanding to a post score that is significantly higher than traditional instruction (Brewer, Sawtelle, Kramer, O'Brien, et al., 2010), has had positive attitudinal shifts across instructors (Brewer et al., 2013), and increased participation in student-student networks (Brewer, Kramer, & O'Brien, 2010).

### **5.2.2. Implications for Researchers**

One of the implications for researchers that has emerged from this study lie within the question regarding student use of model functions that serves as the basis for Chapter 4. The research question of focus here is one that can be implemented across disciplines, as well in courses that focus on models and modeling. While Treagust et al. (2002) have quantitatively explored student understand of the function of scientific models, the phenomenographic methodology used in this study allows for a more nuanced look into how students actually use scientific models. This mechanistic look into student use of

model functions as part of their courses is one that would be complimentary to much of the work that explores research scientists use of these model functions (Odenbaugh, 2005).

### **5.3 Directions for Future Work**

Future work that stems from this research is primarily focused on the development and implementation of curricular materials based off of the suggested University Modeling Instruction framework. The development of these curricular materials is the first step in efforts to provide a reformed curriculum for General Biology I. However, developing and implementing these materials is not enough as it is important to research these materials with two purposes.

One of these purposes is to collect data regarding the efficacy of these developed materials. Studying the efficacy of these materials allows for the use an evidence-based approach to refine and further develop these materials. Another purpose of collecting data on these materials is it allows for me to continue arguing for the need to analyze the complex nature of learning environments from a multi-measure approach. I intend to take this multi-measure approach not only to a developed University Modeling Instruction curriculum for General Biology I, but to apply this practice to further study other reform efforts across the biology education research community.

In this work I have developed a question and applied an appropriate research methodology to also examine a more mechanistic question regarding how students are using scientific models. I believe it would help advance the various fields within Discipline Based Education Research to continue exploring this question across various instructional methods. Conducting this analysis in the future would allow for researchers

to aid in the identification of pedagogical practices that aid in student use of the three primary model functions.

As part of this work I have provided a methodological practice, of multi-measure assessment, that can be used to analyze the efficacy of additional General Biology courses. I have argued for the development of curricula and pedagogies that would engage students in the scientific practice of model building, deploying, revising, and use. Additionally, I have provided a framework for instructors and curriculum developers to draw upon for the development of curricula that would allow students to participate in these authentic practices.

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## APPENDIX A

This Appendix includes the Biological Concept Inventory survey given to students to evaluate conceptual understanding. We dropped question 23 from the original instrument due to disagreement regarding the face-validity of the question when final scores were calculation.

### **Biological Concept Inventory - BCI**

Q1: Many types of house plants droop when they have not been watered and quickly "straighten up" after watering. The reason that they change shape after watering is because ...

- A. Water reacts with, and stiffens, their cell walls.
- B. Water is used to generate energy that moves the plant.
- C. Water changes the concentration of salts within the plant.
- D. Water enters and expands their cells.

Q2. In which way are plants and animals different in how they obtain energy?

- A. Animals use ATP; plants do not.
- B. Plants capture energy from sunlight; animals capture chemical energy.
- C. Plants store energy in sugar molecules; animals do not.
- D. Animals can synthesize sugars from simpler molecules; plants cannot.

Q3: In which way are plants and animals different in how they use energy?

- A. Plants use energy to build molecules; animals cannot.
- B. Animals use energy to break down molecules; plants cannot.
- C. Animals use energy to move; plants cannot.
- D. Plants use energy directly, animals must transform it.

Q4: How can a catastrophic global event influence evolutionary change?

- A. Undesirable versions of genes are removed.
- B. New genes are generated.
- C. Only some species may survive the event.
- D. There are short term effects that disappear over time.

Q5: There exists a population in which there are three distinct versions of the gene A (a1, a2, and a3). Originally, each version was present in equal numbers of individuals. Which version of the gene an individual carries has no measurable effect on its reproductive success. As you follow the population over a number of generations, you find that the frequency of a1 and a3 drop to 0%. What is the most likely explanation?

- A. There was an increased rate of mutation in organisms that carry either a1 or a3.
- B. Mutations have occurred that changed a1 and a3 into a2.
- C. Individuals carrying a1 or a3 were removed by natural selection.
- D. Random variations led to a failure to produce individuals carrying a1 or a3.

Q6: Natural selection produces evolutionary change by...

- A. changing the frequency of various versions of genes.
- B. reducing the number of new mutations.
- C. producing genes needed for new environments.
- D. reducing the effects of detrimental versions of genes.

