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Effect of Process-Oriented Guided-Inquiry Learning on Non-majors Biology Students' Understanding of Biological Classification

By

Breann M. Wozniak

A Thesis Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

In

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Effect of Process-Oriented Guided-Inquiry Learning on Non-majors Biology Students' Understanding of Biological Classification

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Effect of Process-Oriented Guided-Inquiry Learning on Non-majors Biology Students' Understanding of Biological Classification

Breann M. Wozniak, Master of Science Degree
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Mankato, MN
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Abstract

The purpose of this study was to examine the effect of process-oriented guided-inquiry learning (POGIL) on non-majors college biology students' understanding of biological classification. This study addressed an area of science instruction, POGIL in the non-majors college biology laboratory, which has yet to be qualitatively and quantitatively researched. A concurrent triangulation mixed methods approach was used. Students' understanding of biological classification was measured in two areas: scores on pre and posttests (consisting of 11 multiple choice questions), and conceptions of classification as elicited in pre and post interviews and instructor reflections. Participants were Minnesota State University, Mankato students enrolled in BIOL 100 Summer Session. One section was taught with the traditional curriculum (n = 6) and the other section in the POGIL curriculum (n = 10) developed by the researcher. Three students from each section were selected to take part in pre and post interviews. There were no significant differences within each teaching method ($p < .05$). There was a tendency of difference in the means. The POGIL group may have scored higher on the posttest ($M = 8.830 \pm .477$ vs. $M = 7.330 \pm .330$; $z = -1.729$, $p = .084$) and the traditional group may have scored higher on the pretest than the posttest ($M = 8.333 \pm .333$ vs $M = 7.333 \pm .333$; $z = -1.650$, $p = .099$). Two themes emerged after the interviews and instructor reflections: 1) After instruction students had a more extensive understanding of classification in three areas: vocabulary terms, physical characteristics, and types of evidence used to classify. Both groups extended their understanding, but only POGIL students could explain how molecular evidence is used in classification. 2) The challenges preventing students from understanding classification were: familiar animal categories and aquatic habitats, unfamiliar organisms, combining and subdividing initial groupings, and the hierarchical nature of classification. The POGIL students were the only group to surpass these challenges after the teaching intervention. This study shows that POGIL is an effective technique at eliciting students' misconceptions, and addressing these misconceptions, leading to an increase in student understanding of biological classification.

Table of Contents

List of Tables

List of Figures

Introduction

It is imperative that our society have individuals who are scientifically literate in order to create an informed population that is able to make educated decisions about scientific issues at the core of our society. According to the National Research Council (NRC, 2012) there is a lack of "fundamental knowledge" in science, engineering, and technology in the United States. This lack of knowledge puts us at a disadvantage when attempting to solve modern societal problems. A new conceptual framework has been developed by the Board on Science Education in association with the National Research Council of the National Academies in an attempt to approach science education in a new and more effective way. The study of life sciences, in particular, can lead to an understanding of how life on Earth is interrelated. According to the framework (NRC, 2012), "Rapid advances in life sciences are helping people to provide biological solutions to societal problems related to food, energy, health, and environment." (p. 139). This framework addresses what students need to know at all levels with the goal to create a scientifically literate population.

Four core ideas have been outlined for conceptual understanding of the life sciences in the new NRC framework. One of these in particular is of interest to this study: Biological Evolution and Diversity. It examines the "changes in the traits of populations of organisms over time and the factors that account for species' unity and diversity alike" (p. 140). This core idea stresses evidence pointing to shared ancestry emanating from numerous sources, including comparative anatomy and genetics. The study of the classification of organisms incorporates both types of evidence to create a system that demonstrates the similarities and differences between organisms.

It has become clear, through years of science education research on teaching and learning, that students lack an understanding of biological classification along with many other scientific concepts that are required for a scientifically literate population. Some of these concepts include living things and life processes such as nutrition, growth, reproduction, and evolution; materials and their properties such as chemical change and particles; and physical processes such as light, magnetism, gravity, and forces (Driver, Squires, Rushworth, & Wood-Robinson, 1993, Morabito, Catley, & Novick, 2010). A Trends in International Mathematics and Science Study (TIMSS) from 2011 reported a lower percentage of U.S. fourth and eighth-grade students performing at or above the advanced benchmark in science relative to 14 other countries. The Program for International Student Assessment (PISA) results from 2009 show that the average score in science literacy for United States 15 year-olds has improved since 2006, and although that is promising we need to keep adjusting our educational practices to maintain this trend (National Center for Education Statistics, 2011). The study described in this thesis addressed specific conceptions that students have about one core life science concept, biological classification, by implementing process-oriented guided-inquiry learning (POGIL), an instructional method designed to construct new knowledge and based in constructivism that can facilitate conceptual change.

There are many factors that influence student learning; one of the most important may be students' misconceptions. According to Alparslan, Tekkaya, & Geban (2003), misconceptions are students' conceptions that differ from scientific conceptions. The basis for students' misconceptions are their everyday experiences. Conceptual change of these misconceptions occurs when an existing conception is changed and replaced (Franke & Bogner, 2011; Posner, Strike, Hewson et al., 1982). Students' misconceptions have been studied for a significant amount of time, but in spite of research about the nature of them, misconceptions are still present and very much a part of our educational environment. According to Driver, et al. (1993), these notions can even extend into adulthood despite teaching otherwise.

There have been various student misconceptions identified in many areas of biology: ecology, inheritance, and photosynthesis and respiration (Griffiths & Grant, 1985; Clough & Wood-Robinson, 1985; Munson, 1994). However, the majority of published research has been in the area of evolution and natural selection (Balci, Cakiroglu, & Tekkaya, 2006; Robbins & Roy, 2003; Jensen & Finley, 1997; Meir, Perry, Herron et al., 2007, Morabito, Catley, & Novick, 2010). With all the research on evolutionary relationships, there has been little recently published on students' misconceptions regarding the classification of organisms.

Three studies on students' misconceptions about biological classification found that students hold misconceptions on characteristics used to classify organisms, specifically animals. The two most common misconceptions were classifying by habitat and locomotion instead of anatomical structures (Kattmann, 2001; Yen, Yao, & Chiu, 2005; Yen, Yao, & Mintzes, 2007).

Along with these more recent publications on animal classification misconceptions, there are two older pieces published by Trowbridge & Mintezes (1985, 1988). The studies examined elementary school through college students' misconceptions of the following concepts: animal, vertebrate, invertebrate, fish, amphibian, reptile, bird, and mammal. It was found that misconceptions were consistent across all student levels. As with other science concepts, students continue to use their incorrect types of criteria even after they have learned the correct categories of biological classification. Therefore, effective instruction must confront students' classification misconceptions for a lesson to be effective (Kattmann, 2001). However, there have been gaps in the research regarding biological classification conceptions; it focuses only on the nature of students' conceptions. Since no research studies examine the effectiveness of specific teaching techniques on student understanding of biological classification, this study fills the gaps using the POGIL instructional technique.

Misconceptions need to be identified, confronted, and overcome before they can be corrected. Different approaches have been developed to address and foster conceptual change (Science Teaching Reconsidered: A Handbook, 1997). Studies have shown that constructivist learning strategies can sometimes facilitate this change. These strategies are based on constructivist techniques that have been developed to modify students' misconceptions. Some of these strategies are word association, concept maps, clinical interview, conceptual change texts and instruction, analogy, and predict-observe-explain (Bahar, 2003; Alparslan, Tekkaya, & Geban, 2003; Balci, Cakiroglu, & Tekkaya, 2006; Sungur et al., 2001). There have been different studies showing effective implementation of these different instructional strategies in a variety of courses, but there does not seem to be one strategy that fits all situations. The strategy in use may be too course specific, and some strategies were ineffective because of incorrect implementation or design. While some instructional approaches have been shown to foster understanding by altering students' conceptions, science educators have not been able to consistently shape instruction to achieve conceptual change (Scott, Asoko, & Leach, 2007).

While the science education literature clearly and extensively describes students' typical scientific misconceptions and some of the barriers associated with changing them, instructional approaches need to be pursued further. POGIL is an instructional approach which has the potential to overcome the barriers. As mentioned previously, there is a very limited amount of research regarding how to increase student content knowledge and decrease misconceptions regarding the biological classification of organisms. More specifically, POGIL, while shown to increase student learning primarily in chemistry (Hinde & Kovac, 2001; Lewis & Lewis, 2005), has not been studied as an effective instructional method used to increase student understanding of biological classification. This study applies POGIL to this new content area.

A group learning environment may also be imperative for effective conceptual change. Research into best instructional practices for science students shows that guided-inquiry creates a collaborative learning environment that confronts misconceptions and leads to learning gains when compared with traditional teaching methods (Franke & Bogner, 2011; Hanson, 2006; Furtak, 2009). POGIL uses group learning and can confront students' misconceptions and increase understanding.

"POGIL uses guided inquiry – a learning cycle of exploration, concept invention and application as the basis for . . . carefully designed [curriculum] that students use to guide them to construct new knowledge" (http://www.pogil.org/about). POGIL is a teaching and learning strategy and philosophy that uses students working together in groups, emphasizing the social aspect of learning. It is this design that has led to an effective learning environment by creating positive student attitudes and increasing content mastery as well as overall class scores (Farrell et al., 1999; Hanson & Wolfskill, 2000; Hinde & Kovac, 2001; Lewis & Lewis, 2005; Eberlein, Kampmeier, Minderhout et al., 2008; Lewis, Shaw, & Heitz, 2009).

POGIL has been effectively implemented at the high school and college levels and in many different courses, ranging from chemistry to mathematics to anatomy and physiology. Generally, it has been found, when compared to traditional teaching methods, that student attrition is lower; student mastery of content is higher; and most students prefer POGIL over traditional methods (Farrell et al., 1999; Hanson & Wolfskill, 2000; Hinde & Kovac, 2001; Lewis & Lewis, 2005).

POGIL has had a limited role in the biology classroom and an even less of a presence in the biology laboratory. There is a single research publication detailing the effectiveness of POGIL implementation in an anatomy and physiology lecture, but no publications of any kind exist involving POGIL in a college biology laboratory setting. There was also a high school biology text developed and published in the spring of 2012, focusing on non-laboratory classroom activities (POGIL Labs, 2011). In addition, POGIL has not been studied as a tool for conceptual change in biology, or in any area.

This study added to the body of POGIL research by not only implementing it in biology, but in a college biology laboratory setting, aimed at fostering conceptual change.

This study used POGIL to address biology students' understanding of the concept of biological classification. It measured students' understanding of biological classification by examining students' conceptions and content knowledge. The study used a mixed methods research design that combined quantitative and qualitative research to provide deeper insight into the problem.

Purpose

The purpose of this study was to investigate the effectiveness of an inquiry-based pedagogy, process-oriented guided-inquiry learning (POGIL), to address non-majors college biology students' understanding of biological classification. Students' understanding was measured by assessing their biological content knowledge and conceptions. This was a mixed methods study that broadened understanding of the topic by combining both qualitative and quantitative research and methods.

Research Questions

This study investigated the following research questions:

Research question: How does the use of process-oriented guided-inquiry learning affect non-majors college biology students' understanding of biological classification when compared to traditional laboratory instructional methods?

Sub question 1: How do the students score on content knowledge assessments?

Sub question 2: What are student conceptions of biological classification as demonstrated in interviews?

Sub question 3: How do student interview responses compare and contrast with students' content knowledge scores?

Literature Review

This study examined how the use of process-oriented guided-inquiry learning (POGIL) affected non-majors college biology students' understanding of biological classification. This chapter reviews literature on research in education regarding student misconceptions and instructional practices that can be used to confront them. It begins with the theoretical background on conceptual change for this study. Then there is a review of misconceptions and instructional techniques used to address them. The chapter focuses on three techniques in detail: inquiry, cooperative learning, and the learning cycle. The final section addresses POGIL, the technique used in this study. The theoretical background and research on POGIL is reviewed. It is a specific instructional technique developed to help students construct their own understanding and can address misconceptions that incorporates inquiry, cooperative learning in the form of learning teams, and the learning cycle.

The literature review is used to support the study to determine how the use of process-oriented guided-inquiry learning affects students' understanding of biological classification. First, it shows the need for the study by showing that there is a need for instruction to facilitate effective and long-lasting conceptual change. Second, there is a limited amount of research on student conceptions' and understanding in biological classification. Third, POGIL is a technique that has not been implemented or researched in a non-majors college biology laboratory. Lastly, there is no research on how POGIL may affect student understanding of biological classification.

Conceptual Change

In the mid 1900's, cognitive psychologist, Jean Piaget began developing theories on cognition that became influential in forming perspectives on student concepts and conceptual learning. Piaget describes learning as an interactive process where individuals make sense of the world using cognitive schemas, or clusters of concepts, that can change as the individual interacts in his/her environment. His ideas have successfully been applied to education and specifically, in science education curriculum design. There has been significant research conducted on science learning heavily influenced by Piaget (e.g., Koslowski, 1996; Kuhn, 1991; Kuhn, Amsel, & O'Laoughlin, 1988; Metz, 1997, Adey & Shayer, 1993; Lawson, 1985; Shayer, 2003) (as cited in Scott et al., 2007). These ideas have been challenged by some, and the view has shifted from knowledge constructed within the individual to knowledge constructed as the individual functions in social contexts.

Anna Sfard (1998) proposed two different metaphors for learning in social contexts: acquisition and participation. Social constructivism (Vygotsky, 1978) is an approach applied to science learning (Driver et al., 1994; Hodson & Hodson, 1998; Howe, 1996; Leach & Scott, 2002, 2003; Mortimer & Scott, 2003; Scott, 1998; Wells, 1999) (as cited in Scott et al., 2007) and other fields that focuses on the social context as a part of the learning process.

During acquisition, concepts are learned by the individual and then stored within. During participation the learner is interested and participating in activities while learning, and in the process is becoming part of a community, as in situated cognition. In works on the situated cognition perspective, (Rogoff, 1990; Lave & Wenger, 1991; Collins, Brown & Newman, 1989; Roth, 1995) (as cited in Scott et al., 2007) learning occurs when students engage in socially organized practices, authentic activities, where specialized skills are developed in apprenticeship thinking with components of the process being: modeling, coaching, scaffolding, fading, and encouraging learners to reflect on their own problem-solving to enter that community and its culture.

Aspects of both metaphors can assist in gaining greater clarity about what and how students should be taught to learn and engage in science meaningfully (Scott et al., 2007). The POGIL teaching technique is heavily influenced by these perspectives on conceptual change. It incorporates both the individual and social aspects of conceptual change. The POGIL teaching strategy used in this study incorporates conceptual change theory into its structure by including learning through social interaction and participation, using the practices and language of the scientific community, and encouraging reflection on problem-solving.

Misconceptions in Science

Hundreds of studies have been conducted in science education and cognitive science using Piaget's ideas beginning in the 1970's and continuing through today. Research on the cognitive aspects of science learning has assembled important findings that impact many in the field of science education. One of the most prevalent topics in this research are the misconceptions of concepts in scientific disciplines (Mintzes & Quinn, 2007). However, the idea of concept is difficult to define, which makes it difficult to measure conceptual change (DiSessa & Sherin, 1998).

We have extensive knowledge in science concept learning: students' misconceptions in many different science areas, main barriers to conceptual learning as scientific principles are introduced among ideas and language of everyday life, and knowing that learning takes place in engaging in social and individual contexts. However, there are other areas that need to be researched much further, such as determining which instructional approaches help students to learn a scientific point of view (Scott et al., 2007).

Scott et al. outlines areas of future research in conceptual change and lists the following variables that may determine the effectiveness of a teaching approach: clear teaching objectives, motivating activities, engaging and challenging students' thinking, and granting the students the opportunity to articulate their understanding.

Students' misconceptions have been studied for a significant amount of time, but in spite of research about the nature of them, misconceptions are still present and very much a part of our educational environment. According to Driver, et al. (1993), these notions can even extend into adulthood despite teaching otherwise.

There are many factors that affect student learning; teaching and learning styles are two that we are familiar with, but student misconceptions play an important part in this. Bahar (2003) describes that misconceptions are "concepts that have particular interpretations and meanings in students' articulations that are not scientifically accurate" (p. 56). Novak and Gowin (1984) (as cited in Bahar, 2003) proposed the idea of knowledge claims as products of inquiry, this is describing something as "what we think the answer to our question should be". Eight knowledge claims regarding misconceptions were summarized by Bahar:

1. Students come to formal science instruction with a diverse set of misconceptions concerning natural objects and events.

2. The misconceptions that students bring to formal science instruction go beyond age, ability, gender, and cultural boundaries.

3. Misconceptions are tenacious and resistant to extinction by conventional teaching strategies.

4. Misconceptions often parallel explanations of natural phenomena offered by previous generations of scientists and philosophers.

5. Misconceptions have their origins in a diverse set of personal experiences including direct observation and perception, peer culture and language, as well as in teachers' explanations and instructional materials.

6. Teachers often subscribe to the same misconceptions as their students.

7. Students' prior knowledge interacts with the knowledge presented in formal instruction, resulting in a diverse set of unintended learning outcomes.

8. Instructional approaches that facilitate conceptual change can be effective classroom tools (p. 57).

Common biology misconceptions. There have been various student misconceptions identified in the area of biology. Some of them are in ecology (Griffiths & Grant, 1985; Munson, 1994), inheritance (Clough & Wood-Robinson, 1985), and photosynthesis and respiration (Balci, Cakiroglu, & Tekkaya, 2006). The majority of the published research has been in the area of evolution and natural selection.

In 2007, Robbins & Roy identified students' misconceptions about natural selection and successfully challenged these misconceptions with an inquiry-based learning activity. The activity consisted of three steps: identification of existing preconceptions, brief lecture and laboratory exercises designed to challenge these, and the interpretation of data with peer instructions to synthesize new ideas. At the end of the activity 59% of the students accepted evolution regardless of their belief system.

In another study, Jensen & Finley (1997), assessed students' conceptual change on concepts of evolution by successfully using a paired problem solving strategy based on evolutionary history to challenge non-Darwinian misconceptions. After the use of the instructional technique students' responses were more consistent with Darwinian theory.

Meir, Perry, Herron et al. (2007) developed an instrument that identified four misconceptions about evolutionary trees: incorrect mapping of time, tip proximity indicates relationship, node counting, and straight line equals no change. They found that upper level students did better at avoiding these misconceptions than lower level students, but 25% of the upper level students still showed evidence of holding onto misconceptions. Surprisingly, with all of the research on evolutionary relationships, there has been very little recently published on students' misconceptions regarding the classification of organisms into related groups.

Kattmann (2001) conducted a biological classification misconceptions study to determine, "what criteria for classifying animals do students use themselves?" and "what opportunities are opened by the personal conceptions of the students for the meaningful learning of biological taxonomy?". The students applied their own criteria when classifying given animals in different exercises. The two most common misconceptions were classifying by habitat and locomotion, which students continued to use even after they had learned the correct categories of biological classification. Based on this study Kattmann suggests that instruction must confront students' misconceptions for a lesson to be effective.

Yen, Yao, & Chiu (2005) examined elementary through secondary students' misconceptions of reptiles and amphibians with an instrument that consisted of multiple choice and free-response questions along with student interviews focused on items that were related to amphibian and reptile concepts. Students were also asked to classify pictures of animals by placing them in boxes with labels such as, "fish", "amphibian", "reptile", "bird", and "mammal". Misclassification of the reptiles and amphibians seemed to correlate with students' perceptions of anatomical features such as appendages, segmentation, and body covering.

Yen, Yao, & Mintzes (2007) explored 2000 Taiwanese students from elementary school through college to determine their concepts about animal classification. They explored students' misconceptions of animal, vertebrate and invertebrate, fish, amphibian, reptile, bird and mammal. Clinical interviews, sorting tasks, and a two-tiered diagnostic instrument were used to explore these misconceptions and then compared them to conceptions of students in New Zealand, the United States, and the United Kingdom. The common misconceptions, regardless of country of origin, were that "animal" refers to vertebrate, and that animals could move and have “viability”. Students had difficulty seeing differences between vertebrate and invertebrate and reptiles and amphibians and tended to use habitat and movement to categorize organisms.

Along with these more recent publications on animal classification misconceptions there were two older studies published by Trowbridge & Mintezes (1985, 1988). The studies examined elementary school through college students’ misconceptions of the following concepts: animal, vertebrate, invertebrate, fish, amphibian, reptile, bird, and mammal. Students were interviewed and asked to perform a “classification task” which consisted of categorizing animals into pre-labeled groups such as, “fish”, “amphibian”, or “mammal”. Once decided the students placed a drawing of each animal into a box with an identical label. It was found that misconceptions were consistent across all student levels. Students referred to an “animal” as a familiar vertebrate and the misclassification of specific organisms was persistent across all levels.

After considering these studies it is clear that there have been gaps in the research regarding biological classification conceptions. Most focus only on the nature of students’ conceptions, not on the effect of specific teaching techniques on student understanding. This study fills this gap by investigating a teaching method, POGIL, an instructional method designed to construct new knowledge and based in constructivism that can facilitate conceptual change increase student understanding in biological classification.

Instructional Techniques to Address Misconceptions

The Board on Science Education in association with the National Research Council of the National Academies has developed a new conceptual framework in an attempt to approach science education in a new and more effective way. This framework states that early insights as a child build the foundation for how people understand the world. Building and changing this understanding is important when looking at students' misconceptions and how to teach to address them. Additionally, this framework assists in helping students develop an understanding of scientific explanations. This is accomplished by instituting a progressive process that begins by introducing scientific knowledge and practices at a young age. This structure supports "increasingly sophisticated learning" as students progress through their schooling and helps students understand how scientific knowledge and practices are products of social collaboration (p. 26). For conceptual understanding to occur, misconceptions need to be modified as students learn science. Students need an interconnected learning system that involves thought, discourse, and practice in a social context (NRC, 2012).

In the chapter *Misconceptions as Barriers to Understanding Science*, in the book Science Teaching: A Handbook (1997), it is stated, "misconceptions need to be identified, confronted, and overcome before they can be corrected". Bahar (2003) conducted a study of literature on student misconceptions, how they can be formed, research findings on misconceptions in biology, and suggested some commonly used conceptual change techniques for instructors. Some of these techniques include word association, concept maps, clinical interview, conceptual change texts, analogy, and predict-observe-explain.

The following explains other studies that have been conducted on student misconceptions in biology and teaching techniques that have been used to address them.

Alparslan et al. (2003) used conceptual change instruction in an 11th grade biology course. Misconceptions on respiration were first identified and a test was administered to a group of students that received the traditional instruction and administered to the group that received the experimental instruction that included the use of conceptual change texts. Conceptual change texts present students' misconceptions first and then provide students with the correct scientific explanations about the topic at hand to promote conceptual change. Results showed that the experimental instruction resulted in greater achievement on the respiration test.

Balci et al. (2006) studied the effect of two experimental types of instruction, the learning cycle and conceptual change text instruction used together and compared to traditional instruction on eighth grade students' understanding of photosynthesis and respiration in plants. It was found that the experimental instruction were more effective than traditional instruction.

Sungur et al. (2001) investigated the effect of conceptual change texts integrated with concept mapping on 10th grade students' understanding of the circulatory system. Misconceptions were identified through student interviews and related literature and a test was developed. The test was then given to the experimental group which was taught using the conceptual change texts and concept mapping and to the control group which received traditional instruction. It was found that the experimental technique produced a positive effect on the students' understanding of circulatory system concepts.

The previous literature discussed different instructional techniques that have been used in an attempt to change students' misconceptions. In the following sections I will focus on guided inquiry as a teaching strategy to address these misconceptions. It is discussed as a separate instructional strategy because of its importance in the POGIL instructional technique.

Guided Inquiry

Inquiry-based learning is a broad reaching term that covers a wide range of teaching approaches. The definition of guided inquiry learning for this study is learning that is prompted by a question or specific issue and constructed in students' minds based on new knowledge and understanding (Lee et al., 2004) (as cited in Spronken-Smith, Walker, Batchelor et al., 2011). The teacher serves as a facilitator and students are expected to engage in a certain level of self-directed learning. Spronken-Smith et al. (2011) conducted a meta-analysis to determine enablers and constraints in the use of inquiry. They also outlined three different "modes" of inquiry depending on the level of freedom of the learner: structured inquiry, guided inquiry, and open inquiry. Placed on a continuum the first would be highly structured by the instructor, the last being open investigation by the learners. Inquiry-based instruction is a key component in this study because it is inherent in POGIL instructional design, and it has been shown to be in an effective technique in biology laboratories. The definition of guided inquiry learning used in this study is supported by the National Research Council's definition of inquiry. This definition includes the NSES's definition of scientific practices within the newly established Framework for Science Education, and also includes ideas based in constructivist theory and the field of educational change.

Inquiry has been a theme of science curriculum for the past fifty years, becoming increasingly popular in the past two decades. It is a widespread phrase that includes many different aspects of science education. The National Science Education Standards (NSES) identifies three categories of inquiry: scientific inquiry, inquiry learning, and inquiry teaching (Anderson, 2002, 2007; Abd-El-Khalick et al., 2004). All three categories overlap with one another, but still maintain their own distinctions. Along with the three categories there are additional views in other science education literature. The definition of inquiry in this study includes all three categories of inquiry: scientific inquiry, inquiry learning, and inquiry teaching.

In an effort to make the concept of inquiry clear, the National Research Council (NRC)(2000) has published a guide for teaching and learning that provides practical components of inquiry. The NRC published Inquiry and the National Education Standards (2000), which lays out inquiry curriculum as planned activities. There are many implications in using inquiry as a guide for curriculum and the fact that inquiry has so many different meanings affects how inquiry curriculum has been designed.

According to NSES, scientific inquiry is referring to the nature of science, or what scientists do, as the goal for instruction (Anderson, 2002, 2007; Minner et al., 2010). Inquiry learning is an active process where students learn through inquiring in a way that reflects the processes scientists use. Inquiry teaching can come in a variety of forms and refers to the pedagogical approach employed by teachers.

Most recently, the NRC (2012) has developed a framework that consists of knowledge and practices to facilitate student learning and assist them in engagement in scientific inquiry. These scientific practices include:

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information (p. 40)

These practices helped to shape this study's definition of inquiry by incorporating all the steps in this new framework.

Inquiry has roots in the thoughts on the nature of learning and teaching, by the works of Piaget and Vygotsky, among others. Their works have been used to shape curricular materials, and are often referred to as "inquiry-based" (Minner, Levy, & Century, 2010). As explained previously, constructivist approaches include both an individual's active engagement in thinking to alter or replace existing knowledge and his/her participation in a meaningful social interaction in order for learning to take place (Cakir, 2008; Mayer, 2004). These constructivists thoughts on the nature of learning is embedded in the definition of inquiry for this study through the idea that learning is constructed in students' minds based on new knowledge and understanding.

The field of educational change has been influenced by numerous scholars that come from many different areas, psychology, organizational development, and history and educators in different subject areas (Fullan, 2001; Sarason, 1990; Cucan & Tyack, 1997; Miles, 1993) (as cited in Anderson, 2007). The many points of view outline different types of educational practices, and most of these studies indicate that more inquiry needs to be included. This study supports this view by integrating a new inquiry learning technique in the undergraduate non-majors biology laboratory.

Chatterjee, Williamson, & McCann (2009) describe guided-inquiry laboratories as experiments where students follow directions and gather data on variables and analyze these data to establish relationships among them. Chatterjee, Williamson, & McCann surveyed student attitudes and perceptions about guided inquiry labs when compared to open inquiry and found that students have a more positive attitude and feel that they learn more in guided inquiry labs (Freedman, 1997; House, 1995) (as cited in Chatterjee, Williamson, & McCann, 2009).

Furtak et al. (2009) performed a meta-analysis and review on nine recent "gold standard scientific studies" of inquiry teaching and determined the "impact of variations of inquiry-based teaching and learning on student achievement in experimental and quasi-experimental studies" published from 1996-2006. According to the meta-analysis, inquiry-based teaching can be described as a framework with four facets: procedural where students engage in the activities of scientists; conceptual including the facts, theories, and principles of science; epistemic the "understanding about where scientific theories and principles come from"; and finally the social facet where scientific information is created in a collaborative process. It was confirmed by this study that intentionally structured and teacher-guided inquiry leads to content learning gains when compared with traditional teaching methods.

Inquiry in the college biology laboratory. In the traditional lecture-based classroom Piaget (1970) (as cited in Daempfle, 2006) stated that there is no need for student reflection because the instructor is the source of all information. The learner does not need to recognize any cognitive conflicts that could potentially lead to improving reasoning skills and learning new content. If a student has the opportunity to reason in his/her scientific studies she/he are more able to interpret data and observations, determine valid arguments, and draw conclusions. It has been shown (Lawson, 1992; Perry, 1970; King & Kitchener, 1994) (as cited in Daempfle, 2006) that around half of introductory college biology students lack the ability for advanced reasoning. College educators presume that college students, as adults, should have already developed scientific reasoning skills, and when the students have not, the blame is placed on the preparation by secondary educators. However, if a student has never been required to reflect and recognize these cognitive conflicts he/she will not have the ability to reason. It is the responsibility of every educator to weave inquiry experiences into teaching to allow students the chance to develop scientific reasoning skills. Studies have found that inquiry-based lessons and laboratories in biology classrooms have led to gains in learning when compared with traditional teaching approaches (Lord & Orkwiszewski, 2006; Luckie, Maleszewski, & Loznak et al., 2004; Nadelson, Walters, & Waterman, 2010; Wallace, Tsoi, & Calkin, 2003).

Lord & Orkwiszewski (2006) studied 100 non-majors introductory college biology students. The group of students shared the same lecture, but were placed in two different lab sections covering many different introductory biology topics. One of the labs, being the control group, was taught with "cookbook" laboratory exercises and the other lab, the experimental group, was taught in a using an inquiry instructional technique. Students were placed in cooperative groups to design their own experiment on the given topic. It was found that students in the control group did not have as high of a success rate on weekly biology content quizzes as the experimental group and the experimental group had more positive attitudes about their experience in the biology lab.

Luckie, Maleszewski, & Loznak et al. (2004) redesigned four college level introductory biology laboratories into inquiry labs. Students were placed in peer research teams, had to pose a scientific question, propose an experimental design, perform a multi-week investigation, and present their findings. Over four years it was found that students responded positively to the lab design and the students outscored their peers in traditional labs on a standardized test, leading to a conclusion that the inquiry-based labs result in an increase in student learning.

Nadelson, Walters, & Waterman (2010) attempted to integrate undergraduate research experiences into three undergraduate biology courses: Animal Behavior, Marine Biology, and Tropical Marine Biology. There were three instructional approaches used, all reflecting different levels of inquiry, differing in teacher and student responsibility. The lowest level of inquiry, according to their definition, is dependent on the teacher while in the highest, the learner is working almost independently creating the research question, designing the methods and collecting data. Overall, students involved in the courses showed gains in perceived knowledge and interest in science and students involved in the highest level of inquiry had more confidence in doing research and greater gains in scientific knowledge.

Wallace, Tsoi, & Calkin (2003) studied five students' learning in a non-majors Organismal Biology Lab. The labs were rewritten to include more inquiry-based instruction by containing few step-by-step procedures and being more exploratory in nature. Two activities were the focus of the study and both focused on samples collected from a nearby water source and then students analyzed the "ecosystem" collected. Four out of five students interviewed added significantly to their knowledge base of experimental design and two of the five students showed substantial conceptual learning increases.