Q7. If two parents display distinct forms of a trait and all their offspring (of which there are hundreds) display the same new form of the trait, you would be justified in concluding that ...

- A. both parents were heterozygous for the gene that controls the trait.
- B. both parents were homozygous for the gene that controls the trait.
- C. one parent was heterozygous, the other was homozygous for the gene that controls the trait.
- D. a recombination event has occurred in one or both parents.

Q8. You are doing experiments to test whether a specific type of acupuncture works. This type of acupuncture holds that specific needle insertion points influence specific parts of the body. As part of your experimental design, you randomize your treatments so that some people get acupuncture needles inserted into the "correct" sites and others into "incorrect" sites. What is the point of inserting needles into incorrect places?

- A. It serves as a negative control.
- B. It serves as a positive control.
- C. It controls for whether the person can feel the needle.
- D. It controls for whether needles are necessary.

Q9. As part of your experiments on the scientific validity of this particular type of acupuncture, it would be important to ...

- A. test only people who believe in acupuncture.
- B. test only people without opinions, pro or con, about acupuncture.
- C. have the study performed by researchers who believe in this form of acupuncture.

D. determine whether placing needles in different places produces different results.

Q10: What makes DNA a good place to store information?

- A. The hydrogen bonds that hold it together are very stable and difficult to break
- B. The bases always bind to their correct partner.
- C. The sequence of bases does not greatly influence the structure of the molecule.
- D. The overall shape of the molecule reflects the information stored in it.

Q11: What is it about nucleic acids that makes copying genetic information straightforward?

- A. Hydrogen bonds are easily broken.
- B. The binding of bases to one another is specific.
- C. The sequence of bases encodes information.
- D. The shape of the molecule is determined by the information it contains.

Q12: It is often the case that a structure (such as a functional eye) is lost during the course of evolution. This is because ...

- A. It is no longer actively used.
- B. Mutations accumulate that disrupt its function.
- C. It interferes with other traits and functions.
- D. The cost to maintain it is not justified by the benefits it brings.

Q13: When we want to know whether a specific molecule will pass through a biological membrane, we need to consider ...

- A. the specific types of lipids present in the membrane.
- B. the degree to which the molecule is water soluble.
- C. whether the molecule is actively repelled by the lipid layer.
- D. whether the molecule is harmful to the cell.

Q14: How might a mutation be creative?

- A. It could not be; all naturally occurring mutations are destructive.
- B. If the mutation inactivated a gene that was harmful.
- C. If the mutation altered the gene product's activity.
- D. If the mutation had no effect on the activity of the gene product.

Q15: An allele exists that is harmful when either homozygous or heterozygous. Over the course of a few generations the frequency of this allele increases. Which is a possible explanation? The allele ...

- A. is located close to a favorable allele of another gene.
- B. has benefits that cannot be measured in terms of reproductive fitness.
- C. is resistant to change by mutation.
- D. encodes an essential protein.

Q16: In a diploid organism, what do we mean when we say that a trait is dominant?

- A. It is stronger than a recessive form of the trait.
- B. It is due to more, or a more active gene product than is the recessive trait.
- C. The trait associated with the allele is present whenever the allele is present.
- D. The allele associated with the trait inactivates the products of recessive alleles

Q17: How does a molecule bind to its correct partner and avoid “incorrect” interactions?

- A. The two molecules send signals to each other.
- B. The molecules have sensors that check for "incorrect" bindings.
- C. Correct binding results in lower energy than incorrect binding.
- D. Correctly bound molecules fit perfectly, like puzzle pieces.

Q18: Once two molecules bind to one another, how could they come back apart again?

- A. A chemical reaction must change the structure of one of the molecules.
- B. Collisions with other molecules could knock them apart.
- C. The complex will need to be degraded.
- D. They would have to bind to yet another molecule.

Q19: Why is double-stranded DNA not a good catalyst?

- A. It is stable and does not bind to other molecules.
- B. It isn't very flexible and can't fold into different shapes.
- C. It easily binds to other molecules.
- D. It is located in the nucleus.

Q20: Lipids can form structures like micelles and bilayers because of ...

- A. their inability to bond with water molecules.
- B. their inability to interact with other molecules.
- C. their ability to bind specifically to other lipid molecules.
- D. the ability of parts of lipid molecules to interact strongly with water.

Q21: A mutation leads to a dominant trait; what can you conclude about the mutation's effect?

- A. It results in an overactive gene product.

- B. It results in a normal gene product that accumulates to higher levels than normal.
- C. It results in a gene product with a new function.
- D. It depends upon the nature of the gene product and the mutation.

Q22: How similar is your genetic information to that of your parents?

- A. For each gene, one of your alleles is from one parent and the other is from the other parent.
- B. You have a set of genes similar to those your parents inherited from their parents.
- C. You contain the same genetic information as each of your parents, just half as much.
- D. Depending on how much crossing over happens, you could have a lot of one parent's genetic information and little of the other parent's genetic information.

Q23: An individual, "A", displays two distinct traits. A single, but different gene controls each trait. You examine A's offspring, of which there are hundreds, and find that most display either the same two traits displayed by A, or neither trait. There are, however, rare offspring that display one or the other trait, but not both.

- A. The genes controlling the two traits are located on different chromosomes.
- B. The genes controlling the two traits are located close together on a single chromosome.
- C. The genes controlling the two traits are located at opposite ends of the same chromosome.

Q24: A mutation leads to a recessive trait; what can you conclude about the mutation's effect?

- A. It results in a non-functional gene product.
- B. It results in a normal gene product that accumulates to lower levels than normal.
- C. It results in a gene product with a new function.
- D. It depends upon the nature of the gene product and the mutation.

Q25: Imagine an ADP molecule inside a bacterial cell. Which best describes how it would manage to "find" an ATP synthase so that it could become an ATP molecule?

- A. It would follow the hydrogen ion flow.
- B. The ATP synthase would grab it.
- C. Its electronegativity would attract it to the ATP synthase.
- D. It would be actively pumped to the right area.
- E. Random movements would bring it to the ATP synthase.

Q26: You follow the frequency of a particular version of a gene in a population of asexual organisms. Over time, you find that this version of the gene disappears from the population. Its disappearance is presumably due to ...

- A. genetic drift.
- B. its effects on reproductive success.
- C. its mutation.
- D. the randomness of survival.

Q27: Consider a diploid organism that is homozygous for a particular gene. How might the deletion of this gene from one of the two chromosomes produce a phenotype?

- A. If the gene encodes a multifunctional protein.
- B. If one copy of the gene did not produce enough gene product..
- C. If the deleted allele were dominant.
- D. If the gene encoded a transcription factor.

Q28: Gene A and gene B are located on the same chromosome. Consider the following cross: AB/ab X ab/ab. Under what conditions would you expect to find 25% of the individuals with an Ab genotype.

- A. It cannot happen because the A and B genes are linked.
- B. It will always occur, because of independent assortment.
- C. It will occur only when the genes are far away from one another.
- D. It will occur only when the genes are close enough for recombination to occur between them.

Q29: Sexual reproduction leads to genetic drift because ...

- A. there is randomness associated with finding a mate.
- B. not all alleles are passed from parent to offspring.
- C. it is associated with an increase in mutation rate.
- D. it produces new combinations of alleles.

Q30: How is genetic drift like molecular diffusion?

- A. Both are the result of directed movements.
- B. Both involve passing through a barrier.
- C. Both involve random events without regard to ultimate outcome.
- D. They are not alike. Genetic drift is random; diffusion typically has a direction.

## APPENDIX B

This Appendix includes the Maryland Biology Student Expectations Survey given to students to evaluate their attitudes towards biology. Question 24 served as a filtering question requiring students to select an answer of 4 on the 1-5 Likert scale. Questions 28 – 32 responses on the Likert-scale indicated which option, A or B, students agreed with the most. Questions 6, 9, 12, 13,17, 25, 27, and 30 were scored in reverse meaning that a response of 5 on a Likert scale was the favorable response.

### **Maryland Biology Student Expectations Survey**

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 pay 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 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.

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.

## VITA

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### PUBLICATIONS AND PRESENTATIONS

Manthey, S., Samuels, N., Brewe, E., "Developing a Biology Extension Within Physics and Everyday Thinking" Contributed talk presented at the biannual American Association of Physics Teachers National Meeting, Omaha, NE, August 2011.

Manthey, S., & Brewe, E. (2011). Modeling a bacterial cell: An introduction to a model-based curriculum for biology. Poster session presented at the annual meeting of the National Association of Biology Teachers Conference, Anaheim, CA.

Manthey, S., & Brewe, E. (2012). Towards Modeling Instruction - Biology: Adapting Curricular frameworks from physics to biology. Poster session presented at the annual meeting of the Society for the Advancement of Biology Education Research Conference, Minneapolis, MN.

Manthey, S., & Brewe, E. (2012). Towards Modeling Instruction - Biology: Adapting Curricular frameworks from physics to biology. Poster session presented at the biannual meeting of the American Association of Physics Teachers, Philadelphia, PA.

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