The literature reviewed on inquiry in the college biology laboratory shows that most inquiry is incorporated into the laboratory experience by having students design their own experiments to some degree. This works with the guided inquiry definition presented in this research by proving a level of structure that is not "open inquiry" or highly structured, where learning is prompted by a question and knowledge is then constructed in students' minds. Regardless of the differences in definition and technique, these studies have shown student improvements, whether they are quiz and standardized test scores, attitude, confidence and interest in science, or conceptual and experimental design knowledge.

Process-Oriented Guided Inquiry Learning

Process-oriented guided inquiry learning (POGIL) is a teaching and learning strategy and philosophy that uses students working together in groups, emphasizing the social aspect of learning. As previously mentioned, Vygotsky's theory on social development, focusing on how children learn collaboratively, prompts that students develop concepts by engaging in the process with others, whether it be a teacher and student, or a group of students (Vygotsky, 1978; Daiute & Dalton, 1992; Palincsar & Brown, 1984; Driver, Asko, Leach, Mortimer, & Scott, 1994; Schoenfeld, 1983) (as cited in Dalton, Morocco, Tivnan et al., 1997) and embedded in POGIL are these constructivist and cooperative learning ideas. However, POGIL uses the term "learning teams" rather than cooperative learning to avoid preconceptions and to stress how participants work together in teams to develop skills and abilities.

POGIL technique. This study examined how the use of process-oriented guided-inquiry learning (POGIL) affected non-majors college biology students' understanding of biological classification. POGIL recognizes that there are two components to education, "content and process", and that one cannot be stressed more than the other because as our content knowledge expands our process skills become more important (Hanson, 2006). To assist students in learning both content and process skills POGIL is based on research that states students learn best when:

- actively engaged and thinking in the classroom and laboratory
- drawing conclusions by analyzing data, models, or examples and by discussing ideas

- working together in self-managed teams to understand concepts and to solve problems
- reflecting on what they have learned and on improving their performance
- interacting with an instructor as a facilitator of learning (p. 3).

Richard Felder (as cited in Eberlein, Kampmeier, Minderhout et al., 2008) has stated that:

> ...teacher-centered instructional methods [traditional lectures] have repeatedly been found inferior to instruction that involves active learning, in which students solve problems, answer questions, formulate questions of their own, discuss, explain, debate, or brainstorm during class, and cooperative learning, in which students work in teams on problems and projects under conditions that assure both positive interdependence and individual accountability. This conclusion applies whether the assessment measure is short-term mastery, long-term retention, or depth of understanding of course material, acquisition of critical thinking of creative problem-solving skills, formation of positive attitudes toward the subject being taught, or level of confidence in knowledge or skills (p.269).

There are seven components that have been identified based on this research to develop students' process skills and content knowledge: the use of learning teams and guided-inquiry activities, questioning that promotes critical and analytical thinking, problem solving, reporting, metacognition and individual responsibility. Each component is described below.

Learning Teams. Inquiry learning creates an ideal environment for collaboration among students. Previous theoretical work discussed in this literature review (Piaget, 1926 & Vygotsky, 1978), demonstrates how important social interaction is in learning. According to these theories, knowledge is gained by social collaboration, in a specific community, in this case the scientific community, and by generating cognitive conflicts (Bell, Urhahne, & Schanze et al., 2010). Inquiry has embedded within it attributes that reinforce the need and ability for collaboration among students and learners.

Placing students in organized, learning teams to work on a problem or task can stimulate inquiry, improve concept development, enhance student problem solving, and give students have more direction and interest in their own learning (Chiappetta & Koballa, 2002). A cooperative learning environment helps facilitate conceptual change in students (Franke & Bogner, 2011). The success of this may be because misconceptions were used as a basis for constructing lessons (Kattmann, 2001).

POGIL is a teaching and learning strategy and philosophy that uses students working together in groups, emphasizing the social aspect of learning. While POGIL does not refer to its student groups as cooperative learning groups, the groups certainly share many characteristics.

Research has shown that students working in cooperative rather than competitive groups and teaching one another results in an effective learning environment (Totten, Sills, Diggt et al., 1991; Bowen, 2000; McKeachie, Pintrich, Yi-Guang et al., 1986). Students feel better about themselves, have positive attitudes, and learn and understand more than students working independently. They are also able to exchange information, perceptions, and conclusions when working with one another (Hanson, 2006). However, team learning may not be beneficial unless the groups are structured.

In POGIL the teams are highly structured with three to four students, and tasks divided among them by assigning roles such as manager, spokesperson, recorder, and reflector. POGIL also uses constructivist teaching techniques, such as guided inquiry and utilizing the learning cycle.

Guided inquiry and the learning cycle. POGIL's guided-inquiry is structured by the learning cycle that was developed and based on Piaget's mental functioning model (Eberlein, Kampmeier, & Minderhout et al., 2008; Karplus, 2003; Atkin & Karplus, 1962). There are variations of the Learning Cycle (LC), but generally it involves three phases: exploration, invention, and application (Singer & Mosocovici, 2008). During the exploration phase students experience different objects or events designed around a specific concept, encouraging them to discover any patterns or relationships. During invention students are guided by an instructor and provided with key terms to find examples of the concept they have just experienced. Finally, in the last phase students apply their knowledge of the concept to everyday life, helping to reinforce their new knowledge (Chiappetta & Koballa, 2002).

In POGIL's first phase of exploration students are given a model to examine through critical thinking questions that closely follow the learning objectives. During the second phase of invention students discover a pattern to help develop an understanding of the concept at hand. Finally, during application students utilize their new knowledge and apply it to new situations or problems. For example, during a POGIL on cell types students work through three different models, the first looking at cell anatomy, the second, comparing plant and animal cells, and the third is examining a table of prefixes associated with cells terminology. During the final section of the POGIL activity students are asked to apply their newly gained knowledge on cells to determine the effect the structural differences have on the functions of a cell. Specifically focusing on a plant cell with root hairs, muscle cells and their fibers, nerve cells and their extending axons and dendrite, and sperm cells with their tail and mitochondria (In Prokaryotic and eukaryotic cells, 2012).

The learning cycle has been the focus of many studies and found to be an effective way to teach science concepts and reasoning skills (Lawson, 2001). Gabel (2003) has identified this as a highly effective learning strategy, producing better content achievement and more positive attitudes towards science. Collaboration can be incorporated into the learning cycle to increase its effectiveness by increasing achievement scores, long-term retention, higher self-esteem, and increased problem solving ability and concept understanding. According to Guzzetti et al. (1993), the learning cycle has been found effective at eliminating scientific misconceptions. POGIL uses the basic tenants of the learning cycle in its structure, thus making it an effective way to help eliminate scientific misconceptions.

Critical and analytical thinking, problem solving, and reporting. Critical and analytical thinking are used in POGIL to “guide students’ exploration of the models”. This is accomplished by using three types of questions: (1) directed questions that have obvious answers based on the model presented, (2) convergent questions requiring students to create relationships from new and previous knowledge, and (3) divergent questions that are "open ended" encouraging the students to apply to new concepts they have learned in the answer (Hanson, 2006). The POGIL instructors also encourage critical thinking by asking questions that promote thought from the students. When responding to critical thinking questions students are combining their new knowledge with information from other sources enhancing their problem solving ability by applying different problem solving strategies (Rubinstein, 1975; Bunce & Heikkinen, 1986; Reif, Larkin, & Brackett, 1976; Levine, 1994) (as cited in Hanson, 2006). In student reporting, closure to the activity occurs, providing students with the opportunity to develop communication skills. The spokesperson from each team is responsible for presenting and explaining their team's thoughts on a particular question or topic.

Metacognition and individual responsibility. According to Hanson (2006), metacognition is "thinking about thinking". This is used in POGIL by creating an environment where continual improvement is encouraged and students realize that they are in charge of their own thinking. In POGIL this is attempted by utilizing assessments and evaluations by both the instructor and the students on content and process skills. Working in learning teams is a valuable tool for gaining content knowledge and process skills.

POGIL laboratory exercises follow the same general principles: the use of learning teams and guided-inquiry activities, questioning that promotes critical and analytical thinking, problem solving, reporting, metacognition and individual responsibility. The guided-inquiry experiments, structured using the learning cycle, are designed to lead students to hypothesis formation and testing, collecting data, looking for trends, and making conclusions. Each lab begins with a guiding question that is specifically designed for hypothesis formation and testing (Farrell, Moog, & Spencer, 1999; POGIL Labs, 2011) (see Chapter 3 Methods: POGIL curriculum).

POGIL instructor. The role of the instructor in POGIL is unique. The instructor serves as a facilitator, guides students in the process of learning, and is not the sole provider of knowledge. According to Hanson (2006), instructors have four roles to play: leader, monitor and assessor, facilitator, and evaluator. As the leader the instructor develops and explains the lesson, defines what is expected of the students, and organizes the learning event. The instructor monitors by circulating through the class to acquire information from the students. As facilitator the instructor moves around the class asking critical thinking questions and assisting with students' questions, helping to guide them to the correct answers when needed. Finally, as evaluator the instructor asks the groups to report out details about their strategies and results.

POGIL research. POGIL has been effectively implemented at numerous institutions mainly in different chemistry courses, but also in anatomy and physiology. It has been found when compared to traditional teaching methods that student attrition is lower (Lewis & Lewis, 2005), student mastery of content is higher (Lewis & Lewis, 2005; Brown, 2010; Murphy, Picione, & Holme, 2010), and most students prefer POGIL over traditional methods (Eberlein et al., 2008; Brown, 2010). It should be noted that it often takes more than one semester of implementing an instructional technique to determine its effectiveness and mixed results can be due to the difference in students, subject area, or even the time that the lesson was taught. Occasionally, additional modifications of the curriculum are also needed to improve its effectiveness.

Hinde & Kovac (2001) implemented POGIL activities in a college level physical chemistry lecture. Half of the students were in a traditional lecture course with computer-based active learning exercises in cooperative groups and the other half of the students used POGIL and mini-lectures. They found that both instructional strategies resulted in student learning and positive attitudes towards chemistry.

Lewis and Lewis (2005) provided evidence that POGIL improves performance in chemistry by increasing attendance, grades, and enrollment in more advanced chemistry courses. In 2009 Lewis, Shaw, & Heitz studied the role of self-concept in students' academic success in general chemistry. It was found that the self-concept of the students in the course sections taught in the POGIL format, rather than in the traditional format, was improved over the semester.

Three different pedagogies of engagement in science were compared by Eberlein et al. (2008): problem-based learning (PBL), POGIL, and peer-led team learning (PLTL) to create a guide for instructors interested in active learning techniques. They found that these techniques were all based around constructivist learning theories and had students working together in groups. POGIL was unique in the following ways: the groupings were more structured; the instructor worked as a facilitator helping to guide students when needed; activities were designed to be completed in one class, and students and instructors enjoyed the classroom environment more and felt that it was "conductive to the development of important learning skills".

Murphy, Picione, & Holme (2010) implemented POGIL in their college chemistry course. During the first semester of the implementation one-third of the time POGIL sections performed lower than the control. However, during the second semester some of the POGIL activities were changed by adding mini-lectures, and the POGIL sections then performed better than the control.

POGIL has also published numerous texts, mainly in chemistry, that have materials pre-developed for the instructor (Abrahamson, 2011). The POGIL teaching method has been applied in subject areas other than chemistry. The literature contains examples of correctly implemented POGIL curriculum in mathematics, business administration, anatomy and physiology, and information literacy (Johnson, 2011; Brown, 2010; Mitchell, & Hiatt, 2010). However, there is only one publication researching the effect of POGIL on student outcomes in the biology classroom.

In 2010, Brown added POGIL to an introductory anatomy and physiology course with students from varied backgrounds. Half of the lectures were replaced with POGIL activities. These activities had POGIL models that were flowcharts, feedback diagrams, illustrations, patient charts, and graphing. There was an increase in course mean scores from 76% to 89%. Three semesters after POGIL was initially introduced, performance on the final exam increased by 20%. The amount of students earning a D or F was cut in half after the first two semesters. In addition, students were very satisfied with this approach. This study is different from the perviously reviewed POGIL research in numerous ways: it takes place in the college biology laboratory and measures students' mastery of content and learning gains when compared to the traditional instructional method.

POGIL and the NRC 2012 frameworks. While POGIL uses the guided-inquiry approach, it also fulfills many of the eight practices recommended by the National Research Council (2012). The framework developed by NRC consists of knowledge and practices to facilitate student learning and assist them in engagement in scientific inquiry (see Chapter 2 Literature Review: Inquiry). POGIL laboratory activities have specific guidelines to be used for development to ensure that activities have the proper components. It begins with a question posed to the students. For example: “How is the structure of a molecule related to its boiling point?”. Students then analyze a model structured to suggest multiple plausible hypotheses. The model is then used to assist the groups in developing testable hypotheses. Students work to design an experiment that is needed to test their collective hypotheses. The students perform the experiment, with each group collecting data for different sets of molecules. The data from the different groups in the class support and refute different hypotheses. When all class data are pooled and analyzed to test the hypotheses, the question of the day can be answered. Questions are asked to promote application of the topic at hand, possibly through the use of another lab experiment. POGIL laboratory activities include the NRC’s practices 1, 2, 3, 4, 6, 7. POGIL activities can easily be created to include more statistical analysis to fulfill practice 5, and student presentations could be created to fulfill practice 8.

POGIL has already made a significant impact in the area of science education. When comparing it to traditional educational approaches there have been noted differences in student scores on content related material along with process skills, and student attitudes towards the content. POGIL has also been noted as helping to create a more positive and structured learning environment. The effectiveness of POGIL has been demonstrated in college chemistry courses, but its effectiveness in a non-majors college biology laboratory has not been researched nor has its effect on changing students' misconceptions.

The review of literature incorporates research studies of conceptual change strategies to address misconceptions that students hold, literature and research on inquiry, what it is and ways to apply it to teaching and learning in science and biology. Finally, POGIL literature was reviewed demonstrating its applicability both as a possible conceptual change strategy to address students' biological science misconceptions as well as a structured inquiry-based pedagogy. This study was important because it addressed an area of science instruction, POGIL in the non-majors college biology laboratory, which has yet to be qualitatively and quantitatively researched.

Method

In this chapter, the research design, setting, participants, instrumentation, curriculum, procedures, and data analysis plans are described. A concurrent triangulation mixed methods approach was used to measure the effect of process-oriented guided-inquiry learning (POGIL) on non-majors college biology students' understanding of biological classification. Data from three sources were collected concurrently and triangulated: 1) pre and post instruction student assessments measuring content knowledge quantitatively, 2) pre and post student instruction clinical interviews eliciting conceptions qualitatively, and 3) instructor reflections about students' content knowledge, conceptions, and teaching strategies.

Separate quantitative and qualitative methods offset weaknesses in one with the strengths of the other and can result in well-validated findings (Creswell, 2009). Mixed methods research can provide practical methodology that is closer to what educators experience in practice, through formative and summative assessment of their students. In addition, it uses multiple approaches to answer research questions allowing the researcher to obtain valuable answers (Johnson & Onwuegbuzie, 2004).

Triangulation of student assessment, interview, and reflection data allows the researcher to add insight and understanding to student conceptions and content knowledge that may have been missed if only one of the data collection methods would have been employed. For example, one of the disadvantages of a multiple choice student assessment is that there is a high guessing factor that may lead students to choose an answer even if they do not agree with that answer, reducing validity of claims made about students' content knowledge based on the assessment (Nilson, 2003). Some students also tend to answer using information learned in class and not their true conceptions, especially if they know these conceptions differ from what the teacher taught. During interviews their understanding can be probed more deeply.

The quasi-experimental quantitative research design used was a Nonequivalent (Pretest and Posttest) Control-Group Design (see Figure 1). Two sections of ten and six students participated in a two-day lesson on biological classification led by the same lab instructor. One section was taught in the traditional format (control group) and the other section in the POGIL format (experimental group). The participants were restricted to all those individuals enrolled in BIOL 100 and willing to participate in the study. Participants for POGIL Group A and the traditional Group B were selected conveniently since the students select class sections based on their schedules. Both groups took a pretest before the assigned type of instruction occurred, and both took a posttest after instruction (see Appendix C: Pretest/Posttest). Gain scores were calculated and pretest scores recorded since BIOL 100 classes often vary in the previous knowledge brought to class and average exam scores. For example, the researcher taught two sections of the course in the Spring of 2011 and it was apparent that the two sections varied widely in their knowledge level. This can be demonstrated by comparing their first exam scores, one section scored an average of 75% while the other scored an average of 66%.

The qualitative data experimental procedures included pre and post-intervention clinical interviews that elicited student conceptions about biological classification (see

Appendix C for Student Interview Questions). The six participants in the student interviews were selected using simple random sampling by choosing three names at random from each of the two student rosters. The students participating in the pre and post interviews were excluded from taking the pre and posttests to avoid any interference while conveying their conceptions. The remaining students took the pre and posttest.

Immediately after the completion of the lesson, the instructor participated in a 20-minute reflection to confirm that the content was taught as described by the assigned curriculum and to provide feedback on the teaching experience and the students' level of understanding (see Appendix C for Instructor Reflection Questions). The quantitative (test) and qualitative (interview and instructor reflection) types of databases were compared. A visual model of the procedures for this mixed methods study is presented in Figure 2.

Setting

This study took place at a comprehensive, public, semester-based Midwestern university with approximately 17,000 students. Of these students, approximately 80% are full-time, 53% are female and 47% are male, and 9% are students of color. There are 140 undergraduate and 80 graduate programs. The largest programs are nursing, elementary education, biology and law enforcement. Requirements for entrance into the university for first year students include ACT composite scores of 21 or higher, ranking in the top 50% of their high school class, and meeting the college preparation standards (www.mnsu.edu/about).

BIOL 100, Our Natural World, is a general education, introductory course designed for students not majoring in science. It focuses on "basic biological principles with special emphasis on the human species" and "includes scientific problem solving, biodiversity, human and social aspects of biology, ecology, cellular processes and organ function, human reproduction, prenatal development, and heredity" (http://cset.mnsu.edu/biology/courses/biolcourses.html#one). The class sizes for the summer laboratory sections were 10 morning and 6 afternoon students. The summer semester course meets daily for five weeks with one and a half hours of lecture Monday through Friday and one and a half hours of laboratory Monday through Thursday. One section has lab from 9:15 a.m. to 10:45 a.m. while the other has lab from 12:45 p.m. to 2:15 p.m. Both have lecture together from 11:00 a.m. to 12:30 p.m.

BIOL 100 has a variety of laboratory activities in which students are involved throughout the course, and there is not one specific format that every lab follows. For example, throughout the semester students will be involved in a variety of hands-on activities such as working with microscopes, preparing their own slides and viewing pre-made slides, utilizing manipulative models during mitosis and meiosis, observing brief PowerPoint lectures by the instructor, and locating and observing structures on dissected organs and organ models. During the two lab periods preceding the POGIL classification activity students were involved in two laboratory activities. The first lab was "Window into the Cell", where students learned to use microscopes and distinguish between bacteria, plant, and animal cells. The second lab was "Pond Organisms" where, with a microscope, students observed and identified living protists, bacteria, and animals.

The researcher is currently a graduate student in the Biology Education M.S. program at Minnesota State University, Mankato. As an undergraduate, the researcher majored in biology and secondary education, and has four years of experience teaching high school biology and physical science. Currently, the researcher is a lab instructor at Minnesota State University, Mankato, where she has had three semesters of experience teaching the laboratory section of Biology 100, Our Natural World. The researcher's understanding of science education and instruction may enhance the researcher's awareness, knowledge, and ability in the classroom while working with students and developing curriculum. However, the researcher's teaching experiences may create a potential bias because of her commitment to teaching with inquiry and utilizing active learning in the classroom. Every effort will be made to ensure objectivity throughout data collection and interpretation. To ensure this, conclusions will be made based on the data alone, and these conclusions will be confirmed by members of the researcher's graduate committee.

Participants

The participants in this study were students in BIOL 100, Our Natural World, during the Summer 2012 semester. The summer session was five weeks in length, and included a rapidly paced version of all the information that is part of the regular semester course. The participants were non-biology majors taking this course as a general education requirement. The participants in the study were asked to provide basic information including, age, major, and any previous biology courses taken. The majority of the students fell between the ages of 18 and 21 years and most had previously taken a high school level biology course. In addition, three of the students had previously taken BIOL 100 but had either dropped the course or did not earn a satisfactory grade. Their majors ranged from theater to political science. There were 6 males and 10 females, 14 were Caucasian, 1 African American, and 1 was African.

There was six students randomly selected to take part in the student interviews. The POGIL students consisted of two females and one male, ranging in age from 18-30. Two of the students had taken high school biology and one had taken BIOL 100 previously. One of the students qualified for disability services, including testing accommodations, but opted not to use these. Their majors were pre social work and art. The students had varied backgrounds: there was an ESL student, a student beginning school after active military service, one of the students was raised in a small farming community in South Central Minnesota, and one student was interested in becoming an environmental science major. The final BIOL 100 grades for these three students were: A, A, F.

The traditional students consisted of two males and one female. All of the students were 18-21 years old. Two of the students had high school level biology and the other student had already taken BIOL 100 previously. Their majors were political science and psychology. One of the students was raised in small farming community in South Central Minnesota. Their interest level in biology also varied, one was interested in public policy as it related to biology and another had very little interest in science in general. The final BIOL 100 grades for these three students were: C, B, B. This detailed description of the setting and participants provides context for the qualitative potion of the study and specifies the types of generalizations that can be made using the quantitative findings.

The two laboratory sections selected had the same lab instructor during the classification lesson. While it is good to use multiple instructors with both teaching techniques, there were only two sections taught during the experiment, and it was important to control any instructor differences between the sections.

There was purposeful assignment of lab sections to the two different curricula and the use of identical measurement instruments with both groups to measure any change between groups as a result of the new experimental curriculum. The instructor taught the morning lab section in the POGIL format and the afternoon section in the traditional format. The purposeful teaching assignments were due to the number of students enrolled in each section; the POGIL lesson required a minimum of 9 participating students to implement group roles correctly. Three students in the traditional lab section and six students in the POGIL section participated in the pretest and posttest, and three different students in each section participated in the pre and post interviews. One POGIL section student opted out of the study.

Variables

The independent variable in this study consisted of the type of instruction guided by its respective curriculum in BIOL 100. The instructional curriculum materials included the traditional classification laboratory activity and the POGIL classification laboratory activity developed by the researcher. Instructor reflections were collected to confirm accurate implementation of the two types of instruction.

The dependent variable measured by this study consisted of students' understanding of biological classification. Within the dependent variable there were two areas of student understanding that were measured: content knowledge, measured by students' scores on pre and posttests, and student conceptions of classification as elicited in interviews. In addition, the instructor's perceptions of students' knowledge and conceptions were collected using the Instructor Reflection Questions (see Appendix C).

Instrumentation and Curriculum Materials

Instruments. The purpose of both the tests and interviews was to determine students' content knowledge and conceptions about biological classification and whether they changed as a result of instruction. The only organisms used on the test and during the interview were animals, so that the students could answer questions using familiar characteristics and could explain their prior knowledge.

Kattmann (2001) and Yen, Yao, & Mintzes (2007) conducted research on student conceptions, and both studies found that students at all ages hold onto misconceptions about animal classification specifically regarding their morphology, habitat, and their type of movement or locomotion. Yen et al. determined elementary through college level students' conceptions about animal classification. Clinical interviews, sorting tasks, and a two-tiered diagnostic instrument were used to explore these misconceptions and then compared them to findings of other students. Their findings greatly influenced the question selection and design of both instruments used in this research. They helped to shape the misconceptions posed to students in the answer choices on the test and the organisms used in both the test and interview. The two-tiered diagnostic instrument guided the format of test questions. The structure of the sorting tasks was used for the interview protocol.

Student tests. Quantitative data were collected through identical pre and posttests (see Appendix C for Pre and Posttest). The pretest and posttest questions were designed to align directly with each of the learning outcomes in the POGIL Classification Activity (see Appendix A for POGIL Classification Activity and Table 1 for alignment). The learning outcomes specify that students will be able to list, identify, and use anatomical and molecular characteristics to classify organisms. The format was a multiple choice exam where students viewed images of organisms and applied knowledge to a variety of questions. There were 11 objective items on the final version of the test, testing students' understanding of biological classification. The items were modeled, in part, on other researchers' items (Kattmann, 2001; Chiung-Fen, Tsung-Wei, & Mintzes, 2007). The test was designed in three stages: draft, pilot, and final.

The draft instrument was developed by the researcher. Evidence for the content validity of the test items was drawn from comparisons with research on student misconceptions about biological classification, expert review of the items by a taxonomist, and a preliminary test talk-aloud with students.

An expert taxonomist, Dr. Alison Mahoney, was used to review and modify draft test items. Per her suggestion specific wording was changed in items to reduce student confusion. For example, the redundancy of the wording "biological organisms" was reduced to "organisms" for purposes of clarity. Dr. Mahoney also helped to clarify that molecular evidence should be used to classify when conflicting anatomical evidence exists.

The pilot test was split into four sections. Within the four sections the items were designed to confront common misconceptions that students hold on the classification of animals. The most common is classifying based on habitat and locomotion (Kattmann, 2001; Yen, Yao, & Mintzes, 2007). The first section measured one outcome that required the students to be able to identify the presence or absence of specific anatomical characteristics (Figure 3.1).

Within the second section there were two types of questions asked. These questions were aligned with outcomes measuring students' ability to classify organisms into groups and compare and contrast the relatedness of organisms based only on anatomical structures. Both question types presented the students with four animals and asked them to determine which characteristics scientists would use for classification or which characteristics should be used to determine which two were most closely related. For each question type, there were two types of answer sets. In one type of answer set, four possible answers were based on correct and incorrect anatomical structures. In the second type, the four possible answers included both correct and incorrect anatomical structures and common misconceptions (habitat and locomotion) as distracters (Battisti et al., 2010). Figure 3.2 depicts one of the test items and how it was designed to confront these conceptions.

In the third test section the questions were centered on classification based on molecular evidence (see Figure 3.3). These questions were aligned with outcomes that measured students' ability to classify organisms into groups and determine the relatedness of organisms based on molecular data alone. In the fourth test section the questions were aligned with outcomes that expected the student to use both anatomical and molecular characteristics together to classify organisms (see Figure 3.4) and to examine the hierarchal nature of classification. Students had a maximum of 10 minutes to complete the pre and posttest.

The pre and posttest instruments were pilot tested with 75 randomly selected participants in BIOL 100 and BIOL 480 during the semester prior to the implementation of the major study. BIOL 480 is a course taken by elementary education majors, BIOL 480 is often the only college biology course taken and some have taken BIOL 100 the year prior. BIOL 100 students took the test individually in their respective lab section. This data was not used in the pilot test item analysis because the students' answers were affected by the knowledge gained in the Traditional Classification Activity that they took part in one month before. However, their answers were used to make wording, image, and diagram changes prior to the piloting of the instrument with BIOL 480. BIOL 480 students then took the test individually before a lesson on classification. The lab instructor administered the tests.

The p-values and discrimination indices were used to help eliminate questions that were not at the appropriate level (see Table 1). P-values under .200 were considered unacceptable, and discrimination indices less than .200 were considered unacceptable. Items 3, 10, 12, and 18 were problematic and considered for removal. Item 18 was kept because it was found in previous drafts to be necessary to clarify 19. A statistician at

Minnesota State University, Mankato, Dr. Mezbahur Rahmin, assisted in creating a statistical model using MATLAB. This model identified the students who scored 80% or above in the pilot test and identified the test questions that were problematic for these students. Item 12 was problematic and considered for removal.

To determine the test instrument's reliability and validity, the Statistical Package for the Social Sciences (SPSS) was used to calculate Cronbach's Alpha, the reliability or internal consistency of the instrument with each item deleted (see Table 1). Initially, the Cronbach's Alpha for the 20-item pilot instrument was .808. Factor analysis for question relatedness was examined using the correlation matrix in SPSS. The correlation matrix initially identified six components within the pilot instrument. Questions that were shown to be problematic in the correlation matrix because they loaded above .200 on three or more of the six components were vocabulary (items 1, 2, 3) where the students had to identify organisms with an endoskeleton, exoskeleton, and mammary glands and all questions asking which organisms were most closely related based on physical characteristics (items 10, 11, 12) (see Table 1). This analysis showed these items were not measuring specific and unique concepts as intended. These six items were removed. At this point the correlation matrix identified four components. Three items were removed (items 5, 8, 9) after this process that when left in the factor analysis affected the component loading of other questions by causing them to load high on more that one component.

The final test instrument consisted of 11 multiple choice questions with a Cronbach's alpha of .845 (see Table 2). This statistic shows high reliability of the scores measured using the instrument. The items on the final instrument clustered into three factors measuring classification concepts that fit with related literature and the lesson outcomes. The factors illustrate techniques of classification: grouping of organisms based on anatomy (items 1, 2, 3), grouping organisms based on DNA (items 4, 5, 6, 7, 8), and finally a sophisticated process that combines a hierarchical understanding and anatomy and DNA (items 9, 10, 11).

The final test was validated again using the combined pretest scores of the nine students in the control and experimental groups. Factor analysis, Cronbach's Alpha for the overall instrument, and p-values and discrimination indices for each item are in Table 3. The test analysis showed five components and a lower Cronbach's Alpha, possibly due to the small sample size.

Student interviews. Qualitative data was collected through 30-minute pre and post clinical interviews. The format of the interview was semi-structured because it used open-ended questions that allowed the researcher to follow relevant topics as the interview proceeded to uncover any student misconceptions or correct conceptions on classification (Kvale & Brinkmann, 2009). Clinical interviews are used to uncover conceptual understanding. During a clinical interview an interviewer asks the interviewee to complete a particular task or answer questions on the topic at hand. The tasks and questions are specially designed to target common misconceptions. The interviewer encourages the interviewee to discuss his/her thinking as the process unfolds (Lee, Russ, & Sherin, 2008). The interview protocol was developed in three stages: draft, pilot, and final.

Evidence for the content validity of the interview questions was drawn from comparisons with research on student misconceptions about biological classification, an expert review of the questions by a taxonomist, and a preliminary talk-aloud with students. Research by Kattmann (2001) and Yen et al. (2007) was used to design interview questions in hopes of gaining insight into students' conceptions of classification by choosing organisms that may bring about common misconceptions regarding morphology, habitat, and location. Also, their research helped in the design of the structure of the tasks. The same expert taxonomist, Dr. Alison Mahoney, was used to review and modify interview questions. According to her suggestions, while reviewing test items, specific wording was changed in the interview questions to reduce student confusion on the importance of using molecular data when classifying. A preliminary talk-aloud with two individuals guided the researcher's changes in wording in the confusing questions, and gave the researcher practice in conducting clinical interviews.

The pilot interview questions and tasks for this study followed the lesson outcomes, specifically, being able to identify anatomical characteristics, and grouping or classifying based on anatomical or molecular characteristics. There were three task sets presented to the students during the interview. Each task set built upon the first to accurately elicit student conceptions. The first task set asked the students to group 7 different types of pasta, and to describe which characteristics they were using to do so (see Appendix C for Student Interview Questions). In addition, they were asked about the groups that were made and if this was at all similar to or different from the process scientists use to classify organisms. During the second task set students were asked to group or classify 7 different animals (see Appendix C: Student Interview Questions for list of animals). While grouping they were asked to describe the characteristics that they were using, whether they were able to subdivide the groups, to determine which were most closely related, and if this was at all similar to or different from the process scientists use to classify organisms. In the final task set the students were asked to determine relationships of organisms based on biochemical evidence. The 30-minute interviews took place in the laboratory classroom, but outside of the regular class time.

The clinical interview was piloted with three volunteer students from BIOL 100 during the semester prior to the implementation of the major study. The pilot interviews took place individually, outside of normal class time, two days after taking the test pilot, and a month after participating in the Traditional Classification activity. Changes in the interview script were made, along with objects and organisms used during the interview, resulting in the final interview protocol. Some questions were added to increase clarity. There was significant confusion about one question asking the students to identify the broadest group. The question was eliminated and additional probing questions were added. Additional organisms and objects were added to the first two task sets because all students grouped organisms immediately into the smallest subdivisions and were unable to combine groups when asked. There also was not much variation in the groupings made by different students. There was more pasta added to the first task set for a total of 12 types, to make the task more complex and allow for different groupings and hierarchal groupings. Additional organisms, now totaling 13, were also added to the second task for the same reasons. Also, based on the pilot interview it was determined that students taking part in the pre and post interviews should be excluded from taking the pre and posttests because of possible interference. Students repeatedly used information presented in the tests when answering questions asked during the interview. These interviews were audio recorded, coded, and analyzed.

Immediately after the completion of each lesson, the instructor participated in a 20-minute written reflection to confirm that the content was taught and to provide feedback on the teaching experience and the students' level of understanding (see Appendix C for example questions). The reflection included twelve questions. Six of the questions applied to both types of curricula. The first questions asked about any possible changes made during instruction to document how the curriculum was taught. The next set of questions related to student understanding by asking what the instructor thought students learned, whether students enjoyed the lesson, the listing of any classification conceptions that became apparent, and any assistance that was needed from the instructor. These questions were tied directly with the outcomes of the lesson and were another way to collect qualitative data related to students understanding of classification. The other six questions were directed at the POGIL classification activity and were questions that related only to POGIL. They centered on student group roles, group structure, and facilitation to further verify that the curriculum was taught as intended.

Curriculum Materials. Two types of instructional materials were used as part of the intervention to determine the effects of POGIL on students' understanding of biological classification (see Appendix A for samples of the curriculum and materials).

Traditional curriculum. The traditional group's instructional materials were based on a traditional format for instructing students on classification. During this two-day traditional lesson, students were given a brief 15-minute introductory lecture on the traditional system of classification and its hierarchal nature, related vocabulary, how to use a dichotomous key, and how to read a phylogenetic tree. The introduction included topics such as scientific naming and the hierarchical taxonomic categories of kingdom, phylum, class, order, family, genus, and species. Definitions and examples of the following terms were explained: radial and bilateral symmetry, exoskeleton and endoskeleton, segmentation, venation of leaves (parallel or net) and structures of fungi (thread-like mycelium or fruiting body). The instructor then explained how to use a dichotomous key by choosing between two mutually exclusive statements describing structural characteristics of the organism at hand and using it to place the organism in the correct kingdom, phylum, and class. Phylogenetic trees were described by stating that they show the relatedness between organisms through time, and by showing visual examples of their branches and other relevant components.

Once the introduction was finished, the students spent the remainder of the lab period, one hour and thirty-five minutes, in day one and a significant potion of the lab period of day two, about one hour, on their own or in groups of their choosing, observing sixty organisms and placing them in the correct Kingdom, Phylum, and Class. The organisms were live, preserved, taxidermic mounts, preserved in plastic, or photographs. The students used a dichotomous key that focused on key characteristics of certain Kingdoms (Animalia, Plantae, Fungi and Protista), Phyla, and Classes represented.

The following example demonstrates the process that the students go through using the dichotomous key:

1) Presented with a live iguana in a terrarium

2) Use the dichotomous key to choose between the following (Adapted from Classification of Organisms, 2012):

Key to Kingdom Animalia

1a. Radial symmetry... 2

1b. Bilateral symmetry.. 3

3a. Body wormlike, skeleton absent..................................... 4

3b. Body not wormlike...6

6a. Soft body with hard outer shell....................................... 7

6b. Skeleton is present.. 9

9a. Has an exoskeleton...10

Phylum Arthropoda

9b. Has an endoskeleton...12

Phylum Chordata

12a. Appendages as fins, many have scales............Class Osteichthyes

12b. Fins absent..13

13a. Naked skin..14

13b. Skin covered with hair or feathers.............................15

14a. Moist skin, no claws......................................Class Amphibia

14b. Dry, scaly skin, claws if appendages.............Class Reptilia (p. 64).

3) Determine using the dichotomous key that iguanas belong to the Kingdom Animalia, Phylum Chordata, and Class Reptilia.

Once they finished identifying and keying the organisms, they copied the structural characteristics for each classification group used in the key onto a worksheet (25 minutes) and lastly, created a phylogenetic tree using the keyed organisms (25 minutes). The students were free to elicit help from other students or the instructor while completing the different lab activities.

POGIL curriculum. The POGIL instructional materials and curriculum were developed by the researcher using the POGIL laboratory format. The POGIL curriculum was reviewed by a POGIL "expert". This expert has led numerous regional workshops and verified the developed curriculum as a true POGIL design. POGIL is a teaching and learning strategy and philosophy based on constructivism. Students work together in carefully structured groups to complete guided-inquiry activities which use the learning cycle that was developed and based on Piaget's mental functioning model. The learning cycle involves three phases: exploration, invention, and application (Atkin & Karplus, 1962). During the exploration phase students experience different objects or events designed around a specific concept, encouraging them to discover any patterns or relationships. During invention students are guided by an instructor and provided with key terms to find examples of the concept they have just experienced. Finally, in the last phase students apply their knowledge of the concept to everyday life, helping to reinforce their new knowledge (Chiappetta & Koballa, 2002).

POGIL laboratory exercises follow the same general principles. The guided-inquiry experiments are designed to lead students to hypothesis formation and testing, collecting data, looking for trends, and making conclusions. Each lab begins with a guiding question of the day and model that is specifically designed for formation of multiple hypotheses and testing them. The different POGIL groups within the classroom then report out their possible hypotheses to answer the question of the day. The groups, given different sets of objects to test, then design an experiment to test their hypotheses and predict the outcome. Next, the groups perform their experiments, analyze their data by comparing it to the hypotheses, and decide whether to accept or reject. Finally, the class comes back together and groups pool their data to accurately answer the question of the day and attempt to apply this newly attained knowledge to another situation.

It is important to note that there has been no concept introduction done prior to the POGIL lab. Students do not all perform the same experiment during the activity and data is pooled from multiple groups to develop a general trend or concept that addresses the question of the day. The design of POGIL Labs closely follows the steps of the learning cycle. The students' hypothesis formation and testing is equivalent to concept exploration. The collection of data, looking for trends, and making conclusions is concept introduction. Applying the information to new problems is the application of the concept (Farrell, Moog, & Spencer, 1999; POGIL Labs, 2011).

The researcher carefully designed the POGIL Classification activity to contain all the appropriate POGIL components and utilized previous research on students' understanding of classification of organisms (Kattmann, 2001 & Yen, Yao, & Mintzes, 2007). According to this research, Kattmann determined the two most common misconceptions were classifying by habitat and locomotion, and instruction must confront students' misconceptions for a lesson to be effective. Yen, Yao, & Mintzes, explored elementary school through college aged students to determine their concepts about animal classification. They explored these conceptions by assigning sorting tasks and through the use of a two-tiered diagnostic instrument. Students had difficulty seeing differences between vertebrate and invertebrate and reptiles and amphibians and tended to use habitat and movement to categorize organisms. This research was used to shape the curriculum's content by allowing the researcher to design models and questions to address these misconceptions directly.

The instructor's role in POGIL is unique. The instructor, serving as facilitator though three different models in the POGIL classification activity, guided the students. Students were placed in groups of three or four and were each assigned a role (see Appendix A for Group Roles). The first model served as a way to design a hypothesis to answer the question of the day, "What characteristics do biologists use to classify organisms?". The students were presented with 18 plant and animal organisms (moss, mushroom, oak tree, cedar waxwing, corn, octopus, snail, earthworm, tarantula, fish, frog, owl, bat, honeybee, snake, alligator, squirrel, caterpillar) and had to sort these organisms into hierarchical groups (see Appendix A). These specific organisms were chosen because of their familiarity to the students. The students were instructed to separate the organisms into groups of related organisms and to provide a rationale for each group that was created.

In the second model the students worked to confirm or reject their hypotheses (the sorting rationale from Model 1), by testing with new groups of organisms that were designed to contradict common misconceptions about classification. Each of the six POGIL student groups in the classroom had different, specially designed, groups of organisms that confirmed and rejected different hypotheses. For example, one of the POGIL lab groups had the following organisms: crayfish, water beetle, fish, soft shell turtle, snapping turtle, alligator, tiger salamander, African clawed frog, and water moccasin. This group elicited the common misconception that organisms can be classified based on habitat, since all the organisms are aquatic. Some other groups in the class were designed to refute this misconception by placing organisms such as a terrestrial earthworm and an aquatic leech in the same group. Structural characteristics of the organisms were provided to guide them in their grouping. For example: organisms should be initially divided into two groups, one group composed of organisms that have endoskeletons, the other of organisms that have exoskeletons. Once their data were pooled, with different groups discovering classification based on locomotion, habitat, and behaviors did not work, the students developed a conclusion about how to correctly classify and answered the question of the day.

The third and final model asked students to apply their newly attained knowledge by comparing classification based on anatomical structures and biochemical evidence with an activity that incorporated the classification of organisms based on their Cytochrome C sequences. Cytochrome C is a protein coded by DNA that is found in many organisms including unicellular organisms, plants, and animals. Over time, random mutations in the DNA sequence occur resulting in changes in the sequence of Cytochrome C. The relatedness of organisms can be determined by examining their Cytochrome C sequences. The students were provided with a group of organisms and again with correct structural characteristics to group them. The students then classified this group of organisms based on the provided structural characteristics. Once completed, they were given a Cytochrome C table that had all the organisms listed along with the number of Cytochrome C differences between each. The students then compared and contrasted the classification based on structural characteristics alone with the possible changes in classification that could be made based on the Cytochrome C biochemical evidence. Finally, at the completion of Model 3, students were asked to apply their new knowledge about classification by structure and biochemical evidence and classify a genetically modified organism that had both plant and bacterial genes.

It is important to note that at the completion of each model the instructor would engage the class as a whole and gather the students' answers to come to shared conclusions, ensuring that all groups had a common understanding of the material at hand and were collectively ready to move on to the next model (see Appendix A for Lesson Plan for POGIL Classification Activity: How we Classify and Instructor's Guide for POGIL Classification Activity). The POGIL lesson occurred during the first day of instruction (1 hour 50 minutes).

The second day was spent participating in an abbreviated version of the traditional classification lesson, where the students had the same brief introductory lecture and then identified organisms on their own or in small groups and placed them in the correct

Kingdom, Phylum, and Class using a dichotomous key (see Method: Curriculum Materials: Traditional curriculum above). During this the students were only required to identify half of the number of organisms (see Appendix B: Abbreviated List of Organisms for POGIL Lab Day 2). However, these specific organisms were chosen to assure that the students would experience all the key characteristics for the represented Kingdoms, Phyla, and Classes, and the students were not expected to create a phylogenetic tree.

Pilot. Pilot tests were completed to revise the curriculum. An initial talk-aloud with three people helped to revise wording and instructions, the choice of organisms used, and the clarity of the task. A pilot test of the POGIL experimental curriculum was administered in BIOL 480, an equivalent introductory biology course, during the Fall 2011 semester. The pilot served as a way to determine the timing of the three different components of the lesson and feedback from the pilot participants was used to make appropriate changes in the curriculum. During talk-alouds after the curriculum pilot three individuals identified unclear items, and the researcher revised or removed these items. For example, written instructions describing how to hierarchically break down the groups of animals were not effective in Model 1, so a graphic was used to depict the process (see Appendix A: POGIL Classification Activity, Model 1). During the pilot of Model 3 information was presented in two different ways, one provided the students with a pre-drawn diagram, the other had them draw the diagram themselves. It was found that the groups who were not provided the diagram performed better on an end of the unit assessment than those who had the diagram provided for them. With these results in mind, Model 3 in the POGIL activity was changed so that all students must draw out the diagram. In addition, some students met with the researcher and gave suggestions about how the POGIL group roles could be better described for more clarity (see Appendix A for POGIL Group Roles). Initially, there was a separate introductory POGIL activity that incorporated the hierarchal nature of classification, but this was removed after the pilot because it was determined to be too time consuming and simplistic and did not effectively contribute to learning of the outcomes.

Training was needed to properly develop and administer the POGIL curriculum. This training took place during a POGIL conference held in the summer of 2011. The training at this conference ensured that the POGIL materials were developed using the standard POGIL format and taught properly by the researcher. The conference took place at Washington University in St. Louis, throughout three days. The researcher attended various sessions including Introduction to POGIL: The Fundamentals, POGIL Labs, Writing POGIL Activities, Assessing POGIL Activities, Classroom Facilitation, and Scholarship of Teaching and Learning.

Procedure

The researcher designed the POGIL curriculum and instruments to measure how the use of process-oriented guided-inquiry learning affected non-major college biology students' understanding of biological classification when compared to traditional instructional methods. Pre and posttests were administered to the students along with pre and post interviews and a post intervention instructor reflection. The timeline of events is illustrated in Table 5. The instruments were specifically designed to measure the students' scores on content knowledge assessments, student conceptions of biological classification in interviews, and how student interview data compare and contrast with content knowledge scores. The study took place during the summer term of BIOL 100 in two laboratory sections.

Quantitative and qualitative data collection. The traditional group participated in the traditional classification activity during the same days as the experimental group's POGIL Classification activity. Both took identical pre and posttests and participated in identical pre and post interviews. Table 6 outlines the daily schedule for both the laboratory and lecture components of the course that took place during the experiment. The quantitative data were collected through the tests and the qualitative data were collected through clinical student interviews and instructor reflections.

Pretest. The pretest measurement instrument was given to the traditional and POGIL groups of students two days prior to the intervention. The identical pre and posttests were administered by the instructor to the students during the beginning of their respective lab sections. The pretest responses were used as the first set of quantitative data. The students were given the multiple choice test to complete individually (see Appendix C). Before administration of the test the students were prompted, "This is a multiple choice test about classification. Each question will present you with a group of organisms and pose a question about that group. This test does not count towards your grade. Please take the questions seriously." For completing the pretest students were given five points that contributed to their laboratory assignment scores.

Pre interview. The pre interviews took place under non-manipulative settings using a list of student interview questions, divided into three distinct task sets (see

Appendix C for Student Interview Questions). The interviews were conducted in the laboratory classroom on either the same day, but after taking the pretest, or the following day of the intervention and outside of regular class time. The pre interview was the first set of qualitative data. The 30-minute pre interviews were administered by the researcher with individual students. Before administration of the interview students were welcomed, guided through the informed consent process, and prompted, "I am not looking for right or wrong answers. I just want to learn more about how you think about classification. Please think aloud as you answer". Students were then shown the audio recorder, and it was explained that it was used so the researcher could listen closely and didn't have to take notes on what was said. To check reliability and accuracy the researcher rephrased student responses for clarity and encouraged the use of physical items to visualize movement of objects during grouping.

Intervention. The intervention occurred during the students' BIOL 100 Our Natural World Laboratory (1 hour 50 minutes session) on the third and fourth days of lab during the first week of the summer term. It is important to note that one week of lecture, in the rapidly paced summer term, is equivalent to three weeks during the regular semester and one lab in the summer term is equivalent to one in the regular semester. The lab section at 9:15 a.m. took part in the POGIL activity and the lab section at 12:45 p.m. took part in the traditional classification activity. The intervention consisted of the, two-day long, laboratory activity designed in either the POGIL or the traditional format. The activity focused on the classification of biological organisms, and was split into three distinct “models” or units within the lesson itself. The POGIL Classification Activity ended with the completion of the class period.

Instructor Reflection. Immediately after the completion of each day of both the traditional and POGIL classification activities, the instructor participated in a 20 minute written reflection to confirm that the content was taught and to provide feedback on the teaching experience and the students’ level of understanding (see Appendix C for Instructor Reflection Questions). In addition to the 20 minute written reflection, the instructor and limited student dialog during the POGIL lesson was transcribed.

Posttest and post interview. The posttest was administered one week after the completion of the intervention. The posttest was identical in form, administration, and scoring to the pretest. The time between administration of the pre and post test was 10 days, which, with the rapid pace of the summer course, was equivalent to roughly three weeks in a regular semester ensuring minimal interaction between the pre and post data.

The selected students individually took part in the post instrumentation clinical interview one week after the completion of the laboratory and ten days after the pre interview. The same semi-structured format, administration, and scoring was used in the pre and post interviews as the first interview. This served as the second set of qualitative data.

Ethical considerations

The researcher designed the experiment to avoid any anticipated ethical issues that may arise. The research problem was designed so that the individuals being studied would benefit by having access to curricula designed to be an effective way of teaching and by making a contribution to collective knowledge in general. No marginalization of the participants occurred. All participants were kept anonymous, and the purpose of the study was clearly described to the participants. All research plans were reviewed by the University's Institutional Review Board to assess any risk to participants.

Data were analyzed and the owners of these data are the researcher and the major professor of the researcher. During the student surveys, lengths were taken to ensure a positive interviewing environment along with accurate interpretation of student statements.

Data Analysis

Every effort was made to ensure internal and external validity: there was consistency during measurements, and confirmation that the results of this study were due to the intervention. This was achieved by having a control group present in the nonequivalent control group design. Certain variables were controlled, such as consistency of instruction following the intervention, to limit their effect on experimental conditions, ensuring that the only difference between the two groups was the intervention. Both groups received the same maturation, history, testing, and instrumentation effects (Campbell, D.T. & Stanley, J.C., 1963).

SPSS was used for statistical analysis. Final test validity was determined by using factor analysis, calculating Cronbach's Alpha for the overall instrument, and calculating p-values and discrimination indices for each item using the combined pretest scores of the experimental and control group. The results of both the experimental and control groups' pre and posttests were analyzed along with classification quiz scores. Descriptive statistics were calculated including the means, standard errors, and mean gain scores. The Mann-Whitney U test was used to compare mean scores between groups on the pretest, posttest, and classification quiz. The mean pre and posttest scores within each group were also compared using the Mann-Whitney U test.

The qualitative data were transcribed and categorized in terms of themes. Specific interview questions were matched to lesson plan outcomes based on how scientists classify organisms and on students' common misconceptions about classification as revealed in the literature. A coding method was used around these outcomes. Interviews were taped and transcribed verbatim. The data were then prepared and analyzed by reading through the transcripts, coding the data into themes, interrelating themes, and finally interpreting these themes.

The transcribed interview data were processed using the following steps: 1) Organize the data for analysis, by transcribing and organizing the pre and post interviews, 2) First read through the individual pre interviews, make notes and summarize the information and then do the same for the post interviews 3) Code data by hand from interviews by labeling different topics, looking for expected topics and also surprising topics 4) Categorize codes into larger more meaningful chunks with a new label, 5) Use these to create themes of topics found in both the pre and post interviews of both groups and related to the research question of the study, compile related themes into sub themes 6) Each theme representing a separate heading that includes a rich, thick description, that includes key pieces of evidence from multiple sources that support the theme, 7) Interpret the data (adapted from Bui, 2009 & Creswell, 2009).

The instructor written reflections and audio taped POGIL lesson was also analyzed. All audible instructor directions spoken to the class and any other group conversations throughout the lesson were transcribed. This was then coded and analyzed for similar themes as found in the analysis of the student interviews.

Reliability was ensured by including a detailed description of how the interviews were coded and transcribed. To ensure reliability cross-checking was used while coding where the researcher and a colleague coded the same passage in a similar manner and returned to the transcripts to check for mistakes. Data from the interviews were compared with the quantitative data to see if they were in corroboration (Creswell, 2009; Bui, 2009).

Validity was ensured by cross-checking while coding. The researcher provided a colleague with previously coded transcripts and summaries of the student interviews. The colleague then coded the same passage, peer debriefing between the two occurred and any discrepancies were discussed. There was also a rich, thick description of the method, and presentation of discrepant information that was counter to the interview themes.

The data from the tests, interviews, and reflections were analyzed concurrently. Initially, the pretest and pre interviews were analyzed together, followed by an analysis of the posttests, post interviews, and instructor reflections. This data was then combined to create a complete analysis. The possible bias of the researcher was clarified along with a description on how the findings may be shaped by these biases (Creswell, 2009).

Results

The purpose of this study was to investigate the effectiveness of an inquiry-based pedagogy, process-oriented guided-inquiry learning (POGIL), on non-majors college biology students' understanding of biological classification. Students' understanding was measured by assessing their biological content knowledge and conceptions. This was a mixed methods study that combined both qualitative and quantitative research methods. Data from three sources were collected concurrently and triangulated: 1) pre and post instruction student assessments measuring content knowledge quantitatively, 2) pre and post instruction student clinical interviews measuring conceptions qualitatively, and 3) instructor reflections about students' content knowledge, conceptions, and teaching strategies.

This section is organized as follows: 1) quantitative data analysis of pre and posttest scores, and classification quiz scores, 2) qualitative data analysis of student interviews and instructor reflections. The student interview data is described by themes. POGIL student data is reported first, followed by traditional student data. The instructor reflections follow the same pattern. The POGIL lesson reflection is reported and followed by the traditional lesson reflection. The results section concludes with a summary of the findings.

Quantitative Data

Pretest, posttest, and classification quiz. Descriptive statistics are reported for the scores on the pretest, posttest, and classification quiz for both the experimental

(POGIL) and control (Traditional) groups. Table 7 shows the means, standard errors, and post intervention mean gain scores.

Further statistical analysis was completed using the Mann-Whitney U non-parametric tests. This non-parametric test was used because participants were not randomly assigned to groups and the sample size was small. Table 8 shows the results for the Mann-Whitney U test comparing pre and posttest scores between the experimental and control groups. This table indicates that within each teaching method, there were no significant differences ($p < .05$) in the two groups' pretest scores or posttest scores. There were no significant differences within the groups over time ($p < .05$). Table 8 also shows the results for the Mann-Whitney U test comparing the classification quiz scores. This was a laboratory quiz taken by both the POGIL and traditional groups five days after the instructional intervention, focusing on terms used during the classification lab and key characteristics associated with the represented Kingdoms, Phyla, and Classes (see Appendix C: Classification Quiz). Table 8 indicates that there were no significant differences ($p < .05$) between classification quiz scores of the experimental and control groups. However, Table 8 indicates a tendency of difference in the means. The experimental group may have scored higher than the control group on the posttest ($M = 8.830 \pm .477$ vs. $M = 7.330 \pm .330$; $z =-1.729$, $p = .084$). The control group may have scored higher on the pretest than the posttest ($M = 8.333 \pm .333$ vs $M = 7.333 \pm .333$; $z = -1.650$, $p = .099$).

Table 9 Pretest and Posttest Student Answer Choices reports the percentage of students in each section who chose each answer by test. There were no significant differences (Pearson χ^2, $p < .05$) between groups for individual items, except question 6, on either test. Question 6 pretest showed a significant difference between the POGIL and traditional groups' answer choices (Pearson $\chi^2 = .018$, $p = 0.048$).

Qualitative Data

Student interviews. To further investigate the effectiveness of POGIL to address non-majors college biology students' understanding of biological classification, six randomly selected students took part in pre and post instruction clinical interviews measuring their conceptions qualitatively (see Methods: Participants for student descriptions). Several distinct themes emerged that students from both groups discussed.

The following are themes and sub themes that arose. The first theme was that after instruction students had a more extensive understanding of classification in three areas: vocabulary terms, physical characteristics, and types of evidence used to classify organisms. Both the POGIL and traditional students extended their understanding of classification after a teaching intervention, with an increased use of correct vocabulary terms, physical characteristics, and types of evidence used to classify. However, only the POGIL students extended their understanding of classification groups by explaining how molecular evidence is used in classification. It is important to note that POGIL was the only group to experience instruction on molecular evidence.

The second theme was challenges preventing students from understanding classification. These challenges included: familiar animal categories and aquatic habitats, unfamiliar organisms, combining and subdividing initial groupings, and the hierarchical nature of classification. The POGIL students were the only to surpass these challenges after the teaching intervention, and the traditional students were unable to overcome these challenges.

A POGIL student was omitted from the following analysis because the researcher could not decipher the student's meaning during the interview in spite of asking probing and clarifying questions. The following passages during both the pre and post interviews demonstrate this student's typical explanations.

> Researcher: Let's talk about the groups you made and why. So tell me the characteristics you used when you grouped these (duck, ostrich, cardinal).
> Student: I was looking at the similarities and differences that they got. The beep [sic], similar eye size, the body type is different but they have the same structure or function, different size and feathers.
> Researcher: How are the groups you made related to one another?
> Student: They are related because of the space around the ocean area and mostly belongs to water. Their food might be similar in a way. Different weights but has some type of hair on them.
> Researcher: Why are these grouped together (millipede and clam)?
> Student: Cause this could crawl on that. They are on the beach where they connect and they have more difference than similarities.
> Researcher: You have chipmunk, beaver, and seal. Why are they together?
> Student: They are both hairy animals and different characteristics. I think they are both in different living environments, this is water and this is not. The beaver and the seal have more in common. They hands are different and behaviors are different too.

More extensive understanding of classification. Both the POGIL and traditional students displayed a more extensive understanding of classification after the teaching interventions. Most students showed a less extensive understanding of classification during the pre interview, and the majority of students correctly used vocabulary terms and physical characteristics more frequently after the teaching intervention. In addition, the POGIL students understood classification as a process that relies on two types of evidence: molecular data and physical characteristics.

Vocabulary terms. When asked to describe the groups of organisms made in the pre interview, students used a combination of both correct and incorrect terms describing characteristics of the organisms. Table 11 shows the correct and incorrect use of terms and characteristics describing the individual organisms for each student in both the pre and post interviews. The students in both groups showed an increase in the correct use of vocabulary terms during the post interview. The use of new vocabulary terms by students is shown in the following passages.

Typical POGIL student explanations.

Pre Interview. POGIL student 1 used the following terms to describe and group the beaver during the pre interview, "can swim or be on land. . . have fur. . . likely to come in contact or eat the same things being in a similar environment in some cases [as the seal]", using only one correct vocabulary term, "fur".

Post Interview. However, when speaking about the beaver in the post interview, the student used the terms "endoskeleton" and "fur", both correct vocabulary terms to describe the beaver. Student 1 used the term "exoskeleton" in the post interview when describing his/her two initial groupings, "skeletons. . . inside so the birds, beaver, chipmunk, ostrich seal, and these ones have an exoskeleton or don't have one at all". Student 1 also used the term "crustaceans" when asked how the groups are related to one another, "These are probably what you'd consider animals, these are insects, [and] crustaceans".

Pre Interview. POGIL student 3 described limbs in the pre interview as "extremities". When describing the mammals in the pre interview said, "Obviously, they are all mammals, they are warm- blooded, maintain their own body temps, all have four extensions of the body, extremities, all have fur".

Post Interview. In the post interview said the "chipmunk, beaver, and seal are together because they are all fur bearers, four appendages, mammary glands, all warm-blooded". In the post interview referred to limbs as "appendages". The post interview also included the new and correct usage of "mammary glands" and "endoskeleton".

Typical traditional student explanations.

Pre Interview. Traditional student 4 associated the following correct terms with the beaver, chipmunk, and seal during the pre interview, “mammal” and “fur”. When asked which characteristics were used to group them the student said, “It’s fur and they also have kind of fat deposits, and they're mammals from what I remember in biology”.

Post Interview. In the post interview the student added “mammary glands” to the list of correct terms used to describe those organisms. “All have fur, eyes, ears, they can hear things, eat close to the same stuff. . . use mammary glands to feed their children, they have teeth, they all make noises to communicate with each other, and developed smell.”

Pre Interview. Traditional student 5 used the following correct term when describing the birds in the pre interview, “beak”. Student 5 said, “the cardinal and the ostrich [are related], their faces are shaped the same way, with beak. . . and their feet are shaped the same way.

Post Interview. During the post interview used “beak” and “feathers” when describing the birds. Stated birds, “have the beak and feet, even though the ducks are webbed, they are still kind of the same shape with claws. Look at their tails, it’s feathery”.

Pre Interview. When describing the housefly, ant, and millipede in the pre interview said, “I was kind of looking at the outside. . . I’m not sure if they have exoskeletons, but they all have more of a rough exterior and they’re all insects. They all use feelers so they all have similar things going on”.

Post Interview. Traditional student 6 specifically changed “feeler” to “antenna” and “internal skeleton” into “endoskeleton” during the post interview. During the post interview said, “I’ve got the ant and fly together because they each have three pair of legs and it looks like they both have antennae”. He also used the new terms “scales”, “crustacean”, “radial symmetry”, and “bilateral symmetry” correctly during the post interview. For example, when describing groups in the post interview he said, “Then I’ve got my goldfish over here because he’s the only guy with scales and gills. . . I’ve got the millepede by himself because he has a lot of legs and what look like antennae. . . and then the starfish. . . the symmetry is radial. The crab is over here because they have four pairs of legs and they’re crustaceans”.

Physical characteristics. Students in both the POGIL and traditional groups increased in the use of correct physical characteristics when classifying. When asked to describe the groups of organisms made, the students used a combination of both correct and incorrect physical characteristics of the organisms during the pre interview and relied more on correct physical characteristics during the post interview (see Tables 10 & 11). The students also used physical characteristics exclusively when classifying the pasta in the first portion of the interview, and the majority of students increased the number of physical characteristics used to classify the pasta during the post interview (see Table 12). The following passages list all the correct physical characteristics of organisms used in both the pre and post interviews.

Typical POGIL student explanations.

> *Pre Interview.* During the pre interview POGIL student 1 primarily classified based on habitat such as, water versus land. However, the student correctly grouped the birds, using "feathers" as one of the physical characteristics and the beaver and chipmunk were classified together because of the presence of "fur". When asked how the groups were related to one another the student said, "these are water versus land animals, you could also put these with fur, feathers, or something on them". Other correct physical characteristics used doing the pre interview were, "number of legs" and "beak".
>
> *Post Interview.* During the post interview the student divided the organisms into two distinct groups using the physical characteristics "endoskeleton" or "exoskeleton/no skeleton" and used only physical characteristics to classify or describe the organisms. For example, when asked about the groups she said, "Over here they all have feathers and are birds, and the chipmunk, beaver, and seal because they have fur rather than feathers". When describing the grouping of the crab, ant, and housefly said, "I kind of kept it with the exoskeleton thing". The physical characteristics used in the post interview included, "endoskeleton, exoskeleton, fur, feathers, similar legs, and beaks".

Pre Interview. During the pre interview POGIL student 3 began grouping organisms by placing them into familiar categories [birds, mammals, insects] and used correct physical characteristics when grouping them. For example, the chipmunk, seal, and beaver were described as, "warm-blooded, . . . all have four . . . extremities, all have fur." Also used during the pre interview were the following correct physical characteristics: "feathers, beaks, wings, scales, fins, and gills". For example, "The fish is separate, it doesn't have an exterior armor. . . It has scales. . . has more obvious extremities that makes it move faster, fins instead of legs".

Post Interview. In the post interview the student increased the use of correct physical characteristics when grouping, especially with the arthropods [ant, crab, housefly, millipede], mammals, and birds. The student used physical characteristics such as, "jointed appendages, endoskeletons, exoskeletons, antenna, mammary glands, beak, feathers, scales, number of pairs of appendages, and fins." For example, when describing the fish he said, "has scales, endoskeleton, has fins instead of arms or legs".

Typical traditional student explanations.

Pre Interview. Traditional student 4 classified organisms based on incorrect and correct physical characteristics along with type of habitat in the pre interview. He grouped the beaver, chipmunk, and seal correctly together because of "fur" and incorrectly together by "fat deposits". Other correct physical characteristics used during the pre interview were, "fur, feathers, and antenna". For example, he placed the birds together because of, "the feathers. . . birds have hollow bones. . . Although, I know ostriches can fly I just decided he was a bird".

Post Interview. During the post interview the student made identical groupings as during the pre interview, and placed the organisms together based on habitat, correct physical characteristics, and incorrect physical characteristics. However, the number of correct physical characteristics used to group increased. These characteristics included, "fur, mammary glands, wings, feathers, gills, and antenna". When asked to identify the organisms with the most similar characteristics he stated, "I would have to say two groups. This group with the mammals. . . all have fur, eyes, ears, they can hear things, eat close to the same stuff. . . use mammary gland to feed their children, they have teeth, they all make noises to communicate with each other, and developed smell. The duck and the flying birds they have beaks, talons, feathers, of course, hollow bones, also make noise, they have good eyesight."

Pre and Post Interviews. Traditional student 5 grouped the organisms in both the pre and post interview by habitat. However, when the student described the birds in both interviews there were some correct physical characteristics mentioned. The physical characteristics used in the pre interview were, "beak" and "feet shape" and the physical characteristics used in the post interview were, "feathers, beak and feet shape" (see Traditional student 5 passage in the previous theme).

Pre Interview. Traditional student 6 used many physical characteristics to group familiar organisms such as, birds have "wings . . . and have beaks" and insects "possibly have an exoskeleton". The correct physical characteristics used in the pre interview were "exoskeleton, fur, wings, beak, shell, and gills".

Post Interview. During the post interview student 6 consistently classified the organisms by proper physical characteristics and all the animals were grouped correctly. The physical characteristics used in the post interview were, "pairs of legs, antenna, exoskeleton, fur, beak, endoskeleton, wings, scales, gills, and radial symmetry". For example, during the post interview when asked if any of the groups could be combined said, "I could. . . make one giant group of things with endoskeletons versus exoskeletons. I could put my animals with antenna versus animals that don't. . . or symmetry division, bilateral and radial".

Types of evidence used to classify organisms. The types of evidence used by scientists in the classification of organisms includes similar physical characteristics and similar molecular data, with molecular data weighted more than physical characteristics. Students from both groups went from a vague understanding of the correct physical characteristics used to a more accurate and detailed understanding (see previous sub theme: Increase in the use of correct physical characteristics when classifying). These students were able to more accurately describe the physical traits that could be used by scientists to classify. Many students were able to describe how scientists would use physical characteristics and molecular data, such as DNA, to classify organisms. However, after the POGIL lesson, all included POGIL students were better able to explain how molecular evidence is used and that it overrides physical characteristics when present and can be used to determine relatedness. It is important to note that POGIL students were the only group to experience instruction about molecular evidence.

Typical POGIL student explanations.

Pre Interview. During the pre interview POGIL student 1 was asked how scientists classify organisms and replied that scientists "put them in different groupings. . . it's more specific, but in general terms it's similar creatures placed together". The student incorrectly identified relatedness between organisms in the pre interview based on common environments and physical characteristics. For example, when comparing the duck and goldfish with 21 DNA differences said, "they both live in the water, so I see how they are similar in that way and they both swim, but they look a lot different than each other". When asked about the ostrich and duck with six DNA differences, the student said, "they are definitely more related because they are from the bird family . . . although they do not share the same environment, but they do look similar."

Post Interview. During the post interview the student described the process that scientists use to classify as one that uses "physical characteristics" that are "similar". During the post interview the student was able to correctly determine relatedness between organisms. For example, when asked how related the goldfish and the duck were with 21 DNA differences, the student said, "If there's 21 DNA differences I'd say they are pretty far apart from each other". When asked about the nest pair, the chipmunk and the seal, with 8 differences said, "I think that's definitely a lot closer especially from the pairing before. And they have some similar things like the fur and they're a lot more similar than the fish and the duck are totally different".

Pre Interview. During the pre interview POGIL student 3 stated that scientists use, "physical traits" to classify organisms such as "size, features, shape, texture". The student further explained the traits as, "physical appearance, genetic attributes, different ability, different groups of cells, different compositions of animals". The student was able to correctly interpret the number of DNA differences during the pre interview to determine relatedness. When asked how related are the goldfish and duck to one another, he responded by saying, "Not very, cause they have 21 differences in their DNA." When the student was asked about the chipmunk and the seal with eight differences he said, "Genetically they are more similar than the goldfish and duck, but from the obvious physical characteristics there is still a big difference."

Post Interview. In the post interview the student stated scientists use "distinguishing traits that separated each one from the others." In addition, they use different characteristics such as genetics because "a lot of science is based on genetics, so the way things evolve different has a big part in how they're classified". During the post interview the student was able to compare the number of DNA differences with similar or different physical features. For example, when asked how related are the ostrich and duck, the student answered, "closest related pair out of the three so far, but when you look at them physically there is still a big difference. It's pretty impressive that there can be only six differences in DNA and make such a different animal." He used the same reasoning when discussing the number of differences between the turtle and duck, "When you look at the ostrich and duck with 6 differences they are pretty similar animals, both birds, have feathers, 2 wings, 2 legs and there is only one more difference in the DNA" when compared with "the duck and the turtle, and the physical characteristics are so much different . . . the physical differences between them you'd think there'd be a lot more DNA differences."

Typical traditional student explanations.

Pre Interview. In the pre interview traditional student 4 was unable to determine relatedness of organisms based on DNA, but did state that scientists use "physical characteristics" to classify and "usually, you identify animals if they look similar". The student stated that scientists classify living things "in terms of warm-blooded and cold-blooded".

Post Interview. During the post interview the student said scientists use " physical characteristics" and made a superficial mention of DNA saying they use "scientific evidence . . . DNA . . . something deeper and more fact based, each time you do it, it is consistent" to classify organisms.

Pre Interview. Traditional student 6 stated in the pre interview that scientists look at and compare more than just one characteristic. "When you are looking at organisms you have to look at different things." The student said that scientists are "more specific" when classifying, looking at what has "similar characteristics".

Post Interview. During the post interview the student gave more detail to his explanation by stating that, "there is a certain level of observation when classifying animals" and scientists " have a very strict code . . . They have more rules than I do . . . skeletal structures or how many pairs of legs versus antenna, and if they have a shell or a soft body . . . a more strict and accurate form of classifying."

Challenges preventing students from understanding classification. There were various challenges that prevented the students from reaching a complete picture of the process of classification: familiar categories and aquatic habitat, unfamiliar organisms, combining and subdividing initial groupings, and the hierarchical nature of classification. Most students showed did not fully understand classification during the pre interview, but the majority of POGIL students were able to overcome the challenges after the teaching intervention.

Familiar animal categories and aquatic habitat. The groups of organisms created by students during the pre interview show that the majority of students created groups by using a combination of grouping familiar organisms (birds, mammals, insects, fish) and grouping less familiar organisms by their aquatic habitat (starfish, clam, crab). Table 10 shows the groups made by each student in both the pre and post interviews. Common groupings during the pre interview in both groups included "birds" (cardinal, duck, and ostrich), the "aquatic" animals (crab, clam, and starfish), the "insects" (millipede, housefly, and ant), the "mammals" (beaver, seal, and chipmunk), and the goldfish.

POGIL students changed to grouping using physical characteristics instead of simple familiar categories and habitat. During the post interview, after the teaching intervention, all the POGIL students changed their original groupings. Common groups were the “mammals” (beaver, seal, and chipmunk) and the “birds” (cardinal, duck, and ostrich). These groupings were now based mainly on correct physical characteristics that represented these familiar categories.

During the post interview, the majority of traditional students kept their groupings similar, and continued to use habitat as a characteristic for their groups. Common groups used by the traditional students during the post interview were the “birds” (cardinal, duck, and ostrich) and the “mammals” (beaver, seal, and chipmunk). An outlier among the traditional students did not continue to use habitat to group since he did not make any initial groupings based on habitat and did not mention habitat in the post interview.

Typical POGIL student responses.

Pre Interview. During the pre interview the POGIL student 1 student described the following characteristics for groupings, “I was thinking these [seal, goldfish] are kind of with it but not really [crab, clam, starfish]. I was thinking water animals. They swim, technically so do crabs so they could go over here. This is the sea stuff and these are more living [seal and goldfish] animal kind of things. This is not what I would typically think of an animal, a clam or a starfish so I grouped them together”.

Post Interview. During the post interview the student created two large groups based on skeleton type. The first group being: cardinal, ostrich, duck, beaver, chipmunk, and seal with exoskeletons, the second group including ant, housefly, millipede, crab, clam, starfish, and fish with either an endoskeleton or no skeleton. The student was asked what the members of the two groups were and why, and responded, “Skeletons. . . inside so the birds, beaver, chipmunk, ostrich seal, and these ones have an exoskeleton or don’t have one at all”.

Pre Interview. During the pre interview POGIL student 3 described the characteristics used for one of his groupings as follows, “I decide to do aquatic animals. Although, I know that the crab and clam have shells and even the starfish I suppose has shell, but if you can live in water I’ll put it in a group.

Post Interview. The student had the same number of groups of organisms in the post interview, but the ant, housefly, and millipede now included the crab, creating a group of arthropods and eliminating the "insect" group from the pre interview by grouping them based on "pairs of appendages" and "exoskeletons". The student stated, "Housefly, ant, millepede, and the crab together because they all have more than 2 sets of appendages, also have exoskeletons." The groupings still included the "mammals" and the "birds". Now, rather than describing organisms as part of the "bird" or "mammal" group, the student listed correct characteristics for each. The "cardinal, ostrich, and duck are together because all have beaks, 2 leg, 2 wings, feathers" and "lay eggs". The "chipmunk, beaver, and seal together because they are all fur bearers, 4 appendages, mammary glands".

Typical traditional student responses.

Pre Interview. Traditional student 4 was consistent in the groupings that were made during the pre interview, using both physical characteristics and habitat to group organisms. For example, in the pre interview the student said, "They [ant, housefly, millipede] seem like insects to me. . . they have very simple structures and nothing that complicated like a mammal or bird" and "I decided to do aquatic animals [crab, clam, starfish, goldfish]. Although, I know that the crab and clam have shells and even the starfish I suppose has a shell, but if you can live in water I'll put it in a group."

Post Interview. The student continued to use familiar groupings such as "mammals", "birds", and "insects", and used habitat as a characteristic to group the clam, crab, starfish, and goldfish, referring to them as "sea creatures" in the post interview. When describing some of the groups with their characteristics said, "This group I have insects, centipede, ant, housefly. Simplified legs, maybe lack of really complex organs. Then the sea creatures, the crab, clam, sea star and the goldfish. I kinda looked at the physical characteristics there, they have a hard shell, fish has scales, they all live in water".

Pre and Post Interviews. Traditional student 5 classified in a consistent manner, based on habitat, but created more groupings in the post interview by being more specific in the organisms' habitats during the process of classification. For example, in the pre interview she placed the, "seal, beaver, duck, starfish, goldfish, crab, clam [because they] are all the water animals", and in the post interview she said, "I put together the ant and the millepede because they are both ground animals" and "beaver, seal, and the duck because those are all water or land animals".

U*nfamiliar organisms.* It was found that students relied on misconceptions when organisms were unfamiliar to them, most often grouping or classifying them based on habitat. Familiar organisms were recognized by students' descriptions of their characteristics, for example if the students created a "bird" group the organisms were considered familiar. In most cases the misconceptions were present when grouping the aquatic organisms, the crab, clam, and starfish. Most traditional students relied on misconceptions in both the pre and post interviews. However, all the included POGIL students showed a decrease in the use of misconceptions with unfamiliar organisms during the post interview. There was an outlier among the traditional students who placed the organisms in correct groupings during both interviews and did not rely on typical misconceptions.

Typical POGIL student explanations.

Pre Interview. Familiar animals for POGIL student 1 were the birds and insects and unfamiliar organisms were considered to be the aquatic organisms. Student 1 classified the seal and goldfish together based on water habitat, and being more "animal-like" than the clam, crab, and starfish during the pre interview. During the pre interview the student placed the fish and the crab together in the "water" grouping. Then student was asked, because of this grouping, if the fish was more related to the crab or the ant. The student responded by saying, "I think I would put the fish with the crab because of knowing there're in water."

Post Interview. During the post interview the student correctly classified the clam and starfish as having no skeleton and the crab was classified as having an exoskeleton. The student placed the ant, housefly, and crab together because they have exoskeletons. It was because of this grouping the student was asked which is more related to the ant, the housefly or the crab. The student correctly said, "The ant cause they are both insects, have similar legs."

Pre Interview. POGIL student 3 grouped familiar organisms, such as birds, mammals, and insects together during the pre interview. Unfamiliar organisms, such as the clam, crab, and starfish, were grouped together based on a mixture of physical characteristics and habitat, "all aquatic . . cold-blooded . . . have an exterior armor . . . I don't know if it would be an exoskeleton".

Post Interview. The student was able to correctly group the crab in the post interview with the housefly, ant, and millipede because they have "exoskeletons" and "paired jointed appendages". The student also correctly pointed out that the fly is more related to the ant than the crab, "they both have three sets of appendages and antennae."

Typical traditional student explanations.

Pre Interview. Traditional student 4 placed the familiar organisms together, such as "birds", "mammals", and "insects" together in both interviews. Unfamiliar aquatic organisms were grouped together in the pre interview, "I decide to do aquatic animals. Although, I know that the crab and clam have shells and even the starfish I suppose has shell, but if you can live in water I'll put it in a group".

Post Interview. In the post interview he stated, "the sea creatures, the crab, clam, sea star and the goldfish. I kinda looked at the physical characteristics there, they have a hard shell, fish has scales they all live in water."

Pre and Post Interviews. Traditional student 5 grouped organisms based on habitat in both the pre and post interview. The following passages may help to indicate the student's level of unfamiliarity with different organisms, leading to classification based strictly on habitat. In addition, the student did not use physical characteristics when describing the groupings or organisms. "I would group the red cardinal and the housefly because they both fly and I don't think ostriches don't fly. Do they?" "I would put together...I would keep the beaver and the seal together just because they are still like actual water, water animals and they live in a different type of water than the goldfish, starfish, the crab and the clam." "I put together the ant and the millepede because they are both ground animals. As far as I know millepedes crawl through the mud and the dirt and live underground."

Combining and subdividing initial groupings. Misconceptions were also apparent when students were asked to subdivide groups of organisms, such as birds, mammals, and insects. In the pre interview most students in both groups would rely on misconceptions such as habitat or type of locomotion or incorrect physical characteristics to further subdivide the groups. The POGIL students used correct characteristics of organisms when asked to subdivide or combine their groupings during the post interview, while most traditional students continued to use misconceptions such as habitat. An unusual case among the traditional students initially used a combination of correct characteristics and habitat and then used correct characteristics alone during the post interview.

Typical POGIL student explanations.

> *Pre Interview.* POGIL student 1 was asked if it was possible to subdivide the grouping of birds during the pre interview. The student responded by dividing the birds based on habitat saying, "This could be a water animal [duck], and I guess ostriches are more of a wild animal, the cardinal is too but they live in different environments." When asked to combine groups in the pre interview the student said, "I would put these [clam, starfish with the crab] with that [seal, goldfish]. I could move the beaver with the water. I could maybe bring the duck over as well. The water animals and the land animals."
>
> *Post Interview.* In the post interview the student was asked to subdivide the two large groupings made based on organisms with an endoskeleton or organisms with an exoskeleton or no skeleton. The student responded by further subdividing the second group of organisms into two groups, one with organisms with exoskeletons and the other group being organisms with an unknown skeleton type [starfish and clam]. When further subdividing the group with exoskeletons or no skeleton, the student correctly identified that the "millipede, ant and housefly have exoskeletons".
>
> *Pre Interview.* POGIL student 3 was asked during the pre interview if it was possible to subdivide the grouping of birds. The student responded by dividing

them by habitat and type of locomotion saying, "They could be separated into ones that fly and live on land or stays in trees, fly and can live in water, some that only walk".

Post Interview. During the post interview the student demonstrated the ability to combine familiar organisms by stating, "You combine any of the groups. . . You could combine all of the vertebrates together, . . . warm-blooded creatures together, exoskeletons, and endoskeletons in a different group." The student correctly subdivided the group of arthropods (ant, housefly, crab, and millipede) saying, "you could divide the ant and the fly in one group for having three sets of limbs, where the crab has 4 sets and the millepede has who knows how many."

Typical traditional student explanations.

Pre Interview. Traditional student 4 was asked during the pre interview if any of his initial groups could be combined. He responded by saying, "yeah, I suppose the simple way to do it is what can live in water and what can't. . . I'd put the seal, beaver, clam, crab, starfish, and fish together, and the duck cause it lives in water". When asked whether he could subdivide the group that included the clam, starfish, crab, and goldfish he said, "Ones with shells and ones without. The clam and the crab and the starfish have shells, and the fish with no shell structure". When asked if the group of three birds could be divided replied, "Yes, the cardinal and duck fly and the ostrich can't".

Post Interview. During the post interview the student continued to use misconceptions and incorrect physical characteristics to combine or subdivide the groupings. When asked if he could combine any of the groups the student said, "I would take the duck, the sea animals, and then the beaver and the seal, not the chipmunk, but I could take these cause they all live in the water [duck, clam, crab, starfish, goldfish], so now it's water and not water [ostrich, insects, chipmunk, cardinal]. When asked to subdivide the "sea creatures" the student said, " Yeah, I would take just the fish out, because the fish doesn't have a hard shell, it has scales, but doesn't have a hard shell like the. . . clam and the crab, even the starfish has a really hard shell. So just the fish".

Pre Interview. Traditional student 5 was asked in the pre interview if she could combine any of her original groupings. The student replied, " Definitely, I would say you can combine the ant and the millepede with the ostrich and the chipmunk because they are all ground animals in some way". When asked if it was possible to subdivide the aquatic group of animals (duck, goldfish, starfish, clam, crab, seal, beaver) the student said, "I would keep the beaver and the seal together. . . because they are water animals and they live in a different type of water than the goldfish, starfish, the crab and the clam. . . I would think you would find a starfish, the crab, and the clam in ocean or sea water so I would group those 3 together still, and the duck would be in a pond so I would group the duck by itself".

Post Interview. When the student was asked if it was possible to combine groups during the post interview, relied again on habitat and said, "Yes, I would combine the chipmunk and the ostrich with the millepede and the ant. I know that sounds like a weird combination but they're all land animals".

The hierarchical nature of classification. There was an increase in understanding of the hierarchical nature of classification in all included POGIL students. Neither group mentioned any hierarchical processes throughout the pre interview. However, POGIL students were able to provide examples of hierarchy during the post interview, by describing how the process occurs, by creating and grouping in a hierarchical fashion, or by knowing that a particular organism can be a member of multiple groups. There was a unique case among the traditional students where the student was able to demonstrate hierarchy during the post interview.

Typical POGIL student explanation.

POGIL student 1 provided an examples of hierarchy during the post interview when explaining how the pasta was grouped, "I started with the most obvious like the size difference and then I got more specific as I went." The student also stated that scientists, "use simple characteristics and then they break them down into more and more specific groups to get them in the class". In addition, the student began grouping the pasta and organisms in the same fashion, by creating two large groups, and then proceeded to explain ways in which these could be further broken down.

POGIL student 3 spoke about the hierarchical nature of classification in the post interview when explaining how groups of organisms could be combined, "You could combine all of the vertebrates together, you could combine warm-blooded

> creatures together, exoskeletons, and endoskeletons in a different group. Depends how broadly you wanted it divided".

Instructor reflection. Immediately after the completion of each lesson, the instructor participated in a 20-minute written reflection to confirm that the content was taught and to provide feedback on the teaching experience and the students' level of understanding (see Appendix C for example questions).

POGIL lesson implementation.

Summary of lesson with curricular elaboration. The POGIL lesson was changed slightly due to the small number of students, only tables 2, 3, and 4 were used. Model 1 required the students to diagram their process of dividing a group of organisms.

> During Model 1 the instructor explained to the students how to draw the diagram, "What you have in Model 1 is. . . a list of organisms and a diagram that you need to create, you have to group them and I want it drawn out. I gave you an example of how to do that [pointing at the worksheet projected on the doc cam] on your lab table there is a large sheet of paper . . . you are going to draw out and diagram all of these organisms. . . you are going to break these down by whatever rationale you think works".

During Model 2 the students were presented with a list of key physical characteristics to test the classification procedures created by the class at the completion of Model 1. The procedures were physical characteristics, reproduction, locomotion, habitat, behavior, and nutrition. During Model 2 the instructor assisted the groups in placing the proper organisms in the proper groups, demonstrated how to examine the final groupings, and whether to support or refute their classification procedures.

> For example, "we are going to come to a consensus as to the [classification procedures] that we will test. These are our hypotheses if you will, to determine what is actually used to classify organisms. We are going to look at them and find commonalities in the lists [from each group] because many of you used the same

rationale. Take a look at the lists, read through all of them, and see where there is repetition. . . I'm going to need your feedback and we will first use the ones that are repetitive, more then one group used them. . . there's physical characteristics, reproduction, locomotion, habitat, behavior, and nutrition. These are the things we are going to test. . .are these truly what scientists use to classify organisms? We are using Model 2 to test these and see if they are what scientists use".

By the completion of Model 2 the students were able to refute all the incorrect classification procedures created in Model 1 (locomotion, habitat, behavior, and nutrition) and support the correct classification procedures (physical characteristics and reproduction).

> The instructor reinforced this by stating, "Physical characteristics are really the most important thing. . . anatomy is the proper way [to classify] and reproduction falls under anatomy. The reproductive structures are internal so that falls under the umbrella of anatomy. So we know if a bird lays eggs. . . it is because it has the internal structures to produce eggs. This falls under physical characteristics or anatomy. . . this is the only way that you classify things. You never go with habitat, never go with locomotion, always anatomy".
>
> "Everyone agreed with physical characteristics and reproduction. Locomotion is not something that scientists use to classify, there can be different locomotion in different types of animals, and we do not just classify animals, there is no locomotion in plants, so we are thinking of things scientists can use to classify all living things. Habitat can't be used, it is too variable, you find birds in different habitats, reptiles in different habitats, and so on. Behavior, is just to general of a term, what is behavior? It is the way it interacts with others? The way it eats something? Behavior is too general so that cannot be used. Nutrition is not used if we are thinking of what it eats, also too general. Physical characteristics are really the most important thing. . . You never go with habitat, never go with the locomotion, always anatomy. Now, Model 3 is all about molecular evidence. We know that prior to molecular evidence we were using just anatomy. Now we've got this information that points us either in the same direction as anatomy or a different direction. Normally, the data is not dramatically different, it usually follows along the same line. We are going to take a look at it and find a way to integrate them and try to decide which one is more important, anatomy or molecular data".

In Model 3 part A students, again, used only physical characteristics to classify organisms. During Model 3 part B molecular data were used to determine the relatedness of organisms and were incorporated into the classification from part A.

The instructor took special care to ask questions during Model 3, to get a feel for the students' understanding of Cytochrome C and the relationships between the organisms presented. The instructor asked each group about their answer to number 7 to hear their ideas on what was more important, physical characteristics or molecular data. Student misconceptions were confronted by the completion of Model 3 and it was repeatedly made clear to students that anatomical characteristics and molecular data were the only information to be used when classifying organisms.

After Model 3, the POGIL students began an abbreviated version of the two-day traditional classification lab. The key characteristics were explained along with a brief introduction on keying and identifying key characteristics for the organisms presented, and the students were assigned half the amount of organisms to key, and at the conclusion of day two most of the POGIL students completed fillings in key characteristics for each Kingdom, Phylum, and Class for homework.

The students enjoyed observing the different organisms and members of each group were speaking to one another and share their ideas. There was some light hearted teasing and laughing indicating that they were relaxed during the lesson. Interesting conversations arose in some of the groups about the pairs that were made with the cytochrome table that led to a brief discussion about evolution. The instructor liked facilitating the POGIL lesson, felt it was successful and that it was great to see the students depending on one another, talking, and discussing answers and not relying as much on instructor feedback.

Group roles. The students stopped at all the required points within the lesson and waited until further direction to move on. All groups were utilizing their readers, managers, and spokespeople. For example, at Table 3 the manager took the lead and asked the reader to begin by reading question one aloud. This manager also stopped to check that all the members of the group were at the same spot and had identical information recorded. On the second day of the POGIL lesson the groups started on Model 3. All groups reminded one another of their roles and all members discussed the key characteristics presented and placed them in groups together. The readers read the questions as the groups moved along and the spokespeople answered appropriate questions in front of the class.

Instructor as facilitator. During the lesson the instructor worked as the facilitator. For example, during Model 1 Table 3 was listing the group's classification procedures, and the instructor noticed that it did not match with their rationale used during the first part of Model 1. The instructor then helped the group come up with more accurate classification procedures by guiding them through some of the common rationale used in their Model 1 diagram, "I see legs, no legs, wings, no wings, fins, and no fins on your diagram. What are all of these rationale referring to?" Group 2 initially wanted the instructor to provide them with answers and lacked the confidence to rely on one another. To prevent this from happening again the group was encouraged to rely on one another, because it was a large part of the reason that they had been placed in groups.

Student understanding during POGIL lesson. While keying organisms, students expressed some misconceptions about key physical characteristics of organisms. The instructor's reflection was used to create themes about the POGIL students' understanding of biological classification. During the POGIL lesson the following themes appeared: increase in the use of physical characteristics to classify organisms and deepening of understanding in the complexity of classification, including the increased accuracy of classification when using molecular data and exposure to the hierarchical nature of classification.

Increase in the use of physical characteristics to classify organisms. Students increased their use of physical characteristics to group organisms as the lesson progressed. For example, during Model 1 of the POGIL lesson, tables of students came up with different rationale to classify organisms. The tables summarized their rationale for groupings in the following ways: mobility, physical characteristics, reproduction, habitat, locomotion, period of activity (night/day), behavior, anatomy, nutrition, and defense mechanisms.

> Throughout Model 1 the following comments were made by group 3 students about reasons they could use to group the organisms presented to them, "We could put animals in one and non animals in another, and then plants, and mushrooms. So our first rationale would be animals and non animals". When discussing how to further break down the non animals said, "so the mushroom can be. . . isolated . . . So should we put moss, corn and oak tree here?" To further break down the groups students said, "Maybe food sources? Do you think moss is a food source for anything? Lets write down that we have oak tree and moss as inedible". Other comments made by students during Model 1 were, "so for the animals, I think it's going to be winged vs non winged, so like bird, owl, bat", and "How can we break these down further? I was thinking water versus land. Do they go in the water or do you not go in the water, squirrel does not go in the water, but alligator does...can snakes?

> During Model 2 only physical characteristics were mentioned by students when grouping organisms, “More than four pairs of legs, that means more than eight total so these have three and these have four [pairs] so these are a group”. Also while grouping based on the presence or absence of feathers a student stated, “hair versus feathers and wings so bat, owl, and bird [together]”, another group member corrected this grouping by saying, “I don’t think bats have feathers”, and the first student replied, “but it’s got wings. Oh, okay so it’s got hair so it would just be bird and owl”. Other students were examining the skin of the turtle saying, “It looks pretty rough”.

> The following physical characteristics were mentioned as students classified the organisms in Model 3, “The first thing is notochord present or not, and I think the only thing [without] is yeast.” “Is a turtle shell considered an exoskeleton?” “Fly is the only exoskeleton.” “Dogs have paws, not hooves. Do hippos have hooves?” “Do turtles have fins? So those aren’t fins, just limbs”.

Deeper, complex understanding of classification. Students deepened their knowledge of classification by practicing with the hierarchical nature of classification when subdividing groups and by using molecular evidence in conjunction with physical characteristics to classify organisms. The students began each of the three models in the POGIL lesson by making a diagram and subdividing the groups, identical to the hierarchical process used in classification.

> When students were asked whether physical structures or molecular data were more accurate when classifying the responses were, “DNA would be more accurate, and I can see where it makes sense, it should be based on molecules but structure can be taken into account”. “Both are important but molecular make up is most [important] because molecular is more accurate.” “Molecular is most important, but physical can be used to verify it.”

Misconceptions. Students in the POGIL group had a difficult time distinguishing endoskeletons and exoskeletons with the honey bee and tarantula, possibly due to the “hairs”. A number of students had difficulty properly keying the armadillo, they knew it was a mammal, but were confused because of it’s hard “shell”. The bat also created confusion, many students wanted to place it in the class Aves with the birds rather than with the mammals. The students had difficulty discriminating between an amphibian and a reptile, saying things like, “the snake looks like it has smooth moist skin”. The instructor assisted the students with questions to identify the common names of organisms when keying, and helping students make progress when stuck in a spot on the key.

Traditional lesson implementation.

Summary of lesson with curricular elaboration. During the first day of the lesson, the students learned how to use a dichotomous key to identify organisms, the general design of the classification system, how to correctly write a scientific name, and the definitions and examples of important characteristics used in the lab. On the second day of the lesson, the students listed key physical characteristics for each Kingdom, Phylum, and Class, and created a phylogenetic tree based on these characteristics. One change made to the lab was that the students did not have to list the key characteristics of protists. In addition, to the normal lesson plan, the instructor spent time at the completion of day two asking students to list some of the trends that they were seeing when identifying organisms, and encouraging them to look for more the following day. One of the trends mentioned was that members of the Class Insecta had three pairs of legs. The instructor also demonstrated how to draw the phylogenetic tree, creating the first portion of the phylogenetic tree, the Kingdoms Plantae and Fungi, with them. To create the phylogenetic tree, students simply copy the physical characteristics and corresponding Kingdoms, Phyla, and Classes onto the tree diagram. The students enjoyed the lab because they got a chance to look closely at the live organisms found throughout the lab rooms. The instructor enjoyed seeing the student reactions as they observed the animals. Based on the traditional classification lesson, the following theme was created:

Students understanding during traditional lesson: an increase in knowledge of physical characteristics and taxonomic categories. Students increased their knowledge of specific physical characteristics and taxonomic categories in classification. While keying organisms, traditional students, like POGIL students, expressed some misconceptions about keying physical characteristics of organisms. At the beginning of the lesson the students took a significant amount of time working though the key and learning to determine whether certain organisms had certain physical characteristics and to which Kingdom, Phylum, or Class they belonged. For example, some students assumed that the squid and octopus had radial symmetry, and that the earthworm had a flattened body. It took repetition and practice using the dichotomous key with the associated physical characteristics, and taxonomic categories to recognize them more quickly. By the end of day 1 the students were starting to recognize some of the key characteristics of monocots (parallel veins on leaves), that if something "crunches when you initially step on it, it probably has an exoskeleton", and that insects have six legs, no more, no less. By the end of the second day, a few of the students stated that they were recognizing more trends when identifying organisms, for example all fish in the lab belong to the class Osteichthyes and had scales and fins. Further memorization of the key physical characteristics and taxonomic categories occurred on the second day of the lab while the students were filling in the key characteristics tables and the phylogenetic tree, all based on the dichotomous key. There was no mention by students of any other ways to classify or other characteristics to use to classify organisms.

Misconceptions. Students in the traditional group had a difficult time distinguishing endoskeletons and exoskeletons with the honey bee and tarantula, possibly due to the "hairs". A number of students had difficulty properly keying the armadillo, they knew it was a mammal, but were confused because of it's hard "shell". The bat also created confusion, many students wanted to place it in the class Aves with the birds rather than with the mammals. The students had difficulty discriminating between an amphibian and a reptile, saying things like, "the snake looks like it has smooth moist skin". The instructor assisted the students with questions to identify the common names of organisms when keying, and helping students make progress when stuck in a spot on the key.

Summary of Findings

The analysis of the quantitative and qualitative data lead to findings regarding the effect of POGIL on students' understanding of classification. While there was not a significant difference in student scores on the content knowledge assessments, there were tendencies in the means. The experimental group may have scored higher than the control group on the posttest and the control group may have scored higher on the pretest than the posttest. Difference conceptions of biological classification emerged in interviews and the instructor reflection. While both groups of students showed a more extensive understanding of biological classification, only POGIL students showed the ability to overcome challenges that prevented the traditional students from understanding classification in a complete way.

Discussion

This study examined how the use of process-oriented guided-inquiry learning (POGIL) affected non-majors college biology students' understanding of biological classification. This mixed methods study broadened understanding of the topic by combining both qualitative and quantitative research and methods.

This study investigated the following research questions:

Research question: How does the use of process-oriented guided-inquiry learning affect non-majors college biology students' understanding of biological classification when compared to traditional laboratory instructional methods?

Sub question 1: How do the students score on content knowledge assessments?

Sub question 2: What are student conceptions of biological classification as demonstrated in interviews?

Sub question 3: How do student interview responses compare and contrast with students' content knowledge scores?

This study addressed specific conceptions that students have about biological classification, by implementing process-oriented guided-inquiry learning (POGIL), an instructional method designed to construct new knowledge and based in constructivism. While students' misconceptions have been studied in many areas including classification, POGIL has not been studied to address conceptual change. POGIL research has been limited, and is mainly based on chemistry lecture and laboratory activities. This study was important because it addressed an area of science instruction, POGIL in the non-majors college biology laboratory, which has yet to be qualitatively and quantitatively researched.

A discussion of the results of this study will be presented in this chapter. This discussion presents related qualitative and quantitative data. The first portion of this chapter will summarize student understanding. Each summary interprets the main themes that emerge from student interviews, instructor reflections, and quantitative data when applicable. The data were organized under two main themes: students' more extensive understanding of classification after instruction, and challenges that prevent students from reaching a complete understanding of classification. The summary is followed by an explanation, literature that supports the results, and any alternative explanations. Finally, there is a description of the importance of this study, limitations, teaching applications, and recommendations for future research.

More Extensive Understanding of Classification

Vocabulary and physical characteristics. Students demonstrated a more extensive understanding of classification through the use of vocabulary and physical characteristics as shown in the tests, interviews, and instructor reflections. When asked to describe the groups of organisms made in the pre interview, students used a combination of both correct and incorrect vocabulary terms and physical characteristics. The students in both groups showed an increase in the correct use of vocabulary terms and physical characteristics during the post interview. The curriculum summaries within the instructor reflections confirm these results in both the POGIL and traditional lessons. Throughout both lessons students used key physical characteristics and vocabulary.

Finally, on the test instrument questions 1 through 3 asked students to use correct physical characteristics when grouping. There was no significant difference between the POGIL and traditional students on these items (n = 3, 6).

These findings may have occurred because of the time spent and a variety of activities using vocabulary and physical characteristics. There was equal time spent using correct physical characteristics and vocabulary in both groups. The POGIL students were provided a group of organisms and key physical characteristics to hierarchically break these groups down in Models 2 and 3, and were also exposed while keying organisms. The traditional students were also exposed while keying out organisms, placing key physical characteristics with the proper Kingdom, Phylum, and Class, and while pulling vocabulary and characteristics to be used in the phylogenetic tree. Both groups were required to memorize the physical characteristics from the traditional portion of the lab.

According to literature on how to improve reading comprehension through teaching vocabulary, vocabulary is best learned through integration, repetition, and meaningful use (Nagy, 1988). Integration of vocabulary occurred in the traditional and POGIL labs when the students connected unknown terms with known terms and related concepts. Repetition occurred when student in both labs had the opportunity to repeatedly use the words, and there was meaningful use of the terms as students related the words to different organisms.

An alternate explanation for these results could be that there was a difference between POGIL and traditional use of vocabulary. However, this study simply explained the number of new terms used and did not investigate whether there was a difference in how vocabulary or physical characteristics were used by groups of students.

Types of evidence used to classify organisms. As shown in the tests, interviews, and instructor reflections, students demonstrated a more extensive understanding of classification through the use of molecular data used in classification. There was an increase in understanding about the types of evidence used to classify organisms. In post interviews students were able to describe in greater detail how scientists use physical characteristics and molecular data to classify organisms. After the POGIL lesson, all included POGIL students were better able to explain how molecular evidence is used and that it overrides physical characteristics when present and can be used to determine relatedness. The posttest tendency in the difference of the means ($M = 8.830 \pm .477$ vs. $M = 7.330 \pm .330$; $z = -1.729$, $p = .084$) ($n = 3, 6$) showed that the POGIL group's posttest scores tended to be higher, and that the traditional group's pretest score seemed higher than its posttest score. There was a shift in answer choices from the pre to posttest of both groups. The POGIL group showed a possible improvement on the molecular related questions (items 4, 5, 6, 7, and 8) and the traditional group showed a possible a decline in correct answer choices for these same questions. Student quotes and the curriculum summary from the instructor reflection corroborate these results. POGIL students clearly and succinctly explained the importance of DNA when compared to physical characteristics during Model 3 and practiced determining relatedness based on the number of DNA differences between organisms. The instructor reflection for the traditional lesson did not address use of DNA in classification since it was not part of the traditional curriculum.

These findings may have occurred because POGIL students were exposed to the topic and had an opportunity to apply their new knowledge in a unique instructional setting. POGIL students were the only group to use or discuss the application and importance of molecular data in classification, and they may have come to a deeper understanding because their curriculum required them to use both physical and molecular evidence together. The traditional group used only physical characteristics because the use of molecular evidence was not part of their curriculum and may have felt that it was the only evidence used in classification.

In similar research to this, non-science students' evolutionary misconceptions were identified and corrected using an inquiry-based approach. Included in these inquiry-based lessons were multiple types of evidence including fossil evidence, anatomical evidence, DNA, and cladograms, resulting in a significant increase in students understanding in evidence for evolution (Robbins & Roy, 2007). POGIL literature has stated that the design of POGIL creates an environment where students' participation in meaningful social interaction, structured groups, and active engagement in thinking can lead them to alter or replace existing knowledge (Cakir, 2008; Mayer, 2004; Hanson, 2006). Also, the POGIL students were able to work through the learning cycle, allowing them to apply this new knowledge on molecular data (Eberlein, Kampmeier, & Minderhout et al., 2008; Karplus, 2003; Atkin & Karplus, 1962; Singer & Mosocovici, 2008; Chiappetta & Koballa, 2002).

An alternate explanation for these results could be that the traditional group did understand the DNA overrides physical characteristics when classifying, but the interview did not adequately probe this.

Challenges That Prevent Students from Reaching a Complete Understanding of Classification

Habitat and other misconceptions used to classify organisms. Students often could not reach a complete understanding of classification because they relied on common misconceptions, as shown in the tests, interviews, and instructor reflections. Common misconceptions used were grouping by familiar correct categories such as “bird” or “mammal”, and incorrect categories such as “insect” and aquatic habitat. Students relied on misconceptions with unfamiliar organisms and while combining or subdividing initial groupings.

POGIL students demonstrated the same misconceptions as the traditional students when classifying organisms before the teaching intervention. However, the POGIL students were able to correct these misconceptions after the teaching intervention. POGIL students changed to grouping using physical characteristics instead of simple familiar categories and habitat, and POGIL students showed a decrease in the use of misconceptions with unfamiliar organisms and when subdividing and combining groups of organisms. The instructor reflection confirms these findings. During Model 1 in the POGIL lesson students were directed to divide groupings of organisms in any way and by the completion of Model 2 all the students’ incorrect rationales had been confronted, and students were directed to make groupings of organisms based strictly on correct physical characteristics.

The traditional students demonstrated no change in their misconceptions regarding classification, as shown in the tests, interviews, and instructor reflections. The traditional students did not overcome these misconceptions and continued to use misconceptions such as habitat, to group unfamiliar organisms and to combine or divide organisms. The curriculum summary in the instructor reflection points out that there were no classification misconceptions identified during the traditional lesson, and so misconceptions were never addressed. Many posttest questions (items 1, 2, 4, 5, 6, and 11), included common misconceptions. Although there were no significant differences for the individual items (small sample size), the posttest tendency in the difference of the total score means showed that the POGIL group's posttest scores were higher.

These findings may have occurred because of the design of the curriculum and the instructor's facilitation of it. The POGIL curriculum requires that students use only correct physical characteristics to classify organisms during Models 2 and 3. It was stressed by the instructor throughout Model 2 that physical characteristics are the only characteristics that will be used when classifying at that point in the lab, and the instructor specifically went through and confronted each of the students' misconceptions and pointed out why each was incorrect. This did not take place in the traditional lab because there was no place that student misconceptions were confronted.

The findings of this research study support some findings of previous studies on biological classification and students' misconceptions, such as students classifying based on habitat. Student misconceptions have been identified and studied. It has been found that students will correctly classify groups of familiar organisms together such as mammals and birds, and use common misconceptions such as habitat and locomotion to classify even after they have learned the correct categories of biological classification, and that students have misconceptions of the following concepts: animal, vertebrate, invertebrate, fish, amphibian, reptile, bird, and mammal. Students also used physical characteristics, habitat, and movement in distinguishing between common, well-known vertebrates and invertebrates (Chiung-Fen, Tsung-Wei, & Mintzes, 2007; Kattmann, 2001; Trowbridge & Mintezes, 1985).

Literature shows that student misconceptions are difficult to change and must be directly confronted during instruction. In the beginning of the POGIL lesson, the students were able to identify their classification misconceptions. It is known that misconceptions have origins in personal experiences and are resistant to change with traditional teaching strategies (Bahar, 2003). If the instructor is the source of all information, as with most traditional teaching, then the student does not need to recognize any cognitive conflicts that could lead to improvement (Piaget, 1926). Also, at some point the learner needs to decide whether it is worthwhile to reconstruct their conceptions, based on how meaningful, truthful, and useful they are to them (Hewson & Thorley, 1998). Further, the new conception must do more for the person than the misconception (White & Gunstone, 1998). It is suggested that instruction must confront misconceptions for a lesson to be effective and these misconceptions must be modified as the students learn science. Teachers need to make students' misconceptions clear to help them recognize them (Kattmann, 2001; NRC, 2012; Bransford, 2000).

Not only did the POGIL lesson elicit and confront misconceptions, it also used other teaching techniques shown to be effective for teaching new concepts: the learning cycle, guided-inquiry, hands-on manipulation, diagraming, and learning teams. According to a meta-analysis of effective science instructional methods, Guzzetti et al. (1993) found that all of these techniques are effective at altering scientific misconceptions. The learning cycle within the POGIL lesson in this study could elicit misconceptions, confront these, and further student understanding by then applying the new conceptions. Research has shown that students working in learning teams collaboratively and using hands-on manipulations result in an effective learning environment. In the POGIL lesson students worked in structured groups and were encouraged to handle and examine the organisms presented to them. POGIL students also created numerous hierarchical diagrams throughout the lesson. All of these teaching techniques help to dissatisfy the students with their misconceptions and showed the correct conception as a worthwhile replacement (Totten, Sills, Diggt et al., 1991; Bowen, 2000; McKeachie, Pintrich, Yi-Guang et al., 1986).

As previously mentioned, POGIL curriculum made student misconceptions clear and confronted them. However, did the POGIL students really overcome these misconceptions or was it because they felt influenced not to use these in front of the instructor because they were repeatedly told that they were incorrect? Would these misconceptions present themselves after a longer time because literature points out how resistant misconceptions are to change?

The hierarchical process of classification. Students also could not reach a complete understanding of classification because they did not think hierarchically. POGIL students showed an increased understanding of the hierarchical process of classification as demonstrated in the interviews and instructor reflection. There was an increase in understanding of the hierarchical process of classification for only the POGIL students after the teaching intervention. The curriculum summary of the instructor reflection verifies these findings when describing the process students used to hierarchically break down the groups of organisms in Models 1 through 3. Finally, on the test instrument questions 9 and 10 asked students to analyze a hierarchical diagram. There was no difference in choices between the POGIL and traditional students (n = 3, 6). This result contrasts with the qualitative data; it should be noted that the sample size was small and it was possible that the test questions did not measure hierarchy well, so the results are based off of the qualitative data.

These findings may have occurred because of the repeated process used in the POGIL lab to break down groups of organisms. During the POGIL lab students used a hierarchical process to break down groups of organisms three different times in the Models. In addition, POGIL students experienced a brief introductory lecture describing the Kingdom through species format of the system and completed a pre lab activity that had the students create a mnemonic device to help them memorize the different levels of classification. The traditional students received the same brief introduction on the current classification system, and along with the pre lab, were assigned an activity that compared the taxonomic categories to the hierarchical breakdown of the parts of an address from country to street address. While the traditional students were exposed to the hierarchical nature of classification, they did not have the same amount of application and practice with it as the POGIL students did.

The literature states the importance of understanding cladograms and other evolutionary diagrams to create a complete hierarchical evolutionary picture for students, helping them to determine relatedness of organisms (Catley & Novick, 2008; Morabito, Catley, & Novick, 2010; Metzger, 2011). The use of hierarchical diagramming took place during both lessons, but the results indicate that the diagraming completed during Models 1-3 in POGIL were more effective at teaching the students the hierarchical nature of classification. Literature also states inquiry-based instruction, such as POGIL, provides additional benefits, in having students 'do' science for themselves. The traditional lab used direct instruction to teach hierarchical classification and students had no practice applying hierarchical classification to organisms. Direct instruction may send a message to the students that science is just facts to be learned, in bits of unrelated terms, and inquiry-based instruction provides an opportunity for students to "do" science, relate terms and concepts, and further their understanding (Cobern, Schuster, & Adams, 2010; Cakir, 2008).

Importance of This Study

This research addressed an area of science instruction, POGIL in the non-majors college biology laboratory, which had yet to be qualitatively and quantitatively researched. POGIL research has mainly focused on chemistry, and one published piece of literature in biology lecture; the findings of these studies were that student attrition is lower (Lewis & Lewis, 2005), student mastery of content is higher (Lewis & Lewis, 2005; Brown, 2010; Murphy, Picione, & Holme, 2010), and most students prefer POGIL over traditional methods (Eberlein et al., 2008; Brown, 2010). Additionally, research on biological classification has identified misconceptions, but has not implemented curriculum to change these misconceptions and describe the results qualitatively. The findings of this study seem to be that POGIL is an effective technique at eliciting students' misconceptions, and addressing these misconceptions, leading to an increase in their understanding of biological classification.

Limitations

The following limitations have been acknowledged concerning this study:

Quantitative data. There may have been limitations in the quantitative portion of the study, including the inherent limitation in the small sample size, time between the pre and posttest, and the test itself. Improvements could have been made by calculating individual gain scores, rather than mean gain scores, to provide a more in depth statistical analysis of the pre and posttests scores. In addition, the sample size was small (n = 3, 6), and could have played a factor in the calculation of p-values with no significance. Even with the statistical analysis of the pilot test instrument, it is possible that the test may not have measured what was intended with the new group used during the final study. The testing time between the pre and posttest may not have been long enough, resulting in participants remembering responses when answering on the posttest (Ding et al., 2008).

Qualitative data. There may have also been limitations in the qualitative portion of the study, including the student sampling techniques, and the conformation of data collected. Student sampling for the interviews could have been done differently to collect data that would better inform the research questions. Students who were retaking the class could have been excluded; students could have been chosen based on their current standing in the course; and students who would inform the researcher the most about the research question could have been purposefully selected. The researcher was also unable to go back and confirm any qualitative data collected during the interviews.

The audio taping of the interviews was difficult to interpret at times. It would have been beneficial to videotape the interviews to see the students as they were taking part and then to examine body language, etc. The interview instrument could have led to questions that directed the students towards a specific answer because the interviewer was the researcher and students' instructor. Finally, the short timeline in the summer may have not allowed for a long enough time between the pre and post interviews, affecting the students' post interview responses.

Audio taping of the POGIL lesson was difficult to interpret as well, and instruction reflections were incomplete. Additionally, audio taping of individual students while working through both the traditional and POGIL lessons could have provided more insight into their misconceptions. The audio taping and transcription of the POGIL lesson was unplanned and led to an unequal picture when comparing it with the traditional lesson, and because of this these were not true participant observations with strict protocol. There was no discourse analysis of student language and interactions to show understanding.

Other limitations. There were further threats to validity including history, because as time passed between both pre and post instruments further BIOL 100 instruction occurred on topics, such as ecosystem diversity and climate change, that may have influenced the outcome beyond the experimental treatment. Additionally, it has been found to take time to see measurable differences when implementing new curriculum. Furthermore, the student population of this Summer Session of BIOL 100 is markedly different in the fact that there were four students out of fifteen who were repeating the course and the small class size allowed for the curriculum to be more easily implemented than with a larger class size. Finally, because the setting and participants of the experiment were unique in many ways and because of the emphasis placed on the qualitative data, the results found do not generalize to other situations.

Evidence for students 2 and 6. A POGIL student was omitted from the analysis because the researcher could not decipher the student's meaning during the interview in spite of asking probing and clarifying questions (see passage in Results: Qualitative Data: Student Interviews).

Student 6 came with extensive prior knowledge when compared with all others, and was not a "normal" student to represent the traditional group. He showed considerable prior knowledge in the following areas: physical characteristics and vocabulary associated with organisms, the hierarchical structure of classification, and was able to determine relatedness of organisms based on molecular data. None of the other interviewees showed this level of prior knowledge and this student was intended to provide a more complete picture but was identified as an outlier.

Teaching Applications

The following includes teaching applications that are suggested based on the results of this study. As pointed repeatedly in the literature, student misconceptions need to be identified in order to be confronted and changed. In addition, students must feel that the new conceptions are worthwhile in order to change. Analysis of this study shows that classification misconceptions seem to be corrected by implementing this POGIL lesson. Additionally, inherent in POGIL lesson design are the benefits of guided inquiry, utilizing hand-on manipulations and creating diagrams during team learning, and the Learning Cycle, leading to the assumption that POGIL lessons could confront student misconceptions in other areas of biology. Also, the time students spend on various applications of the material improves the learning of vocabulary and physical characteristics. The entire perspective of classification as a cohesive unit needs to be taught for a complete understanding of all components including vocabulary, the process of classification, physical characteristics used, and molecular data used. Most importantly, according to the new Framework on Science Education, an understanding of classification leads to a clearer understanding of diversity and evolution of life on Earth.

Recommendations for Future Research

Considering the results of this study, more research can be conducted on the effect of POGIL in a non-majors college biology laboratory. This study could be repeated with a larger sample size, additional instructors, and more time between the intervention and posttest/post interview. Also, this study could be used to design POGIL curriculum to address misconceptions in other areas of biology. There could be further analysis of POGIL student dialog while working in groups. Lastly, POGIL helped to change student misconceptions. However, we don't know if a traditional lecture stressing the incorrectness of common classification misconceptions could have the same outcome, because the two curricula were not equal in the content taught (misconceptions and the use of DNA). The study could be repeated with traditional and POGIL curricula that have equal content.

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Table 1

Item Analysis Data for Pilot Tests

Item No.	**Outcome**	**Answer Types[a]**	**Discrimination Index (D)**	**Difficulty Index (p)**	**Cronbach's Alpha with item deleted**
1	ID anatomical vocabulary	NA	.400	.550	.810
2	ID anatomical vocabulary	NA	.440	.480	.811
3	ID anatomical vocabulary	NA	.100	.860	.810
4*	Classify org. based on anatomical	H, L, & S	.340	.520	.810
5	Classify org. based on anatomical	H, L, & S	.250	.890	.811
6*	Classify org. based on anatomical	H, L, & S	.410	.410	.811
7*	Classify org. based on anatomical	S	.250	.770	.810
8	Classify org. based on anatomical	S	.240	.270	.810
9	Classify org. based on anatomical	S	.290	.610	.810
10	Relatedness of org. based on anatomical	H, L, & S	.530	.110	.810
11	Relatedness of org. based on anatomical	H, L, & S	.290	.480	.809
12	Relatedness of org. based on anatomical	H, L, & S	.230	.110	.810
13*	Classify org. based on molecular	S	.370	.800	.810
14*	Relatedness of org. based on molecular	NA	.490	.820	.811
15*	Classify org. on both anatomical and molecular	NA	.290	.730	.810
16*	Use molecular to evaluate anatomical classification	NA	.220	.550	.742
17*	Use molecular to evaluate anatomical classification	NA	.470	.730	.742
18*	Hierarchical organization	NA	.030	.910	.742
19*	Hierarchical organization	NA	.460	.750	.742
20*	2 types of characteristics used to classify	NA	.420	.360	.789

Note. * *Denotes test items used in the final test instrument.*

[a] *Denotes answer types targeting misconceptions on habitat, locomotion, & structure (H, L, & S) or only structure (S). n = 75.*

Table 2

Correlation Matrix and Cronbach's Alpha Calculated for Final Test Instrument with Pilot Student Population

Item No.	Component		
	1	2	3
4	-.147	-.548	**.479**
6	-.163	.012	.**704**
7	.074	-.147	**.802**
13	.073	**.856**	.258
14	-.306	**.781**	.134
15	.107	**.796**	.055
16	**.991**	.005	.014
17	**.991**	.006	.023
18	**.990**	-.008	.019
19	**.990**	-.002	.022
20	**.780**	.029	.083

Cronbach's Alpha	N of Items
.845	11

Note. Boldface shows items clustered together for each component.

n = 75.

Table 3

Item Analysis Data for Pretest of Control (Traditional) and Experimental (POGIL) Groups

Item No.	Pilot Item Test No.	Outcome	Discrimination Index (D)	Difficulty Index (p)
1	4	Classify org. based on anatomical	-.080	.890
2	6	Classify org. based on anatomical	-.040	.670
3	7	Classify org. based on anatomical	.010	.780
4	13	Classify org. based on molecular	.780	.560
5	14	Relatedness of org. based on molecular	.400	.780
6	15	Classify org. on both anatomical and molecular	.520	.440
7	16	Use molecular to evaluate anatomical classification	.420	.670
8	17	Use molecular to evaluate anatomical classification	.270	.780
9	18	Hierarchical organization	.440	.890
10	19	Hierarchical organization	.460	.560
11	20	2 types of characteristics used to classify	.780	.560

Note. n = 9.

Table 4

Correlation Matrix and Cronbach's Alpha Calculated for Pretest of Control (Traditional) and Experimental (POGIL) Groups

	Component				
Item No.	1	2	3	4	5
1	.132	-.456	.747	.366	.169
2	-.661	.331	-.122	.184	-.474
3	-.582	.430	.301	-.361	.238
4	.560	.717	.128	-.327	-.139
5	.714	.092	-.160	-.563	.008
6	.115	.674	-.385	.447	.262
7	.501	.183	-.284	.303	-.600
8	.437	.102	-.564	.209	.577
9	-.408	.798	.338	-.059	.098
10	.901	-.076	.387	-.059	-.094
11	.457	.530	.572	.400	.037

Cronbach's Alpha	N of Items
.479	11

Note. n = 9.

Table 5

Timeline of Events and Instruments of the Study

event:	pre interview	pretest	intervention	instructor reflection	posttest	post interview
purpose:	1st set of qualitative data, elicit prior conceptions	1st set of quantitative data, elicit prior conceptions, content knowledge	implement POGIL curriculum and traditional curriculum	confirmation of content taught, feedback, perceptions of student content knowledge & conceptions	2nd set of quantitative data, elicit any changes in conceptions & content knowledge	2nd set of qualitative data, elicit any changes in conceptions

Table 6

Daily Lecture and Laboratory Schedule During the Experiment

Day	Lecture	Laboratory Topic	Course Assessments	Lab Curriculum		Instruments Used
1	What is Life?	Intro to Microscopes & Cells			Traditional	Pretest
2	Biodiversity	Pond Organisms			Traditional	Pre interview
3	Biodiversity	Classification Day 1	Lab Quiz 1 (Intro and Pond)	POGIL Day 1	Traditional	Instructor Reflection
4	Biomes of the World	Classification Day 2		POGIL Day 2	Traditional	Instructor Reflection
5	Exam 1	No Lab	Lecture Exam 1 (lectures 1-4)		Traditional	
6	Environmental Problems	Tree Diversity	Lab Quiz 2 (classification)		Traditional	
7	Environmental Problems	Tree Diversity			Traditional	
8	Scientific Method	Economic botany & Watershed	Lab Quiz 3 (Trees)		Traditional	Posttest
9	Exam 2	No Lab	Lecture Exam 2 (lectures 6-8)		Traditional	Post interview

Table 7

Descriptive Statistics for the Pretest, Posttest, and Classification Quiz for Two Different Types of Instruction

	Mean	Standard Error	Mean Gain Score
Pretest Experimental Group (POGIL, n = 6)	7.170	1.014	
Pretest Control Group (Traditional, n = 3)	8.330	0.333	
Posttest Experimental Group (POGIL, n = 6)	8.830	0.477	1.667
Posttest Control Group (Traditional, n = 3)	7.330	0.333	-1.000
Classification Quiz Score Experimental Group (Traditional, n = 3)	14.778	1.267	
Classification Quiz Score Control Group (POGIL, n = 6)	17.333	0.760	

Note. Mean and SE calculated using total scores.

Table 8

Statistical Comparison of Means of Pretest, Posttest, and Classification Quiz after Two Different Types of Instruction

	z-value	Sig. (2-tail)
Pretest Experimental vs. Pretest Control	-0.264	0.792
Posttest Experimental vs. Posttest Control	-1.729	0.084+
Pretest Experimental vs. Posttest Experimental	-1.149	0.250
Pretest Control vs. Posttest Control	-1.650	0.099+
Classification Quiz Score Experimental vs. Classification Quiz Score Control	-1.394	0.163

Note. $^{+}p < .10$.

Calculated with Mann Whitney U.

Table 9

Proportion of Students who Answered Correctly on Pretest (n = 9) and Posttest (n = 9) for Traditional and POGIL Groups

Question 1

Considering characteristics that scientists use to classify organisms, which should be grouped together? What characteristic did you use for this grouping?

Answer Options	**Traditional**		**POGIL**	
	Pre	**Post**	**Pre**	**Post**
Bird & Ant lay eggs	0.00	0.00	0.00	0.00
✓Housefly & Ant have hard outer coverings on their bodies	0.667	1.00	1.00	0.833
Housefly & Bird live in the air and on plants	0.00	0.00	0.00	0.167
Housefly & Bird fly	0.333	0.00	0.00	0.00

Pre		**Post**	
$\chi 2$	**p-value**	$\chi 2$	**p-value**
0.134	0.333	0.453	1.000

Question 2

Considering characteristics that scientists use to classify organisms, which should be grouped together? What characteristic did you use for this grouping?

Answer Options	**Traditional**		**POGIL**	
	Pre	**Post**	**Pre**	**Post**
✓Owl & Penguin have feathers	0.667	1.00	0.667	1.00
Owl & Bat fly	0.00	0.00	0.167	0.00
Penguin & Bat have wings	0.00	0.00	0.00	0.00
Owl & Bat live in the forest	0.333	0.00	0.167	0.00

Pre		**Post**	
$\chi 2$	**p-value**	$\chi 2$	**p-value**
1.000	1.000	NA	NA

Question 3

Considering characteristics that scientists use to classify organisms, which two should be grouped together? What characteristic did you use for this grouping?

Answer Options	Traditional		POGIL	
	Pre	Post	Pre	Post
Dog & Lizard have four limbs	0.00	0.00	0.00	0.00
Lizard & Snake have a tail	0.00	0.00	0.167	0.00
Dog & Snake have an inner skeleton	0.00	0.00	0.167	0.167
✓Lizard & Snake have scales	1.00	1.00	0.667	0.833

Pre		Post	
$\chi 2$	p-value	$\chi 2$	p-value
0.257	0.500	0.453	1.000

Animal	Number of differences from Turtle
Turtle	0
Chicken	45
Toad	67
Large mouth bass	125

Question 4

Considering characteristics that scientists use to classify organisms, which two should be grouped together? What characteristic did you use for this grouping?

Answer Options	Traditional		POGIL	
	Pre	**Post**	**Pre**	**Post**
✓Turtle & Chicken DNA sequences differ the least.	0.667	0.333	0.500	0.833
Turtle & Toad both live on land.	0.333	0.667	0.00	0.00
Turtle & Large mouth bass both swim.	0.00	0.00	0.167	0.00
Large mouth bass & Turtle their DNA sequences differ the most.	0.00	0.00	0.333	0.167

Pre		Post	
$\chi 2$	**p-value**	$\chi 2$	**p-value**
0.635	1.000	0.134	0.226

Animal Pairs	Number of Differences
Dog & Penguin	14
Dog & Turtle	13
Turtle & Penguin	8

Question 5

Out of the pairs of organisms in Table 2, which are most closely related? What characteristic did you use for this?

Answer Options	**Traditional**		**POGIL**	
	Pre	**Post**	**Pre**	**Post**
Dog & Penguin DNA sequences differ the most.	0.00	0.00	0.00	0.00
Dog & Turtle both have 4 legs.	0.00	0.00	0.00	0.00
✓Turtle & Penguin DNA sequences differ the least.	0.667	0.667	0.833	1.00
Turtle & Penguin both live in the water.	0.333	0.333	0.167	0.00

Pre		**Post**	
$\chi2$	**p-value**	$\chi2$	**p-value**
0.571	1.000	0.134	0.333

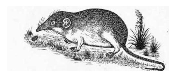
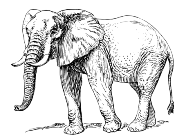
Animal Pairs	# of Differences
Duck & Tortoise	10
Duck & Snake	22
Tortoise & Snake	15

Question 6

Based on the information above, which two organisms should be grouped together?

Answer Options	Traditional		POGIL	
	Pre	**Post**	**Pre**	**Post**
✓Duck & Tortoise both have inner skeletons and their DNA sequences differ the least.	1.00	0.333	0.167	0.500
Duck & Snake their DNA sequences differ the most.	0.00	0.00	0.00	0.00
Tortoise & Snake they both have scales and while their number of DNA sequences differ more than Duck & Tortoise, the sequences are still similar.	0.00	0.667	0.667	0.500
Tortoise & Snake live on land.	0.00	0.00	0.167	0.00

Pre		Post	
$\chi 2$	**p-value**	$\chi 2$	**p-value**
0.018	0.048*	0.635	1.000

	Giant Elephant Shrew	Common Shrew	Manatee	Elephant	Mouse
Picture					
Number of differences	0	33	4	6	31

Question 7

The Giant Elephant Shrew is a new mammal species discovered recently. Scientists named and classified this organism based on characteristics shared with the Common Shrew. Then scientists compared the DNA sequence of the Elephant Shrew along with 4 other organisms. Would you change the classification of the Giant Elephant Shrew based on this new DNA data? Why or why not?

Answer Options	**Traditional**		**POGIL**	
	Pre	**Post**	**Pre**	**Post**
No, don’t change its classification. The original classification with the Common Shrew is most accurate because they look the most similar.	0.333	0.333	0.167	0.00
No, don’t change its classification because the DNA data show it to be most closely related to the common shrew.	0.00	0.00	0.167	0.333
✓Yes, change its classification because the DNA data show that the Giant Elephant Shrew is least related to the Common Shrew.	0.667	0.667	0.667	0.667
Yes, change its classification because it has a trunk-like structure similar to the elephant.	0.00	0.00	0.00	0.00

Pre		**Post**	
$\chi2$	**p-value**	$\chi2$	**p-value**
1.000	1.000	1.000	1.000

Question 8

Based on Table 4, which organism should the Giant Elephant Shrew be classified with?

Answer Options	Traditional		POGIL	
	Pre	Post	Pre	Post
The Common Shrew	0.00	0.00	0.167	0.00
The Common Shrew & Mouse	0.00	0.333	0.00	0.00
✓The Elephant & Manatee	1.00	0.667	0.667	0.833
The Mouse	0.00	0.00	0.167	0.00

Pre		Post	
$\chi 2$	p-value	$\chi 2$	p-value
0.257	0.500	0.571	1.000

Question 9

As you move from column 1 to column 3 in Figure 1 what happens to the number of members in each group?

Answer Options	Traditional		POGIL	
	Pre	Post	Pre	Post
They increase	0.00	0.333	0.00	0.00
✓They decrease	1.00	0.667	0.833	1.00
They stay the same	0.00	0.00	0.167	0.00
None of the above	0.00	0.00	0.00	0.00

Pre		Post	
$\chi 2$	p-value	$\chi 2$	p-value
0.453	1.000	0.134	0.333

Question 10

As you move from column 1 to column 3 in Figure 1 what happens to the number of similarities among members in a group?

Answer Options	Traditional		POGIL	
	Pre	Post	Pre	Post
✓They increase	0.333	0.333	0.667	0.500
They decrease	0.667	0.667	0.167	0.333
They stay the same	0.00	0.00	0.167	0.167
None of the above	0.00	0.00	0.00	0.00
	Pre		**Post**	
	$\chi 2$	**p-value**	$\chi 2$	**p-value**
	0.343	0.524	0.635	1.000

Question 11

Which 2 types of characteristics can be used to classify organisms?

Answer Options	Traditional		POGIL	
	Pre	Post	Pre	Post
✓anatomical & molecular	0.670	0.333	0.500	0.833
habitat & anatomical	0.333	0.00	0.333	0.00
locomotion & anatomical	0.00	0.667	0.167	0.167
locomotion & habitat	0.00	0.00	0.00	0.00
	Pre		**Post**	
	$\chi 2$	**p-value**	$\chi 2$	**p-value**
	0.635	1.000	0.134	0.226

Note. * $p < .05$.

✓ indicates correct answer for each item.

Table 10

Characteristics Used by Students for Grouping Animals in Pre and Post Interview

Potential Correct Grouping Students Could Create

Example 1

Organisms	Goldfish, beaver, chipmunk, seal, cardinal, duck, ostrich	Millipede. housefly, ant, crab	clam, starfish
Char.	Endoskeleton	Exoskeleton	No skeleton

Example 2

Organisms	Clam	Starfish	Goldfish	Millipede, housefly, ant, crab (arthropods)	Beaver, chipmunk, seal (mammals)	Cardinal, duck, ostrich (birds)
Char.	shell	radial symmetry	Scales, fins, gills	pairs of jointed appendages, segmented body	Hair, mammary glands	feathers

Example 3

Organisms	same as above	Crab	Housefly, ant (insects)	Millipede	same as above
Char.		Crustacean, 5 pairs of legs	Insects, 3 pairs of legs, antenna	2 pairs of legs per segment	

Note. This potion of the table shows potential correct groupings that could be made by the students.

POGIL Student 1

Pre interview

Organisms	Crab, clam, starfish	Seal, goldfish	Millipede, housefly, ant	Beaver, chipmunk	Cardinal, duck, ostrich
Char.	Water, not typically though of as animal, sea stuff	Water, living animal kind of things	Insects and bugs	Fur	Birds

Post interview

Organisms	Cardinal, ostrich, duck, beaver, chipmunk, seal	Ant, housefly, millipede, crab, clam, starfish, fish
Char.	Skeleton present	Exoskeleton or no skeleton

POGIL Student 2

Pre interview

Organisms	Clam	Goldfish	Ant, fly	Seal, beaver, chipmunk	Duck, ostrich, cardinal	Crab	Millipede	Starfish
Char.	Hard shell	No skeleton, soft body gills	6 legs, antenna	Mouth, eyes, ears, hairy, tails	Beak, eye size, body type, feathers	Soft	Lines, different shape	Flat

Post interview

Organisms	Clam, millipede	Goldfish, starfish	Fly, crab, ant	Seal, beaver, chipmunk	Duck, ostrich, cardinal
Char.	Crawl, ocean	Water	Shape of ant head and body shape of crab	Hair	Feather, beak, eyes, eye color, diet, climate

POGIL Student 3

Pre interview

Organisms	Clam, crab, starfish	Goldfish	Ant, housefly, millipede	Beaver, chipmunk, seal	Cardinal, duck, ostrich
Char.	Aquatic, cold-blooded, exterior armor	No exoskeleton, scales, fast, fins, gills, eyes, reacts	Insects	Mammals, warm-blooded, 4 extremities, fur	Birds, four extremities, warm-blooded, feathers

Post interview

Organisms	Starfish, clam	Goldfish	Ant, housefly, millipede, crab	Beaver, chipmunk, seal	Cardinal, duck, ostrich
Char.	Exoskeleton, water, diet	Scales, endoskeleton, fins, non-jointed appendages	Pairs of appendages, exoskeleton	Fur, 4 appendages, mammary glands, warm-blooded	Beak, 2 legs, 2 wings, feathers, warm-blooded, lays eggs

Traditional Student 4

Pre interview

Organisms	Clam, crab, starfish, goldfish	Ant, housefly, millipede	Beaver, chipmunk, seal	Duck, cardinal, ostrich
Char.	Aquatic	Insects, not aquatic, simple structures (limbs and antenna, organs)	Fur, fat deposits, mammals	Bird, feathers, hollow bones

Post interview

Organisms	Clam, crab, starfish, goldfish	Ant, housefly, millipede	Beaver, chipmunk, seal	Duck, cardinal, ostrich
Char.	Sea creatures, hard shells and scales	Insects, simplified legs, lack complex organs,	Mammals, fur, whiskers, defined vision, diet, habitat, respiration, mammary gland	Birds, wings, feathers w waxy coat, feet w talons

Traditional Student 5

Pre interview

Organisms	Seal, beaver, duck, starfish, goldfish, crab, clam	Ant, millipede	Chipmunk, ostrich	Cardinal, housefly
Char.	Water animals	Ground/dirt animals	Land animals	Air/fly animals

Post interview

Organisms	Clam, crab, starfish	Ant, millipede	Chipmunk, ostrich	Goldfish	Beaver, seal, duck	Cardinal, housefly
Char.	Ocean water	Ground animals, crawl	Land animals	Regular water	Water/land animal	Air, fly

Traditional Student 6

Pre interview

Organisms	Crab and clam	Housefly, ant, millipede	Beaver, chipmunk, seal	Cardinal, duck, ostrich	Goldfish	Starfish
Char.	Shells, lay eggs	Exoskeleton, insects, feelers	Mammals, do not lay eggs	Wings, lay eggs, beaks or bills	Gills, lays eggs, breath underwater, aquatic	Unique reproduction (limbs), eating, internal makeup

Post interview

Organisms	Crab	Millipede	Ant, housefly	Seal, beaver, chipmunk	Cardinal, duck, ostrich	Goldfish	Starfish	Clam
Char.	4 pairs of legs, crust- acean	Many pairs of legs, antenna	3 pairs of legs, antenna	Mammals, internal skeletons	Birds, wings, beaks, feathers, legs, spines, eggs, nests	Scales, gills	No feet, radial symmetry	No legs, different move/ behavior

Table 11

Correct and Incorrect Characteristics Used by Students to Classify and Describe Each Organism in Interviews

POGIL Student 1 — **Organisms**

Student Interview Answer Choices		Ant	Beaver	Cardinal	Chipmunk	Clam	Crab	Duck
Pre	Correct	Insects, # of legs	Fur	Birds, beak, feathers, wings, 2 legs	Fur		Number of legs	Birds, beak, feathers, wings, 2 legs
	Incorrect		Swimming, water, or land, eat similar things to seal	Wild animal, fly,		Water, not typical “animal”, swim, sea stuff	Water, not typical “animal”, swim, sea stuff, same size as fish	Water, fly,
Post	Correct	Exoskeleton, insect	Endoskeleton, fur	Endoskeleton, bird, feathers, beaks	Endoskeleton, fur		Exoskeleton	Endoskeleton, bird, feathers, beaks
	Incorrect	Leg type				Don’t know skeleton type		

		Goldfish	Housefly	Millipede	Ostrich	Seal	Starfish
Pre	Correct		Insects		Birds, beak, feathers, wings, 2 legs,		
	Incorrect	Water, living animal kind of things, swimming, same size as crab		Insect	Wild animal, fly, wild environment	Water, living animal kind of things, swim or land, eat similar things to beaver	Water, not typical “animal”, swim, sea stuff
Post	Correct		Exoskeleton, insect	Exoskeleton	Endoskeleton, bird, feathers, beaks	Endoskeleton, fur	
	Incorrect	No endoskeleton	Leg type				Don’t know skeleton type

POGIL Student 2 — **Organisms**

Student Interview Answer Choices		Ant	Beaver	Cardinal	Chipmunk	Clam	Crab	Duck
Pre	Correct	6 legs, antenna	Hair	Beak, feathers, # toes	Hair	Hard shell		Beak, feathers, # toes
	Incorrect	Skeleton/hard body, crawl on legs, live in holes	Mouth, eyes, ears, different arms and legs, water, food type, tails, walks, grow, size, senses	Eye size, size, shape, tail	Mouth, eyes, ears, different arms and legs, crawl, tails, walks, grow, size, senses		Soft, crawl on legs, water	Eye size, size, shape, tail
Post	Correct	3 pairs legs, antenna	Hair	Feathers, beak	Hair			Feathers, beak
	Incorrect	Head shape, fly, crawl, no wings	Water, "hand type"	Eye, eye color, diet, trees	Not water, "hand type"	Ocean	Body shape, leg shape, crawl, water	Eye, eye color, diet, trees

		Goldfish	Housefly	Millipede	Ostrich	Seal	Starfish
Pre	Correct	Gills	6 legs, antenna	Lines	Beak, feathers, # toes	Hair	
	Incorrect	No skeleton	No skeleton/soft body, crawl on legs, live in holes	Different shape	Eye size, size, shape, tail	Mouth, eyes, ears, different arms and legs, water, food type, tail	Flat
Post	Correct		3 pairs legs, antenna		Feathers, beak	Hair	
	Incorrect	Water	Crawl, wings	Ocean, crawl	Eye, eye color, diet, ground	Water, "hand type"	Water

POGIL Student 3 **Organisms**

Student Interview Answer Choices		Ant	Beaver	Cardinal	Chipmunk	Clam	Crab	Duck
Pre	Correct	Insect	Mammal, warm-blooded, fur	Bird, warm-blooded, feathers, 2 wings, beaks	Mammal, warm-blooded, fur	Cold-blooded	Cold-blooded	Bird, warm-blooded, feathers, 2 wings, beaks
	Incorrect		4 limbs, tail	4 limbs, fly, live in trees,	4 limbs, tail	Aquatic, exterior armor, tongue	Aquatic, exterior armor	4 limbs, fly, live in water
Post	Correct	3 pairs of jointed appendages, exoskeletons, antenna	Fur, 4 appendages, mammary glands, warm-blooded, endoskeleton, live birth	Beak, appendages, feathers, warm-blooded, lays eggs, endoskeleton	Fur, 4 appendages, mammary glands, warm-blooded, endoskeleton, live birth		4 pairs of jointed appendages, exoskeletons	Beak, appendages, feathers, warm-blooded, lays eggs, endoskeleton
	Incorrect					Exoskeleton, water, diet	Set of pinchers?	

		Goldfish	Housefly	Millipede	Ostrich	Seal	Starfish
Pre	Correct	No exoskeleton, scales, fins, gills	Insect		Bird, warm-blooded, feathers, 2 wings, beaks	Mammal, warm-blooded, fur	Cold-blooded
	Incorrect	Non-jointed appendages					Exoskeleton, water, diet
Post	Correct	Scales, endoskeleton, fins	3 pairs of jointed appendages, exoskeletons, antenna	Many pairs of appendages, exoskeletons	Beak, appendages, feathers, warm-blooded, lays eggs, endoskeleton	Fur, 4 appendages, mammary glands, warm-blooded, endoskeleton, live birth	
	Incorrect	Water	Crawl, wings	Ocean, crawl	Eye, eye color, diet, ground	Water, “hand type”	Water

Trad. Student 4 **Organisms**

Student Interview Answer Choices		Ant	Beaver	Cardinal	Chipmunk	Clam	Crab	Duck
Pre	Correct	Insect, simple structures (limbs and antenna, organs)	Fur, mammal	Bird, feathers, hollow bones	Fur, mammal	Shell		Bird, feathers, hollow bones
	Incorrect	No water	Fat deposits, water, eyes, teeth, whiskers	Fly, no water, mammal	Fat deposits, no water, eyes, teeth, whiskers	Aquatic	Aquatic,shell	Fly, water, mammal
Post	Correct	Insect	Mammal, fur, whiskers, mammary glands	Bird, wings, feathers, hollow bones, warm-blooded	Mammal, fur, whiskers, mammary glands	Shell	Gills	Bird, wings, feathers, hollow bones
	Incorrect	Simplified legs, lack of complex organs	Defined vision, diet, survive in water if they want, respiration, ears to hear, teeth	Funny feet with talons, fly, make noise, good eyesight	Defined vision, diet, survive in water if they want, respiration, ears to hear, teeth	Sea creature	Sea creature, shell, rudimentary legs, can't fly, eat fish	Funny feet with talons, fly, make noise, good eyesight

		Goldfish	Housefly	Millipede	Ostrich	Seal	Starfish
Pre	Correct		Insect, simple structures (limbs and antenna, organs)	Simple structures (limbs and antenna, organs)	Warm-blooded, bird, feathers	Warm-blooded, fur, mammal	
	Incorrect	Aquatic, no shell	No water	Insect, no water	Hollow bones, can't fly, no water, mammal	Fat deposits, water, eyes, teeth, whiskers	Aquatic, shell
Post	Correct	Scales	Insect		Bird, wings, feathers	Mammal, fur, whiskers, mammary glands, warm-blooded	
	Incorrect	Sea creature	Simplified legs, lack of complex organs, rudimentary legs, fly	Insect, simplified legs, lack of complex organs	Funny feet with talons, make noise, good eyesight	Defined vision, diet, survive in water if they want, respiration, ears to hear, teeth	Sea creature, shell

Trad. Student 5 — **Organisms**

Student Interview Answer Choices		Ant	Beaver	Cardinal	Chipmunk	Clam	Crab	Duck
Pre	**Correct**			Beak, feet shape				
	Incorrect	Ground/dirt, crawl	Land and water, live in dams	Fly, air, bird	Land, ground	Water, sea water	Water, sea water	Water, pond water
Post	**Correct**			Feathers, beak, feet shape				Feathers, beak, feet shape
	Incorrect	Ground, dirt, crawl, don't fly	Water or land, don't fly	Air, fly, wings	Land, don't fly, respiration	Ocean water	Ocean water	Water or land, pond,

		Goldfish	Housefly	Millipede	Ostrich	Seal	Starfish
Pre	**Correct**				Beak, feet shape		
	Incorrect	Water	Fly, air	Ground/dirt, crawl	Don't fly, land, ground, bird	Land and water, live on rocks	Water, sea water
Post	**Correct**						
	Incorrect	Regular water, respiration	Air, fly, wings	Ground, dirt, crawl, don't fly	Land, don't fly	Water or land, don't fly, respiration	Ocean water

Trad. Student 6 — **Organisms**

Student Interview Answer Choices		Ant	Beaver	Cardinal	Chipmunk	Clam	Crab	Duck
Pre	Correct	Exoskeleton, insect, feeler, lay eggs	Mammal, fur	Wings, lay eggs, beak	Mammal, rodent, fur	Shell	Lay eggs	Wings, lay eggs, beak
	Incorrect		No eggs, land and aquatic	Fly	No eggs, land	Lay eggs	Shell	Fly
Post	Correct	3 pair legs, antenna, exoskeleton	Internal skeleton, mammal, fur	Wings, beaks, legs, spines, eggs, bird, endoskeleton	Internal skeleton, mammal, fur	No legs	4 pairs of legs, crustacean	Wings, beaks, legs, spines, eggs, bird, endoskeleton
	Incorrect	Form of movement		Different sizes, nests		Moves/ acts different	Form of movement	Different sizes, nests

		Goldfish	Housefly	Millipede	Ostrich	Seal	Starfish
Pre	Correct	Gills	Exoskeleton, insect, feeler	Exoskeleton, feelers	Wings, lay eggs, beak	Mammal	Internal structure
	Incorrect	Lay eggs, aquatic, respiration unique	Fly	Insect		No eggs, land and aquatic	Limbs grow back, diet, aquatic
Post	Correct	Scales, gills, internal skeleton	3 pair legs, antenna	Many legs, antenna	Wings, beaks, legs, spines, eggs, bird, endoskeleton	Internal skeleton, mammal, fur	Radial
	Incorrect				Different sizes, nests		

Table 12

Common Characteristics used by Students to Classify Pasta in Pre and Post Interview

	Characteristics											
Student	spiral	type of spiral	flat/straight	hollow	circular	edges	texture	size	shape	length/ width	ingredients	color
Student 1 POGIL	x o	x o	x o	x o	x o	x o	x o	x o	o	o		o
Student 2 POGIL	x o		x			x o	x	x o	x o	x o	x o	x
Student 3 POGIL	x o		x o	x o	x o	x o	x o	o	x o	o		
Student 4 Traditional	x o	o	x o	x o		o	x o	o		x o		
Student 5 Traditional	x o	o	x	x o	x		x o	x o	x o	x o		
Student 6 Traditional	x o	x o	o	x o	x	o	x o	x	o	x o		x

Note. Pasta types include linguini, fettucini, lasagna, bow-tie, elbow macaroni, ridged penne, smooth penne, rigatoni, gemmelli, fusilli, cavatappi, and fusilli corti bucati.

Group A 0--------------X------------0

Group B 0----------------------------0

Figure 1. Nonequivalent (Pre-Test and Post-Test) Control-Group Design. The quasi-experimental quantitative research design (Adapted from Creswell, 2009).

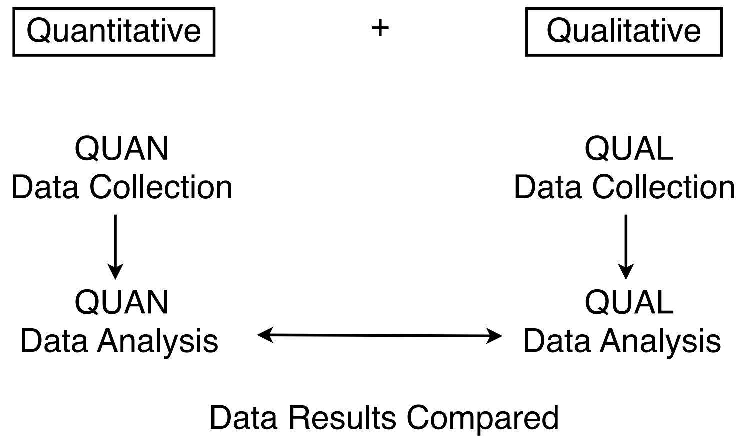


Figure 2. Concurrent Triangulation Design. A visual model of the procedures for this mixed methods study (Adapted from Creswell, 2009).

3. Which one of the following organisms has an exoskeleton?

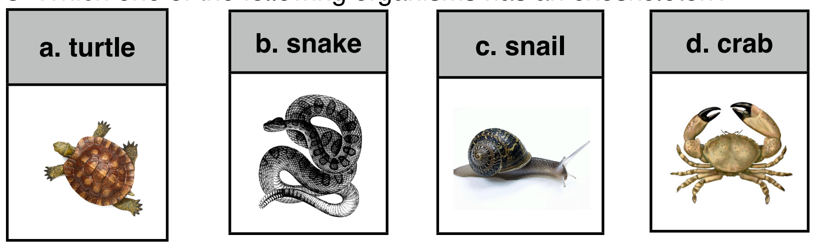


Figure 3.1. Example Item from Pilot Test Section 1, Identifying Anatomical Vocabulary.

4. Considering characteristics that scientists use to classify organisms, which two should be grouped together? What characteristic did you use for this grouping?

a. Owl & Penguin have feathers
b. Owl & Bat fly
c. Penguin & Bat have wings
d. Owl & Bat live in the forest

Owl	Penguin	Bat
		

Figure 3.2. Example Item from Pilot Test Section 2, Classification and Relatedness Based on Anatomical Characteristics.

Table 2. The number of differences between a comparable DNA sequence of selected pairs of animals.

Animal Pairs	Number of Differences
Dog & Penguin	14
Dog & Turtle	13
Turtle & Penguin	8

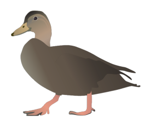
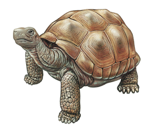
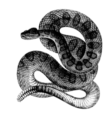
16. Out of the pairs of organisms in Table 2, which are most closely related? What characteristic did you use for this?

a. Dog & Penguin DNA sequences differ the most.
b. Dog & Turtle both have 4 legs.
c. Turtle & Penguin DNA sequences differ the least.
d. Turtle & Penguin both live in the water.

Figure 3.3. Example Item from Pilot Test Section 3, Classification and Relatedness Based on Molecular Data.

Table 3. The number of differences between DNA sequences of selected pairs of animals.

Animal Pairs	# of Differences
Duck & Tortoise	10
Duck & Snake	22
Tortoise & Snake	15

Duck	Tortoise	Snake
		

17. Based on the information above, which two organisms should be grouped together?

a. Duck & Tortoise both have inner skeletons and their DNA sequences differ the least.
b. Duck & Snake their DNA sequences differ the most.
c. Tortoise & Snake they both have scales and while their number of DNA sequences differ more than Duck & Tortoise, the sequences are still similar.
d. Tortoise & Snake live on land.

Figure 3.4. Example Item from Pilot Test Section 4, Combining Types of Evidence to Classify.

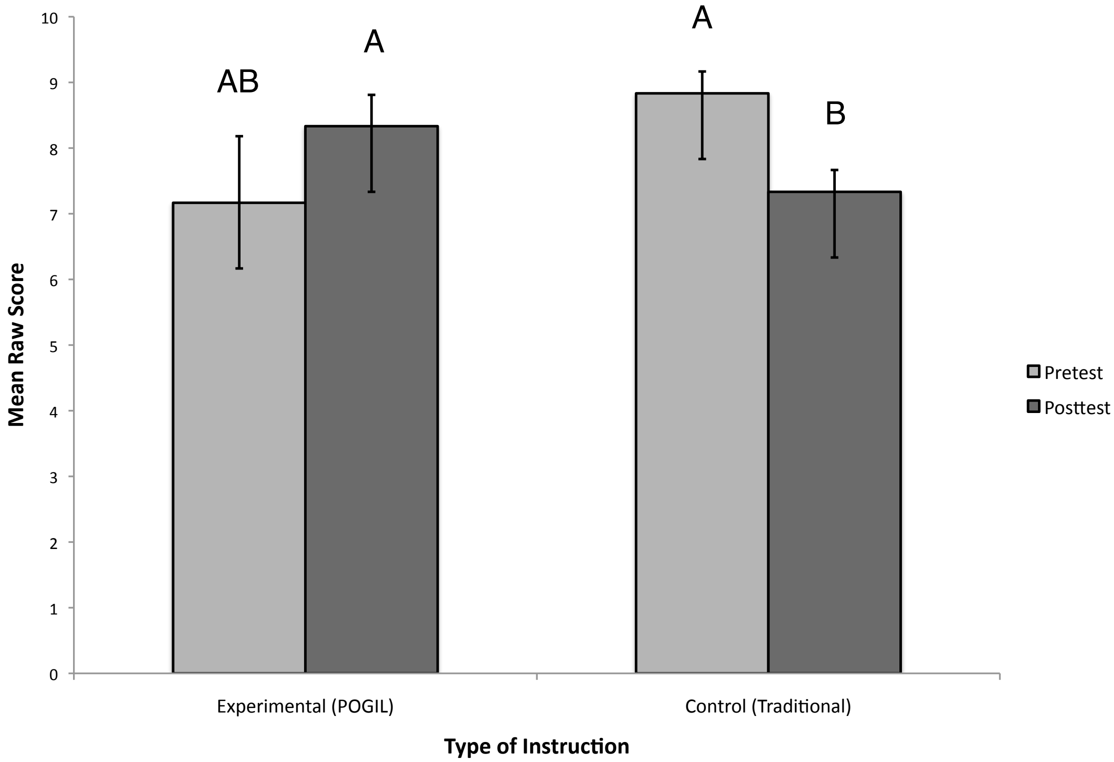


Figure 4. Mean Pretest and Posttest Scores after Two Different Types of Instruction for the Experimental (n = 6) and Control (n = 3) Groups. Error bars represent standard error of the mean. Calculated with Mann-Whitney U. Bars with different letters show a tendency of difference between the means, $p < .10$.

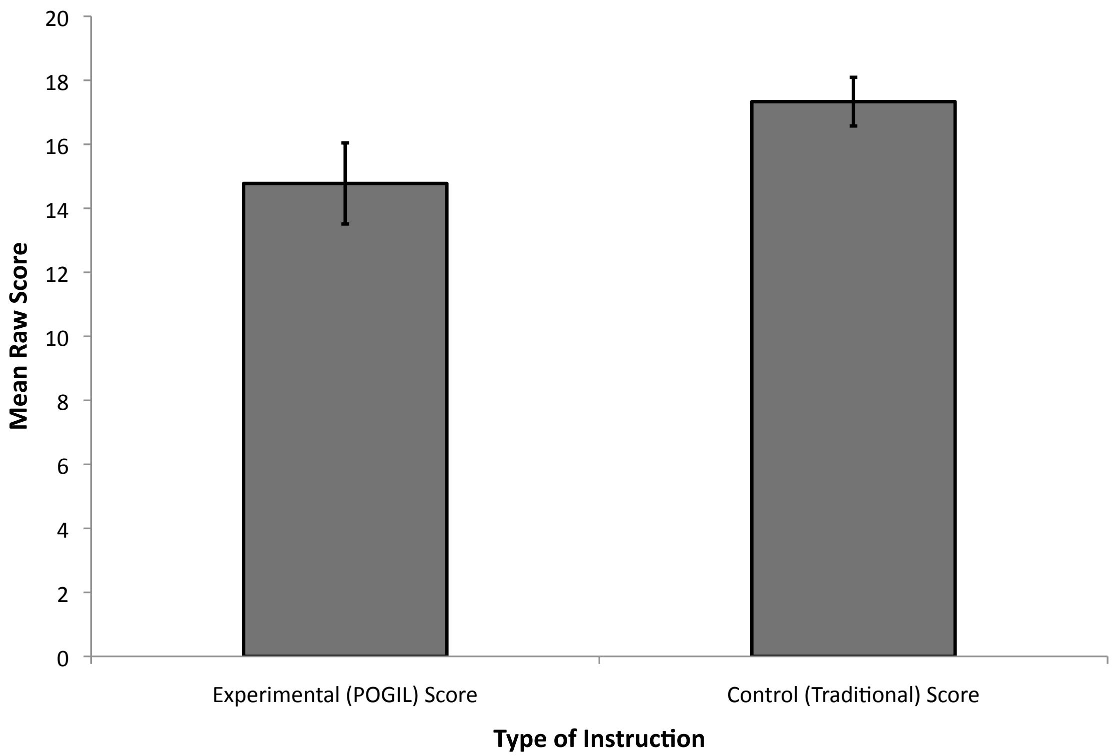


Figure 5. Mean Classification Quiz Scores after Two Different Types of Instruction for the Experimental (n = 6) and Control (n = 3) Groups. Error bars represent standard error of the mean. Calculated with Mann-Whitney U.

Appendix A: POGIL Laboratory Activity

- POGIL Classification Activity: How we Classify
- Lesson Plan for POGIL Classification Activity: How we Classify
- Instructor's Key for POGIL Classification Activity
- POGIL Group Roles
- POGIL Lesson Materials

Manager ___________________ Reporter ______________________
Recorder ___________________ Quality Control ____________________

Classification: How to Classify Organisms

Question of the Day: What characteristics do biologists use to classify organisms?
Outcomes:
Given models of organisms and/or molecular data, students should be able to
1. List the two types of characteristics (anatomical and molecular) that can be used to classify biological organisms
2. Describe and identify anatomical characteristics including the presence or absence of endoskeleton or exoskeleton, notochord, mammary glands, opposable thumbs, hooves, and presence of feathers
3. Classify organisms into hierarchical groups based on anatomical characteristics only
4. Compare and contrast the relatedness of organisms based on molecular data only
5. Classify organisms into hierarchical groups based on molecular characteristics only
6. Explain that both anatomical and molecular characteristics could be used together to classify organisms
7. Use molecular characteristics to evaluate and reorganize groupings of organisms based on anatomical characteristics
8. Analyze a biological classification system in terms of the number organisms per group and the number of similarities among organisms in a group

Model 1: Design Your System (40 minutes)

1. Examine the organisms provided at the front of the room.
   a. Separate the organisms into groups of "related" organisms. Follow the general format provided below.
   b. Provide the rationale for the groups that you create. Continue until each organism is <u>isolated</u> with a rationale. Space is provided for your diagram on the next page.

Format for Grouping

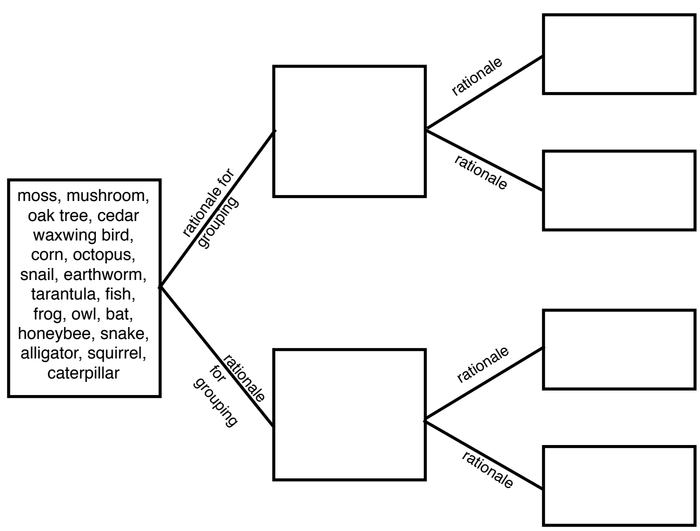


Diagram for Model 1

2. Create a few classification procedures that could be used to classify <u>any</u> organism. These procedures should be based on the rationale used in question 1b. These should be broad, general statements, not specific. (Here's an example: Rationale- absorbs food, eats food. You could generalize this as a type of nutrition).

STOP

3. Once the class's classification procedures have been determined, record them in the appropriate column in Table 1.

Table 1

	Classification Procedures from Model 1	Supported	Refuted	Supported by the class
A				
B				
C				
D				
E				
F				

STOP

Model 2: Testing Your System (30 minutes)

1. Examine the organisms given to your table.

2. Work with the members of your group to separate the organisms into groups of related organisms. Using the key characteristics provided to guide your groupings. Space is provided for your diagram on the next page.

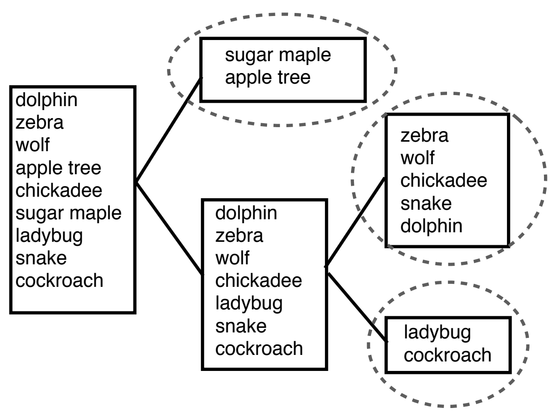


Figure 2

NOTE* Organisms will not always end up isolated.

Diagram for Model 2

3. Examine and CIRCLE the final groupings you have created. (Dashed circles in Figure 2 denote final groupings.)

4. Refer to the classification procedures that were listed in Model 1, Table 1. For each procedure determine if it is supported or refuted by your Model 2 circled final groupings. Use this information to check the appropriate column in Table 1. Make your decision based on all of the circled final groupings considered together.

Model 3: Structures, molecular makeup, or both? (25 minutes)

Part A:

1. Use the following list of organisms and the provided key characteristics to separate them in the same format you used in Models 1 and 2. Space is provided for your diagram on the next page. Circle your final groupings.

human	duck	fly
monkey	penguin	fungus (yeast)
dog	turtle	pig
horse	rattlesnake	hippopotamus
rabbit	tuna fish	whale

Diagram for Model 3

Part B:

READ THIS!

Genes are made of DNA and are inherited from parent to offspring. Some DNA codes for the amino acid sequence of proteins. Cytochrome C is a protein and is found in most cells. Over time, random mutations in the DNA sequence occur. As a result, the amino acid sequence of Cytochrome C also changes. You can compare the relatedness between organisms by examining the amino acid sequence in the protein, Cytochrome C.

1. Examine the Cytochrome C data table provided. The two most closely related species have the fewest differences in amino acid sequence.
2. Look at the final groupings created using the key characteristics in Part A. Any final group with only one organism can be ignored.
   a. List the organisms for each final group in pairs in Table 2. The first few pairs have been provided.
   b. In the next column of Table 2, list the number of Cytochrome C differences found between each pair of organisms. The first number has been provided.

Table 2

Names of Organisms Compared	# of Cytochrome C differences
horse & pig	**5**
pig & hippo	
hippo & horse	

3. After examining the number of differences, which pairs should be split because of a high number of Cytochrome C (10 or more) differences?

4. Could the pairs that have 10 or more differences in their Cytochrome C be placed with a different, more closely related organism? Use the Cytochrome C chart to guide you. If so, list the new pairs.

5. Explain why more closely related organisms have more similar Cytochrome C.

6. Do the data from the Cytochrome C chart generally agree with the key characteristics that were used to make Part A? (i.e., Do organisms with fewer shared anatomical characteristics also have more amino acid differences?)

7. What if the structural similarities and molecular data do not agree? What do you think is more accurate to base the classification of organisms on, structures, molecules, or both? Explain.

8. When looking at the diagrams created in Models 1,2 & 3, what happens to the number of similar characteristics in a group as you move from the large initial group of organisms to the final groupings of organisms?

Part C:

Golden rice is a genetically modified (GM) rice that was created to produce Vitamin A. It has been created for underdeveloped countries as a cure for prevalent Vitamin A deficiency. Young people lacking adequate amounts of this vitamin may become blind as a result. Unlike the non-GM rice, golden rice is yellow because of the presence of betacarotene, a source of Vitamin A.

There are three new genes have been incorporated to create golden rice, two from daffodils and one from a bacterium. Golden rice contains genes from the Plant and Bacteria Kingdoms. In nature DNA from two different Kingdoms has never combined.

9. Given that this plant has both plant and bacterial genes, how should scientists classify this? Explain your answer.

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Classification: How to Classify Organisms

Outcomes:

Given models of organisms and/or molecular data, students should be able to

1. List the two types of characteristics (anatomical and molecular) that can be used to classify biological organisms
2. Describe and identify anatomical characteristics including the presence or absence of endoskeleton or exoskeleton, notochord, mammary glands, opposable thumbs, hooves, and presence of feathers
3. Classify organisms into hierarchical groups based on anatomical characteristics only
4. Compare and contrast the relatedness of organisms based on molecular data only
5. Classify organisms into hierarchical groups based on molecular characteristics only
6. Explain that both anatomical and molecular characteristics could be used together to classify organisms
7. Use molecular characteristics to evaluate and reorganize groupings of organisms based on anatomical characteristics
8. Analyze a biological classification system in terms of the number organisms per group and the number of similarities among organisms in a group

Materials

- Copies of POGIL Lab- 1 per student
- Copies of laminated POGIL role cards- 4 per table (describing each unique role)
- Rulers, pencils, extra blank paper
- Model 1:
  - Organisms at front of room (live, plastimount, stuffed, and photos)
    - moss, mushroom, oak tree, cedar waxwing, corn, octopus, snail, earthworm, tarantula, fish, frog, owl, bat, honeybee, snake, alligator, squirrel, caterpillar
- Model 2:
  - Organisms at tables (live, plastimount, stuffed, and photos) for Model 2

    - Table 1: planarian, tapeworm, *Caenorhabditis elegans*, heartworm, leech, earthworm, octopus, snail, squid
    - Table 2: planarian, tapeworm, *Caenorhabditis elegans*, heartworm, leech, earthworm, octopus, snail, squid, jellyfish, brittle star, sea urchin
    - Table 3: tarantula, tick, honeybee, praying mantis, bat, cedar waxwing, owl, alligator, grey squirrel
    - Table 4: crayfish, water beetle, fish, soft shell turtle, snapping turtle, alligator, tiger salamander, African clawed frog, water moccasin
    - Table 5: *Buttercup*, oak tree, corn, orchid, button mushroom, bracket fungus, *Rhyzopus*, moss, hemlock, blue spruce, *Elodea*
    - Table 6: button mushroom, bracket fungus, *Rhyzopus*, white pine, blue spruce, spider plant, corn, moss, *Geranium*, oak tree, *Elodea*
    - Copies of Key Characteristics sheets for Model 2 at each applicable table
    - Copies of organism lists for Model 2 at each applicable table
- Model 3:
  - Copies of Model 3 Part A -Key Characteristics- all tables get the same
  - Copies of Cytochrome C Table- all tables get the same
  - Copies of Picture of all organisms represented in Model 3- all tables get the same
  - Copies of group assessment, 1 per table
- Instructors: POGIL Lab Key, Lesson Plan: How to Classify, Diagram Answer Keys for Models 2 and 3 Part A, Introduction PowerPoint

Pre-Lab Preparations

1. Have laminated POGL role cards at Instructor desk
2. Set out/identify all organisms for Model 1, see Materials
3. Set out all organisms and tape down documents for Model 2, see Materials and attached doc Organism Location for help
4. Documents for Model 3 can be kept at Instructor desk until needed, see Materials
5. Make copies of How to Classify for all students
6. Make copies of How to Classify Lesson Plan, How to Classify Key, and all table diagrams for instructors, email instructors introduction PowerPoint

Procedures

1. Introduction to POGIL PowerPoint: Provide students with a brief background on POGIL. (5 min)

- What it is
- Why use it
- Describe and randomly assign group roles and the importance of these
  - Read through each laminated/color coded role card and stress the different responsibilities of each.
  - Reassure the students that it can be a challenge to follow these roles and that it takes practice.
  - Stress the fact that only ONE packet will be turned in for the group, the recorder's, but all members should be writing the information on their packets.

2. Hand out How to Classify POGIL activity
   - THINK-PAIR-SHARE as tables: Introduction to Lab: Instructor will direct students to the Question of the Day: What characteristics do biologists use to classify organisms? (2 min)
     - Spokesperson of each table reports to the class, sharing the group's agreed upon answer.
3. **Model 1**: Direct students to Model 1: Design Your System. (40 min total)
   - Point out parts of the POGIL lesson before beginning Model 1:
     - what is meant by "Model"-the diagrams created and supplied to the students
     - stopping at stop signs and waiting for further instructions
     - time to be finished with Model 1 (35 min), managers keep track of time for their groups
   - Students work on #1 & 2
   - Encourage students to get up and look at the organisms in Model 1 to identify characteristics.
   - As groups are working, walk around and address the managers of each group with probing questions on why/ how their group is determining the rational for dividing the groups
     - *Example: Why did you place these organisms together?*
   - As students finish their diagrams, assist each table with creating their classification procedures for #2 by encouraging the students to look at <u>general patterns.</u> It is important for at least two groups to recognize internal/external structures as rationale.
     - *Example: What kind of characteristics did you use to split apart the groups of organisms? Do these characteristics you've used show any type of pattern?*
   - Once ALL tables are finished, the recorder for each table lists the table's answers to #2 on the doc cam. Each group should list at LEAST 3 procedures.
   - Work with the class to circle commonalities in the lists on the doc cam.

- example: one group listed environment and another listed habitat, these can be listed together as habitat
- Note: six “classification procedures” for the class are needed.
- List the final six “classification procedures” in Table 1 under the column “Model 1 Classification Procedures”. This also addresses # 3 on the worksheet.
- Explain that these six different classification procedures will be tested in Model 2 to determine which biologists truly use to classify organisms. You will fill in the rest of the columns on Table 1 at this time.

4. **Model 2:** Pass out and explain materials used for Model 2. (30 min total)
    - Each table needs lists of organisms, unique and designated key characteristics, and organism examples.
        - Assign an efficient and academically strong group to table 2.
            - *NOTE: Larval form, sea stars and urchins are considered to have bilateral symmetry, but for purposes of being consistent with the traditional classification we are only considering the adult form.*
    - NOTE: A diagram answer key for each table is included for instructors ONLY.
    - Tell the group managers they have 25 minutes to complete Model 2, #1-3.
    - As students work through # 1-3, monitor diagraming and facilitate as needed. Guide students so their diagrams match the key.
    - Once all tables have finished # 1-3, read # 4 aloud and provide an example using Figure 2 in Model 2 and a couple of the “classroom procedures” listed in Table 1.
        - “4. Refer to the classification procedures that were listed in Model 1, Table 1. For each procedure determine if it is supported or refuted by your Model 2 circled final groupings. Use this information to check the appropriate column in Table 1. Make your decision based on all of the circled final groupings considered together.”
            - *In Fig 2 the circled final groupings refute the following: locomotion (birds fly, snakes do not have legs, etc.) and habitat (dolphins live in water, wolves live in the woods, etc.)*
    - Tables will then be given 2 minutes to determine whether their “final groupings” support or refute each procedure and check the appropriate column.
    - Instructor will read the six classification procedures aloud one by one and have each table’s spokesperson raise his/her hand if the classification procedure was SUPPORTED. If all tables support the procedure then the students should check the last column in Table 1, “Supported by the Class”.
        - ★Be carful NOT to refute any of the valid classification procedures, such as internal or external characteristics (e.g., anatomy, morphology, skeleton type).
        - ★Conclusion should be made that internal and external structures are what we use to classify organisms. Habitat, locomotion, behaviors, and color should be refuted.

- ★ See Diagram Answer Key for Instructors for ideas to help facilitate this discussion.

5. Model 3: Structures, Molecular Makeup, or Both? (35 min total)

- Reiterate the conclusions that the class came to based on the classification procedures supported in Model 2:
  - "The class has determined, based on characteristics, that biologists use internal and external anatomical characteristics to classify all organisms. Efforts are currently being made to incorporate a newer type of biological information available, molecular or biochemical evidence, into the classification of organisms. The point of Model 3 is to analyze both anatomical characteristics and biochemical evidence to compare and contrast the two sources of information and find a way to integrate them."
- Pass out one set of materials for Model 3 to each table: Key Characteristics for Model 3, Pictures of organisms listed in Model 3, Cytochrome C Data Table
- Instructor will need to explain any unfamiliar characteristics shown in Model 3, especially:
  - notochord: a flexible supporting rod of cells that exists in the embryos of all chordates, remains in the adults of some primitive forms (as lancelets and lampreys), and is replaced by the backbone in most vertebrates
  - ask students to identify which of the animals have mammary glands (human, monkey, dog, horse, rabbit, pig, hippo, whale)
  - See Key characteristics sheet for others.
- Students diagram Model 3: Part A; announce to managers time alloted (10 min).
- Demonstrate how to read the Cytochrome C table.
  - *Example: Locate the 3rd row that is labeled "dog" , locate the 2nd column "monkey", follow the row and column until they meet, notice the number "12". This is the number of Cyt C differences between these two organisms.*
- Students work on Model 3: Parts B & C; manager notes the time allotted (25 min).
- Facilitate as needed.
  - Be sure student diagrams match the Instructor's Diagram Answer Key for Model 3
  - Be sure that students are filling out Table 2 correctly, especially listing all combinations of pairs when there are three organisms in a final grouping.
    - Duck & penguin are easy to miss.
  - Have students show a pairing with over 10 differences. Have students pick one member of the pair and locate it on the Cyt C chart, and identify the smallest number to make a new pairing.
  - As tables finish, ask the tables about their answers and reasoning behind # 6 & 7.

- Once all groups finish, ask the tables to look at their answer to #4 and decide on a specific pairing that they found interesting. The spokesperson shares this pairing with the class along with why the group found it interesting.
  - *Common findings: bird and turtle pairings with lower Cytochrome C #'s, Whale and hippo's relatedness indicated by low #'s of Cytochrome C. Many of these new pairings show evolutionary relatedness previously unknown before molecular evidence.*
- Readdress the Question of the day: What characteristics do biologists use to classify organisms? Have the students answer. The correct answer should be: (1) internal & external anatomical characteristics, (2) biochemical/molecular evidence.
- Encourage any discussion regarding these 2 main types of evidence. Ask students how they would have classified in Part C. How does this relate to what biologists use?
  - Biologists use both, but molecular evidence trumps anatomical evidence when they are not in agreement.

6. The Quality Control person fills out the group assessment with the members of the group.
   - Collect:
     - Recorder's copy only (Must have all group names on it) of How to classify POGIL &
     - Group assessment

Adaptations

Tables need 3-4 students to form a group. If there are 3 students, combine the following roles into one: Quality Control and Spokesperson.

If there are not enough students to make 6 tables Model 2 can be modified in the following way:

Use only tables 2, 3, 4, 6 OR only 1,2,3,4 (eliminate the plants)

Manager ___________________ Reporter ______________________
Recorder ___________________ Quality Control ____________________

Instructor Key-Classification: How to Classify Organisms

Question of the Day: What characteristics do biologists use to classify organisms?
Outcomes:
Given models of organisms and/or molecular data, students should be able to
1. List the two types of characteristics (anatomical and molecular) that can be used to classify biological organisms
2. Describe and identify anatomical characteristics including the presence or absence of endoskeleton or exoskeleton, notochord, mammary glands, opposable thumbs, hooves, and presence of feathers
3. Classify organisms into hierarchical groups based on anatomical characteristics only
4. Compare and contrast the relatedness of organisms based on molecular data only
5. Classify organisms into hierarchical groups based on molecular characteristics only
6. Explain that both anatomical and molecular characteristics could be used together to classify organisms
7. Use molecular characteristics to evaluate and reorganize groupings of organisms based on anatomical characteristics
8. Analyze a biological classification system in terms of the number organisms per group and the number of similarities among organisms in a group

Model 1: Design Your System (40 minutes)

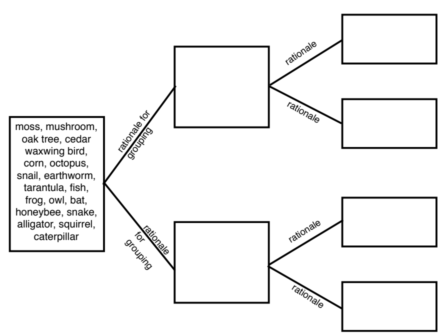
1. Examine the organisms provided at the front of the room.

moss, mushroom, oak tree, cedar waxwing bird, corn, octopus, snail, earthworm, tarantula, fish, frog, owl, bat, honeybee, snake, alligator, squirrel, caterpillar

   a. Separate the organisms into groups of "related" organisms. Follow the general format provided below.
   b. Provide the rationale for the groups that you create. Continue until each organism is <u>isolated</u> with a rationale. Space is provided for your diagram on the next page.

   any rationale at this point is acceptable

Format for Grouping



2. Create a few classification procedures that could be used to classify any organism. These procedures should be broad, general statements, not specific. (Here's an example: Rationale- absorbs food, eats food. You could generalize this as a type of nutrition).

Common answers to expect: habitat, movement, behaviors, reproduction, locomotion, kingdom, appendages, organism type

correct characteristics for classification: internal/external structures

** If these come up be sure to include them*

STOP

3. Once the class's classification procedures have been determined, record them in the appropriate column in Table 1. *(possible examples in Table 1 "Classification Procedures")*

Table 1

	Classification Procedures from Model 1	Supported	Refuted	Supported by the class
A	*Habitat*		x	
B	*Locomotion*		x	
C	*anatomical structures*	x		x
D				
E				
F				

STOP

Model 2: Testing Your System (30 minutes)

1. Examine the organisms given to your table.

Differing organisms at each table, see How to Classify LP for details

2. Work with the members of your group to separate the organisms into groups of related organisms. Using the key characteristics provided to guide your groupings. Space is provided for your diagram on the next page.

See Model 2 diagram answer keys for Table X

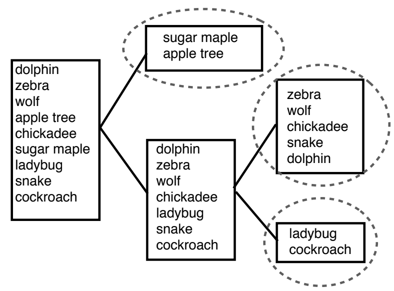


Figure 2

NOTE* Organisms will not always end up isolated.

3. Examine and CIRCLE the final groupings you have created. (Dashed circles in Figure 2 denote final groupings.)

4. Refer to the classification procedures that were listed in Model 1, Table 1. For each procedure determine if it is supported or refuted by your Model 2 circled final groupings. Use this information to check the appropriate column in Table 1. Make your decision based on all of the circled final groupings considered together.

See Table 1 columns 3 & 4

Instructor reads the six classification procedures and each spokesperson raise his/her hand if the classification procedure was SUPPORTED. If all tables support the procedure then the students should check the last column in Table 1, "Supported by the Class".

Model 3: Structures, molecular makeup, or both? (25 minutes)

Part A:

1. Use the following list of organisms and the provided key characteristics to separate them in the same format you used in Models 1 and 2. Space is provided for your diagram on the next page. Circle your final groupings.

See Model 3 Part A Diagram Answer Key for Instructors which is based on key characteristics for Model 3: Part A

human	duck	fly
monkey	penguin	fungus (yeast)
dog	turtle	pig
horse	rattlesnake	hippopotamus
rabbit	tuna fish	whale

Part B:

READ THIS!

Genes are made of DNA and are inherited from parent to offspring. Some DNA codes for the amino acid sequence of proteins. Cytochrome C is a protein and is found in most cells. Over time, random mutations in the DNA sequence occur. As a result, the amino acid sequence of Cytochrome C also changes. You can compare the relatedness between organisms by examining the amino acid sequence in the protein, Cytochrome C.

1. Examine the Cytochrome C data table provided. The two most closely related species have the fewest differences in amino acid sequence.
2. Look at the final groupings created using the key characteristics in Part A. Any final group with only one organism can be ignored.
   a. List the organisms for each final group in pairs in Table 2. The first few pairs have been provided.
   b. In the next column of Table 2, list the number of Cytochrome C differences found between each pair of organisms. The first number has been provided.

Table 2

Names of Organisms Compared	# of Cytochrome C differences
horse & pig	5
pig & hippo	4
hippo & horse	5
human & monkey	1
dog & rabbit	6
rabbit & whale	13
whale & dog	13
rattlesnake & turtle	30
duck & penguin	3

3. After examining the number of differences, which pairs should be split because of a high number of Cytochrome C (10 or more) differences?

rabbit & whale, whale & dog, rattlesnake & turtle

4. Could the pairs that have 10 or more differences in their Cytochrome C be placed with a different, more closely related organism? Use the Cytochrome C chart to guide you. If so, list the new pairs.

Some possibilities: rabbit & pig, whale & hippo, dog & pig, turtle & duck or penguin

5. Explain why more closely related organisms have more similar Cytochrome C.

The organisms have inherited similar amino acid sequences because they have ancestors that are closely related.

6. Do the data from the Cytochrome C chart generally agree with the key characteristics that were used to make Part A? (i.e., Do organisms with fewer shared anatomical characteristics also have more amino acid differences?)

Generally, they agree. Some animals have anatomical similarities and closely related Cyt C:

- *horse, pig, & hippo all have hooves and their Cyt C #'s are similar*
- *human & monkey have mammary glands and opposable thumbs and their Cyt C #'s are similar*
- *duck & penguin have feathers and their Cyt C #'s are similar*

There are exceptions as noted in the answer to Model 3 Part B #3.

7. What if the structural similarities and molecular data do not agree? What do you think is more accurate to base the classification of organisms on, structures, molecules, or both? Explain.

This is opinion, but we hope that students choose molecules because it is most accurate to use molecular data to come up with realistic classification

8. When looking at the diagrams created in Models 1,2 & 3, what happens to the number of similar characteristics in a group as you move from the large initial group of organisms to the final groupings of organisms?

The number of similar characteristics increases as you move from the initial group to the final groups.

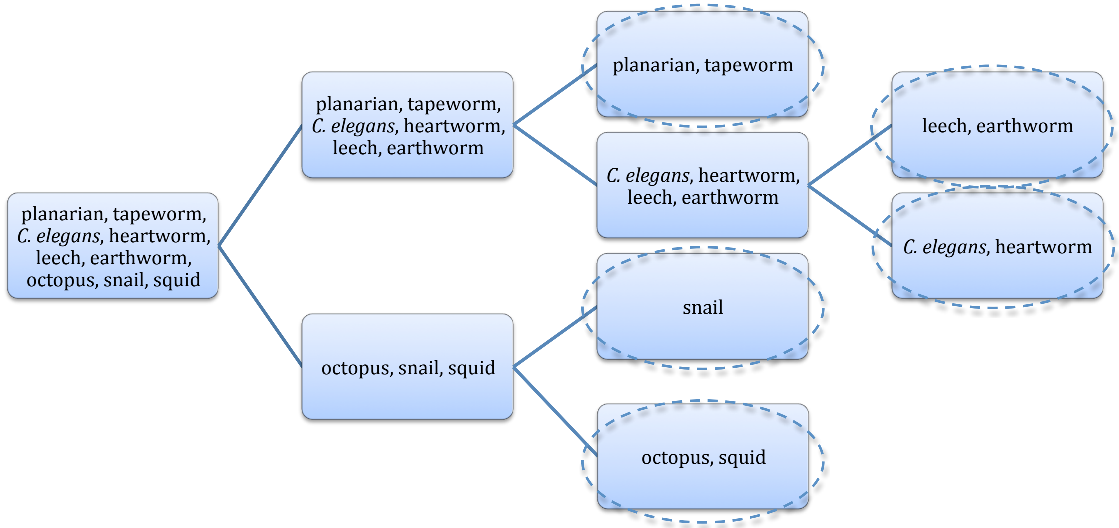
Part C:

Golden rice is a genetically modified (GM) rice that was created to produce Vitamin A. It has been created for underdeveloped countries as a cure for prevalent Vitamin A deficiency. Young people lacking adequate amounts of this vitamin may become blind as a result. Unlike the non-GM rice, golden rice is yellow because of the presence of betacarotene, a source of Vitamin A.

There are three new genes have been incorporated to create golden rice, two from daffodils and one from a bacterium. Golden rice contains genes from the Plant and Bacteria Kingdoms. In nature DNA from two different Kingdoms has never combined.

9. Given that this plant has both plant and bacterial genes, how should scientists classify this? Explain your answer.

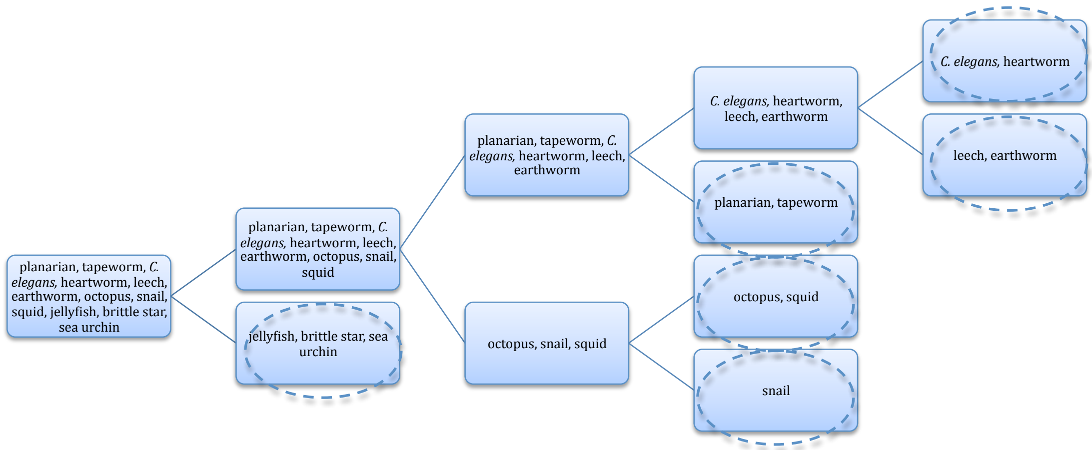
This is opinion, but within their explanation there should be mention of the presence of plant structures and genes along with bacterial genes.



Notes for Instructors:

- Supported: external structures, locomotion
- Refuted:
  - Habitat:
    - planarian (aquatic or terrestrial) & tapeworm (intestines)
    - C. elegans (terrestrial/soil) & heartworm(circ. sys.)

Model 2 Table 1 Diagram Answer Key for Instructors

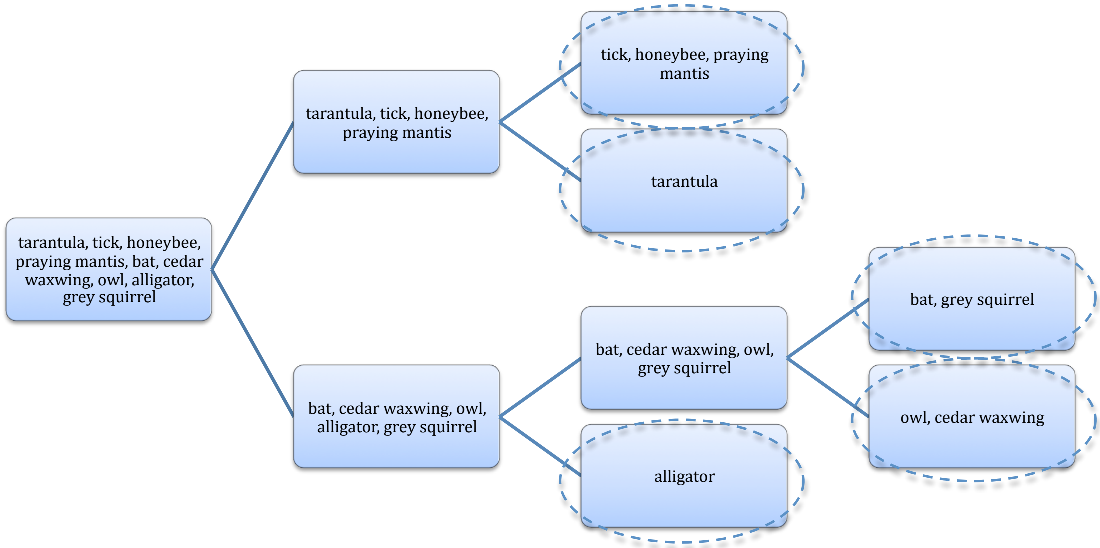


[1]

Notes for Instructors:

- Supported: external structures, locomotion
- Refuted:
  - habitat
    - C. elegans (terrestrial/soil) & heartworm (cric. sys.)
    - planarian (aquatic or terrestrial) & tapeworm (intestines)

Model 2 Table 2 Diagram Answer Key for Instructors

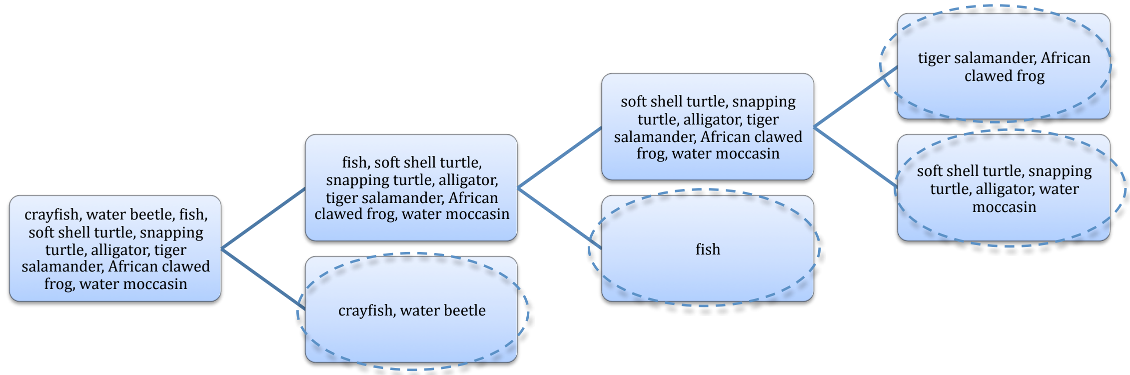


[1]

Notes for Instructors:

- Supported: external structures, habitat
- Refuted:
  - Locomotion
    - Bat (fly) & grey squirrel
    - Tick (DOESN'T fly) & honeybee, praying mantis

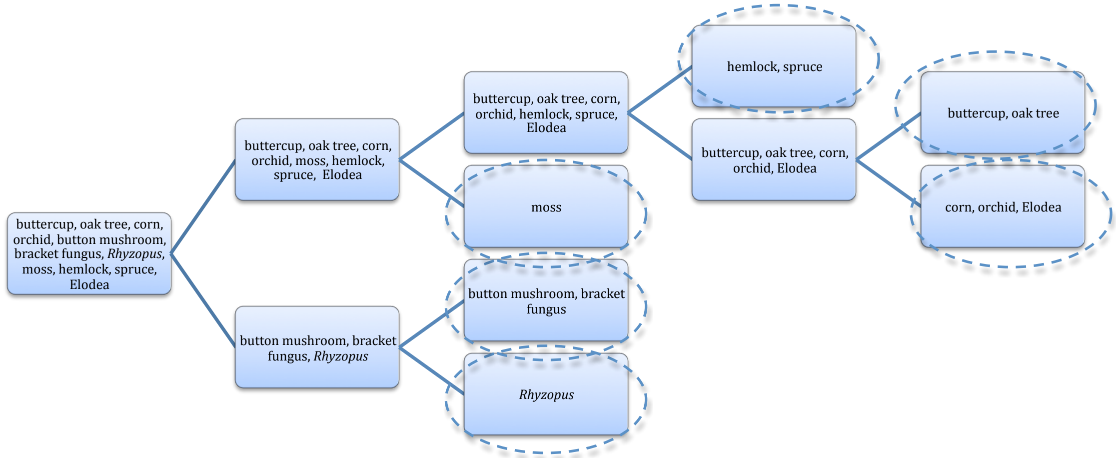
Model 2 Table 3 Diagram Answer Key for Instructors



Notes for Instructors:

- Supported: external structures, habitat
- Refuted:
  - Locomotion
    - Water moccasin (lateral undulation) & turtles (swim/walk) & alligator (swim/walk)
    - Crayfish (flaps tail) & water beetle (swims with appendages)

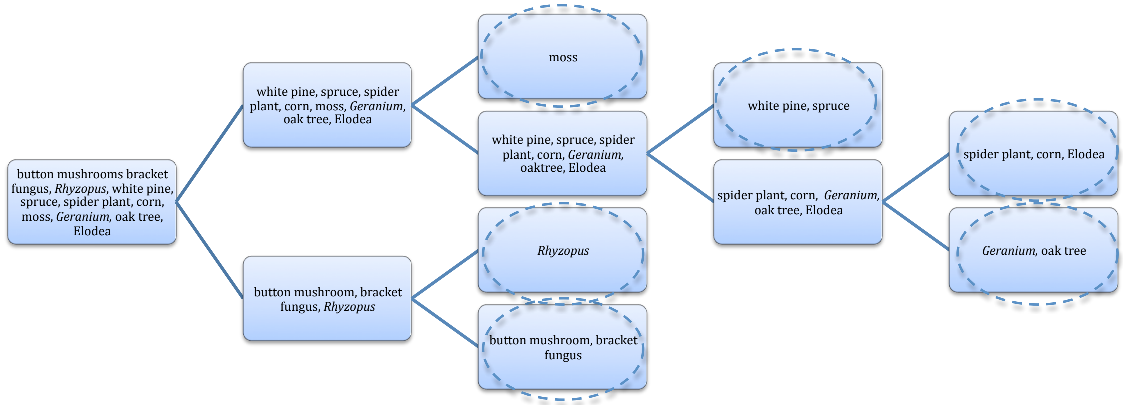
Model 2 Table 4 Diagram Answer Key for Instructors



Notes for Instructors:

- Supported: external structures
- Refuted:
  - Locomotion (none)
  - Habitat
    - Corn (field), buttercup (wetlands), orchid (aerial epiphyte) & Elodea (aquatic)

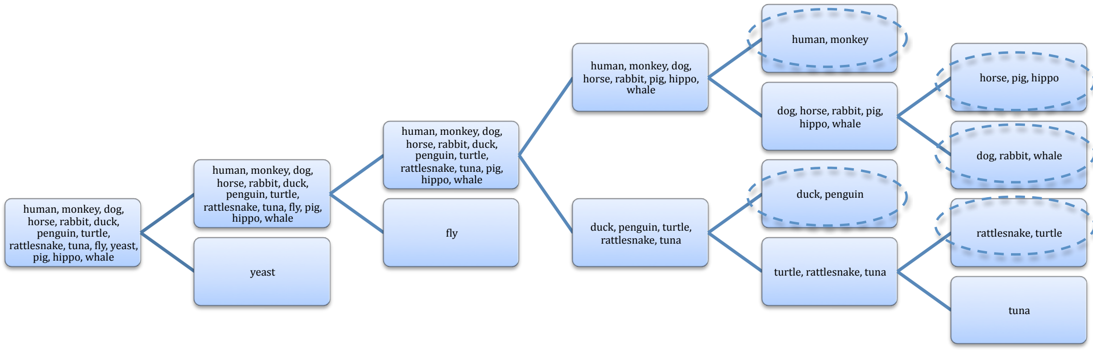
Model 2 Table 5 Diagram Answer Key for Instructors



Notes for Instructors:

- Supported: external structures
- Refuted:
  - Locomotion (none)
  - Habitat
    - spider plant (tropical), corn (field), & Elodea (aquatic)

Model 2 Table 6 Diagram Answer Key for Instructors



Model 3 Part A Diagram Answer Key for Instructors

Manager

- Ensures that members
  - are fulfilling their roles
  - tasks are being accomplished on time

- Instructor will respond to questions from the manager only.

Recorder

- Recorder ensures that everyone has the same information written down and comes to the same conclusions.

- The recorder's report is turned in and graded for the group.

Spokesperson

- Presents consensual group answers to the class.
- Should be concise.

Reader/Reflector

- Reads questions and content aloud to group.

- Observes and comments on group dynamics and behavior with respect to the learning process.

- May be called upon to report to the group about how well the group is operating.

Model 2 Key Characteristics

Table 1

- Body wormlike: (see Figures 1 & 2)
    - Flattened body
    - Cylindrical body
        - Segmentation present
        - Segmentation absent
- Not wormlike:
    - Has shell
    - Does not have shell

Figure 1: body wormlike, segmentation present

Figure 2: body wormlike, segmentation absent, flattened body

Model 2: Organisms for Table 1

1. planarian
2. squid
3. snail
4. octopus
5. *C. elegans* (roundworm)
6. tapeworm
7. earthworm
8. heartworm
9. leech

Model 2 Key Characteristics

Table 2

Radial symmetry (See Figures 1)
Bilateral symmetry (See Figures 1)
    Body wormlike: (see Figures 2 & 3)
        Flattened body
        Cylindrical body
            Segmentation present
            Segmentation absent
    Not wormlike:
        Has shell
        Does not have shell

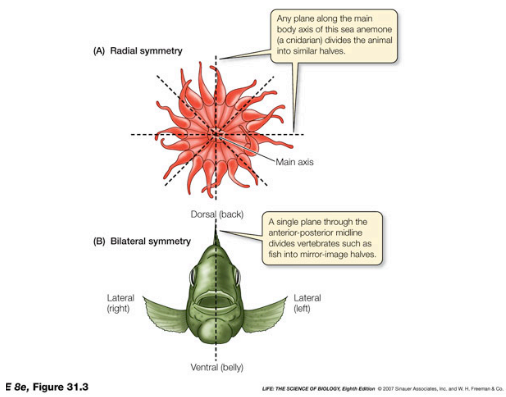


Figure 1

Figure 2: body wormlike, segmentation present

Figure 3: body wormlike, segmentation absent, flattened body

Model 2: Organisms for Table 2

1. jellyfish
2. planarian
3. squid
4. snail
5. octopus
6. *C. elegans* (roundworm)
7. tapeworm
8. earthworm
9. heartworm
10. leech
11. brittle star
12. sea urchin

Model 2 Key Characteristics

Table 3

Skeleton type (exoskeleton vs endoskeleton) (See Figures 1 & 2)
- Has an exoskeleton
  - Number of legs
    - Five or more pairs
    - Fewer than five pairs
- Has an endoskeleton
  - Naked, scaly skin
  - Skin covered in hair or feathers
    - Hair present and mammary glands
    - Feathers and wings present

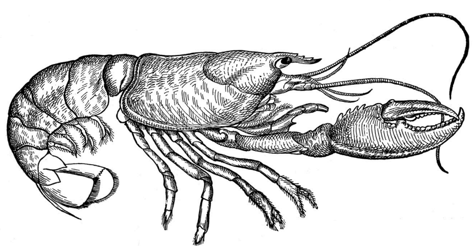


Figure 1: Exoskeleton

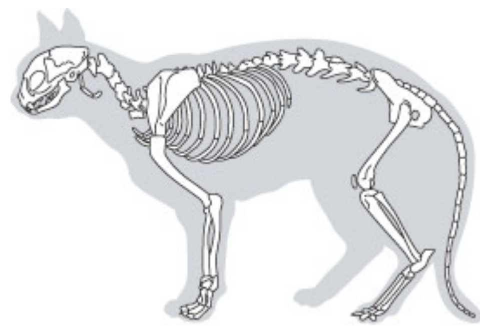


Figure 2: Endoskeleton

Model 2: Organisms for Table 3

1. tarantula
2. tick
3. honeybee
4. praying mantis
5. bat
6. cedar waxwing
7. owl
8. alligator
9. grey squirrel

Model 2 Key Characteristics

Table 4

Skeleton type (exoskeleton vs endoskeleton) (See Figures 1& 2)
- Has an exoskeleton
- Has an endoskeleton
  - Appendages adapted as fins
  - Fins absent
    - moist/slimy skin, no claws
    - dry, scaly skin, claws IF it has appendages

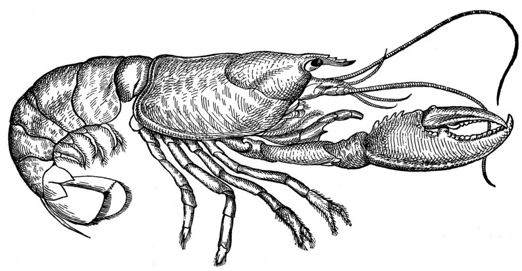


Figure 1: Exoskeleton

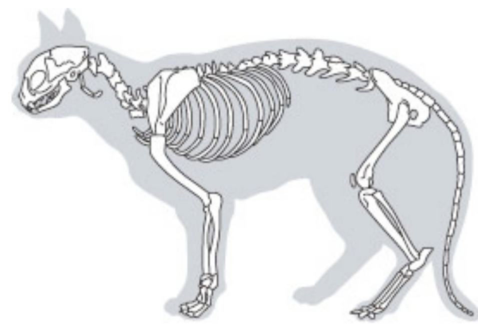


Figure 2: Endoskeleton

Model 2: Organisms for Table 4

1. crayfish
2. water beetle
3. fish
4. soft shell turtle
5. snapping turtle
6. alligator
7. salamander
8. African clawed frog
9. water moccasin

Model 2 Key Characteristics

Tables 5 & 6

- Chlorophyll (green) present
    - More than 5 inches tall
        - Needle leaved (see Figure 1)
        - Broad leaved (see Figure 2)
            - Parallel venation (see Figure 3)
            - Net venation (see Figure 3)
    - Less than 5 inches tall
- Chlorophyll (green) absent
    - Mass of filamentous cells (see Figure 4)
    - Conspicuous fruiting bodies such as top of mushroom or bracket fungi

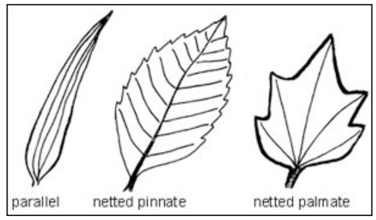


Figure 3: Different types of broad leaf venation


Figure 1: Needle leaved

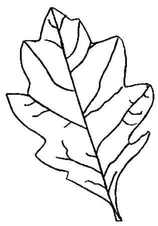


Figure 2: Broad leaved


Figure 4: Mass of filamentous cells

Model 2: Organisms for Table 5

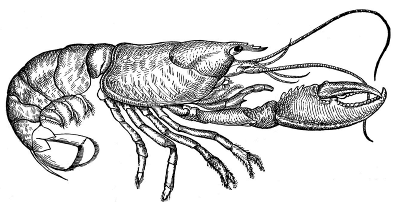
1. *buttercup*
2. oak tree
3. corn
4. button mushroom
5. orchid
6. bracket fungus
7. *Rhyzopus*
8. moss
9. hemlock
10. blue spruce
11. Elodea

Model 2: Organisms for Table 6

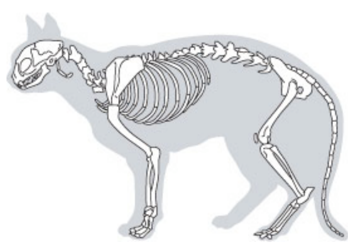
1. button mushroom
2. bracket fungus
3. *Rhyzopus*
4. white pine
5. blue spruce
6. spider plant
7. corn
8. moss
9. *Geranium*
10. oak tree
11. Elodea

Key Characteristics for Model 3: Part A

- Notochord not present
- Notochord present
    - Exoskeleton
    - Endoskeleton
        - Mammary glands
            - Opposable Thumbs
            - No opposable thumbs
                - Hooves
                - No Hooves
        - No mammary glands
            - Feathers Present
            - No Feathers
                - Appendages adapted as fins
                - Fins absent

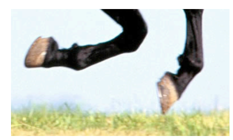


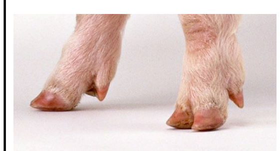
Exoskeleton



Endoskeleton

Examples of Hooves





Model 3 Organisms

Model 3: Number of Differences in Cytochrome C Sequences (Edited for Educational Purposes)

	Human	Monkey	Dog	Horse	Pig	Hippo	Whale	Rabbit	Duck	Penguin	Turtle	Rattlesnake	Tuna	Fly	Yeast
Human	0														
Monkey	1	0													
Dog	13	12	0												
Horse	17	16	10	0											
Pig	13	12	4	5	0										
Hippo	15	17	12	5	4	0									
Whale	14	18	13	6	4	2	0								
Rabbit	12	11	6	11	6	12	13	0							
Duck	17	16	12	16	13	17	18	10	0						
Penguin	18	17	14	17	13	17	16	11	3	0					
Turtle	19	18	13	16	13	18	17	11	7	8	0				
Rattlesnake	20	21	30	32	30	33	35	25	24	28	30	0			
Tuna	31	32	29	27	25	26	27	26	26	27	27	38	0		
Fly	33	32	24	24	26	25	23	23	25	28	30	40	34	0	
Yeast	63	62	64	64	64	65	66	62	61	62	65	61	72	59	0

Appendix B: Traditional Classification Activity

- Traditional Classification Activity: Classification of Organisms
- Lesson Plan for Classification of Organisms
- Abbreviated List of Organisms for POGIL Lab Day 2

Classification of Organisms 6

Objectives:

Students will be able to:
1. Develop an awareness of the diversity of life on earth.
2. List key characteristics of animal and plant phyla and classes.
3. List key characteristics of fungi phyla.
4. Explain how the current scientific classification system of organisms is organized and list the taxonomic categories in sequence.
5. Classify organisms into the appropriate kingdom, phylum, and class using observable physical characteristics.
6. Define the term "dichotomous key" and be able use one to identify unknown organisms.
7. Write a scientific name in the proper format and list the taxonomic categories used in a scientific name.
8. Classify humans into all taxonomic categories from kingdom to species and list the key characteristics of each group.

Introduction

At some time in your college career you will have to write a research paper for a class assignment. Now, imagine that you never have used the college library for a research project before. Naturally, you would go to the information desk at the library and request assistance in locating information about the subject you selected for your paper. However, to your surprise (and dismay), the librarian responds by saying, "Oh we don't really have a filing system. We just put books where there's an open space on the shelf." In a library with perhaps a million books, journals, and government publications, you could spend your entire college career writing that one term paper. In the same way that you need a library with an organized classification and filing system, biologists need a biological classification system for the estimated 5-30 million different organisms on our planet.

All organisms that have been classified are divided into a number of taxonomic categories. These categories start with a very general group and narrow into more specific groups. In this lab we will use a classification system with seven categories. From most general to most specific; these are kingdom, phylum (plural-phyla), class, order, family, genus (plural-genera), and species (both singular and plural). The classification system that is used by biologists is based on characteristics of structure, mode of development and other distinguishing features of the organisms. The classification of organisms helps scientists identify the organisms and also expresses relationships among various organisms.

Activity 1 illustrates how the classification system shows relationships among organisms. There is a list of several geographic areas, and you will place them in categories starting with the most general and ending with the most specific. The areas listed include continents, countries, states, counties, cities and street addresses. While a continent is a very broad category, a street address is specific; this geographic system is analogous to the system used by biologists to classify organisms.

Scientific Naming

All organisms are given scientific names which list the genus and species names of the organisms. The genus name is listed first and is capitalized. The species name is listed second and is not capitalized. The names are either italicized or underlined. For example, humans belong to the genus, Homo, and the species, sapiens. The scientific name is therefore *Homo sapiens* or Homo sapiens. The classical definition of a **species** is a group of individuals that can breed and produce fertile offspring.

Pre-Lab Activity:
Create your own mnemonic device to help you remember the order of the taxonomic catergories in the classification system (see Activity 1 for the list of taxonomic categories).

K

P

C

O

F

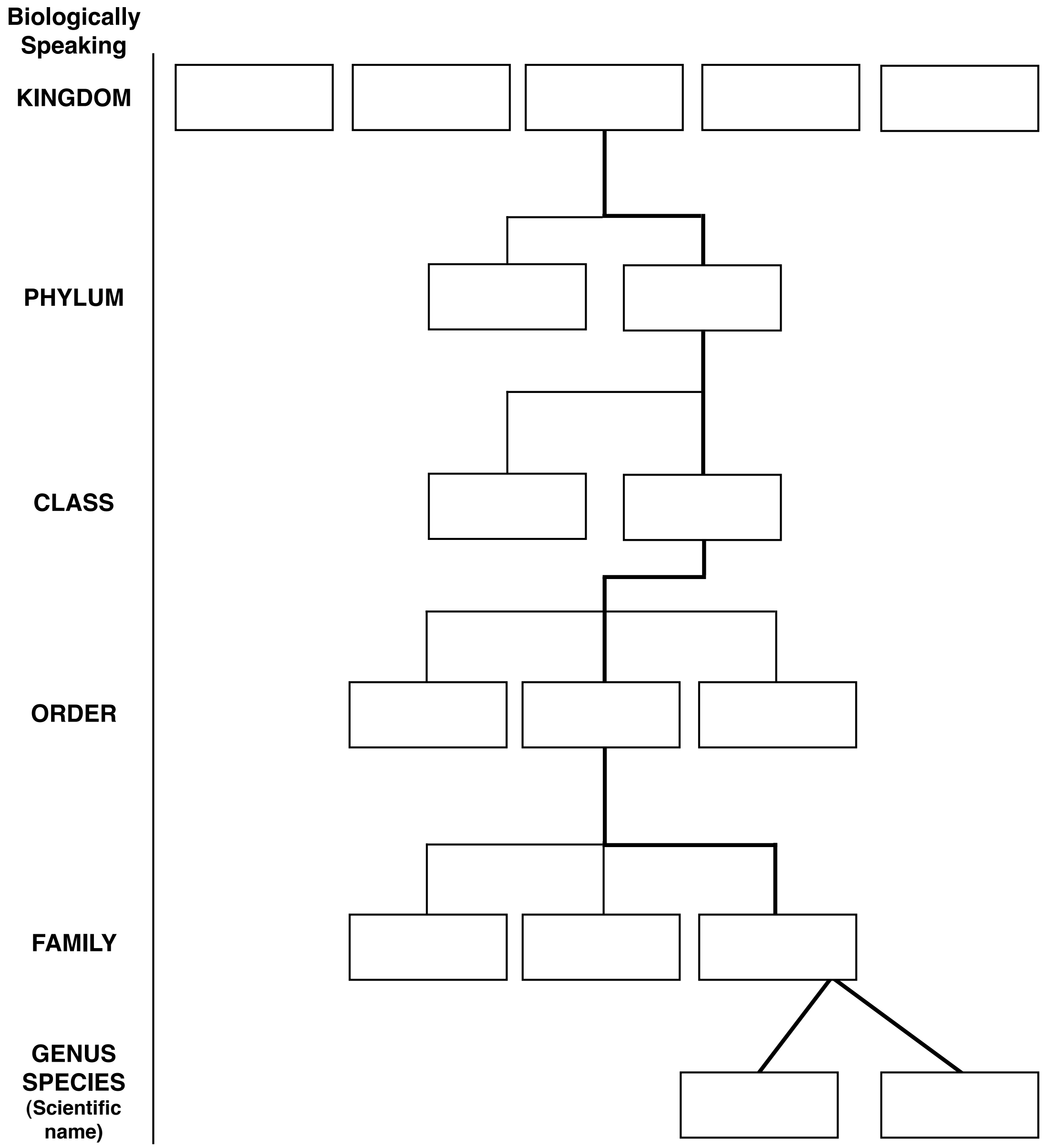
G

S

Activity 1: Taxonomic Categories in the Classification System

Place each of the 17 places listed below into its proper level of classification. Be sure each square touching the bold line contains a geographic area that can fall within the square above it. For example, United States should be in the box connected to North America with the bold line.

- United States
- Garden City (town)
- Minnesota
- Blue Earth (county)
- Australia
- Mankato (town)
- 1500 Warren St.
- Africa
- North America
- 515 N 5th St.
- Asia
- Canada
- Wisconsin
- Good Thunder (town)
- Hennepin (county)
- Europe
- Nicollet (county)



Activity 2: Classification of Organisms

There are 26 stations set up with different organisms. The stations will include organisms from the plant, animal and fungi kingdoms. Some stations may have more than one organism. If so, these organisms will belong to the same phylum or class and will have the same key characteristics. **Key characteristics** are characteristics that distinguish one group of organisms from another. For example, the phylum Anthophyta has the key characteristic of being a flowering plant. This characteristic separates it from the phylum Pinophyta which has cones instead of flowers.

1. Before classifying the organisms, define and sketch a picture of the following vocabulary terms with your class.

   Radial Symmetry -

   Bilateral Symmetry -

   Exoskeleton -

   Endoskeleton -

   Parallel Veined -

   Net Veined -

   Mycelium -

2. For each station follow the directions below, filling in your lab manual as you go (blank pages with station numbers AND Characteristics Worksheets).

   a. Observe and record the key characteristics of each organism or group of organisms at the station. If you have a station with multiple organisms you need to look for the common key characteristics of all the organisms. For example, if you have a station with an ant, a spider, and a hermit crab, and you need to find out which phylum they belong to you should look for characteristics that they have in common. All of these organisms possess the same key characteristics of having bilateral symmetry, bodies that are not worm like, paired jointed appendages, and an exoskeleton, which puts them into the phylum Arthropoda.

   b. Depending on what the card at the station says, place the organisms into the appropriate kingdom and phylum OR kingdom, phylum, and class using the dichotomous key. A **dichotomous key** is a series of two choices of opposite characteristics used to identify organisms.

   c. On the Characteristics Worksheets, find the class or phylum you just keyed. Write the key characteristics of this group of organisms in the appropriate box on the worksheet. Be brief but thorough because this will serve as your study guide.

   d. If the organism has an information card, note what the organism eats in your lab manual next to the classification information.

Station #1: ______________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #2: ______________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #3: ______________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #4: _____ ___________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #5: __________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #6: ____________________________ kingdom ______________________

phylum: ______________________

class: ______________________

Station #7: ____________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #8: ______________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #9: ____________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #10: _____ ____________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #11: _____ ____________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #12: ____________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #13: ______________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #14: _____________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #15: ____________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #16: ________________________________ kingdom: ______________________

phylum: ______________________

class: ______________________

Station #17: ______________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #18: ________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #19: _____ __________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #20: _____ __________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #21: _________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #22: ____________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #23: ___________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #24: _________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #25: _____________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #26: ______________________ kingdom: ______________
phylum: ______________
class: ______________

Station #27: ______________________ kingdom: ______________
phylum: ______________
class: ______________

Station #28: ______________________ kingdom: ______________
phylum: ______________
class: ______________

Station #29: ______________________ kingdom: ______________
phylum: ______________
class: ______________

Station #30: ______________________ kingdom: ______________
phylum: ______________
class: ______________

Station #31: ______________________ kingdom: ______________
phylum: ______________
class: ______________

Station #32: ______________________ kingdom: ______________
phylum: ______________
class: ______________

Station #33: ______________________ kingdom: ______________
phylum: ______________
class: ______________

Station #34: ______________________ kingdom: ______________
phylum: ______________
class: ______________

Station #35: ______________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #36: ______________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #37: ______________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #38: ______________________________ kingdom: ____________________

phylum: ____________________

class: ____________________

Station #39: ______________________________ kingdom: ____________________

phylum: ____________________

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Station #40: ______________________________ kingdom: ____________________

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Station #41: ______________________________ kingdom: ____________________

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Station #42: ______________________________ kingdom: ____________________

phylum: ____________________

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phylum: ____________________

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Station #44: ______________________ kingdom: ______________
phylum: ______________
class: ______________

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phylum: ______________
class: ______________

Station #46: ______________________ kingdom: ______________
phylum: ______________
class: ______________

Station #47: ______________________ kingdom: ______________
phylum: ______________
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Station #48: ______________________ kingdom: ______________
phylum: ______________
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phylum: ______________
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Station #50: ______________________ kingdom: ______________
phylum: ______________
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Station #51: ______________________ kingdom: ______________
phylum: ______________
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Station #52: ______________________ kingdom: ______________
phylum: ______________
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Station #53: ______________________________ kingdom: ______________________
phylum: ______________________
class: ______________________

Station #54: ______________________________ kingdom: ______________________
phylum: ______________________
class: ______________________

Station #55: ______________________________ kingdom: ______________________
phylum: ______________________
class: ______________________

Station #56: ______________________________ kingdom: ______________________
phylum: ______________________
class: ______________________

Station #57: ______________________________ kingdom: ______________________
phylum: ______________________
class: ______________________

Station #58: ______________________________ kingdom: ______________________
phylum: ______________________
class: ______________________

Station #59: ______________________________ kingdom: ______________________
phylum: ______________________
class: ______________________

Station #60: ______________________________ kingdom: ______________________
phylum: ______________________
class: ______________________

Key to the Kingdom Animalia

1a. Radial symmetry......2
1b. Bilateral symmetry......3

2a Body soft with tentacles ...... Phylum Cnidaria
2b. Hard body with spines over entire body ...... Phylum Echinodermata

3a. Body wormlike, skeleton absent......4
3b. Body not wormlike 6

4a. Flattened body...... Phylum Platyhelminthes
4b. Cylindrical body 5

5a. Segmentation present ......Phylum Annelida
5b. No segmentation ......Phylum Nematoda

6a. Soft body, with hard outer shell and one muscular foot **OR** tentacles with soft body
Phylum Mollusca......7
6b. Skeleton is present and paired, jointed appendages, if animal has limbs 9

7a. Shell reduced, arms or tentacles with suckers ...... Class Cephalopoda
7b. Hard distinct shell, no arms 8

8a. One large shell, tentacles on the head, gills or lungs ......Class Gastropoda
8b. Shell in two parts, the shell has two valves ...... Class Bivalvia

9a. Has an exoskeleton (outer skeleton)
Phylum Arthropoda 10
9b. Has an endoskeleton (inner skeleton) with a spinal cord
Phylum Chordata......12

10a. Five or more pairs of legs, two pairs of antennae...... Class Crustacea
10b. Fewer than five pairs of legs......11

11a. Three pairs of legs, one pair of antennae, can have wings ......Class Insecta
11b. Four pairs of legs, no antennae ......Class Arachnida

12a. Appendages adapted as fins, many have scales as part of their epidermis......Class Osteichthyes
12b. Fins absent 13

13a. Naked skin......14
13b. Skin covered with hair or feathers 15

14a. Moist, slimy skin, usually no claws ......Class Amphibia
14b. Dry, scaly skin, claws present if appendages are present......Class Reptilia

15a. Feathers and wings present ......Class Aves
15b. Hair present, mammary glands present ......Class Mammalia

Key to the Kingdoms Fungi and Plantae

1a. Chlorophyll present (Kingdom Plantae) 2
1b. Chlorophyll absent (Kingdom Fungi) 6

2a. Small plants (less than 5 inches tall), no roots and stems (non-vascular) .... Phylum Bryophyta
2b. Large plants (more than 5 inches tall), true roots and stems (vascular) 3

3a. Compound leaves, stem underground, spores under leaf .... Phylum Pteridophyta
3b. Stem above ground, seeds produced at maturity 4

4a. Leaves are needle or scalelike, cones at maturity .... Phylum Pinophyta
4b. Leaves usually broad, flowers present at maturity (Phylum Anthophyta) 5

5a. Parallel-veined leaves, flower parts in 3's .... Class Monocotyledonae (Monocots)
5b. Net-veined leaves, flower parts in 4's or 5's .... Class Dicotyledonae (Dicots)

6a. Visible whitish or greyish thread-like mycelium (mass of filamentous cells) ... Phylum Zygomycota
6b. Usually non-visible mycelium (in soil or tree) with conspicuous fruiting bodies in the form of mushroom puffballs and/or bracket fungi .... Phylum Basidiomycota

Protists / Plants / Fungi Characteristics Worksheets

Examine the organisms keyed out in lab. List the key characteristics seen within each phylum/class.

Phylum Euglenophyta (Protist)

____
____
____
____
____

Phylum Chlorophyta (Protist)

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____
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____

Phylum Rhizopoda (Protist)

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Phylum Ciliophora (Protist)

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Phylum Bryophyta (Plant)

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Phylum Pteridophyta (Plant)

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Phylum Pinophyta (Plant)

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____

Phylum Anthophyta (Plant)

Class Monocotyledonae (Plant)

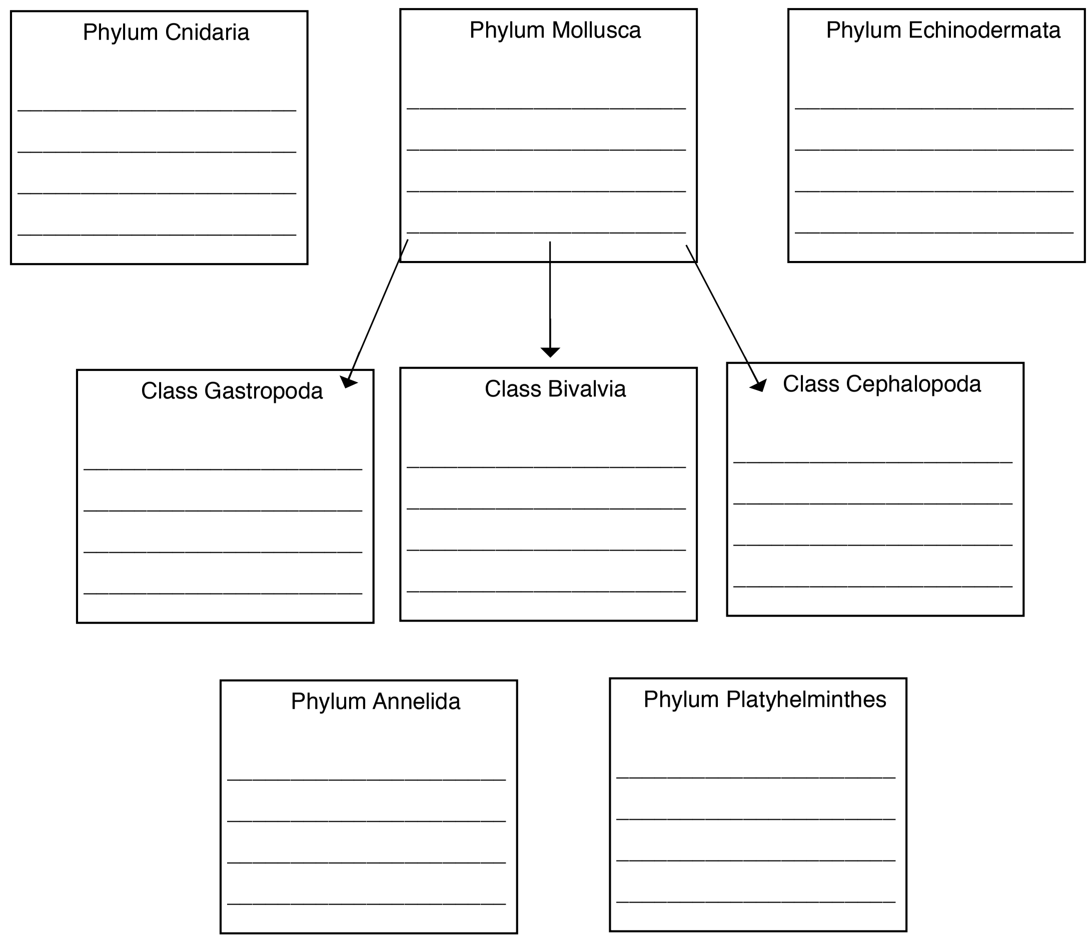
Class Dicotyledonae (Plant)

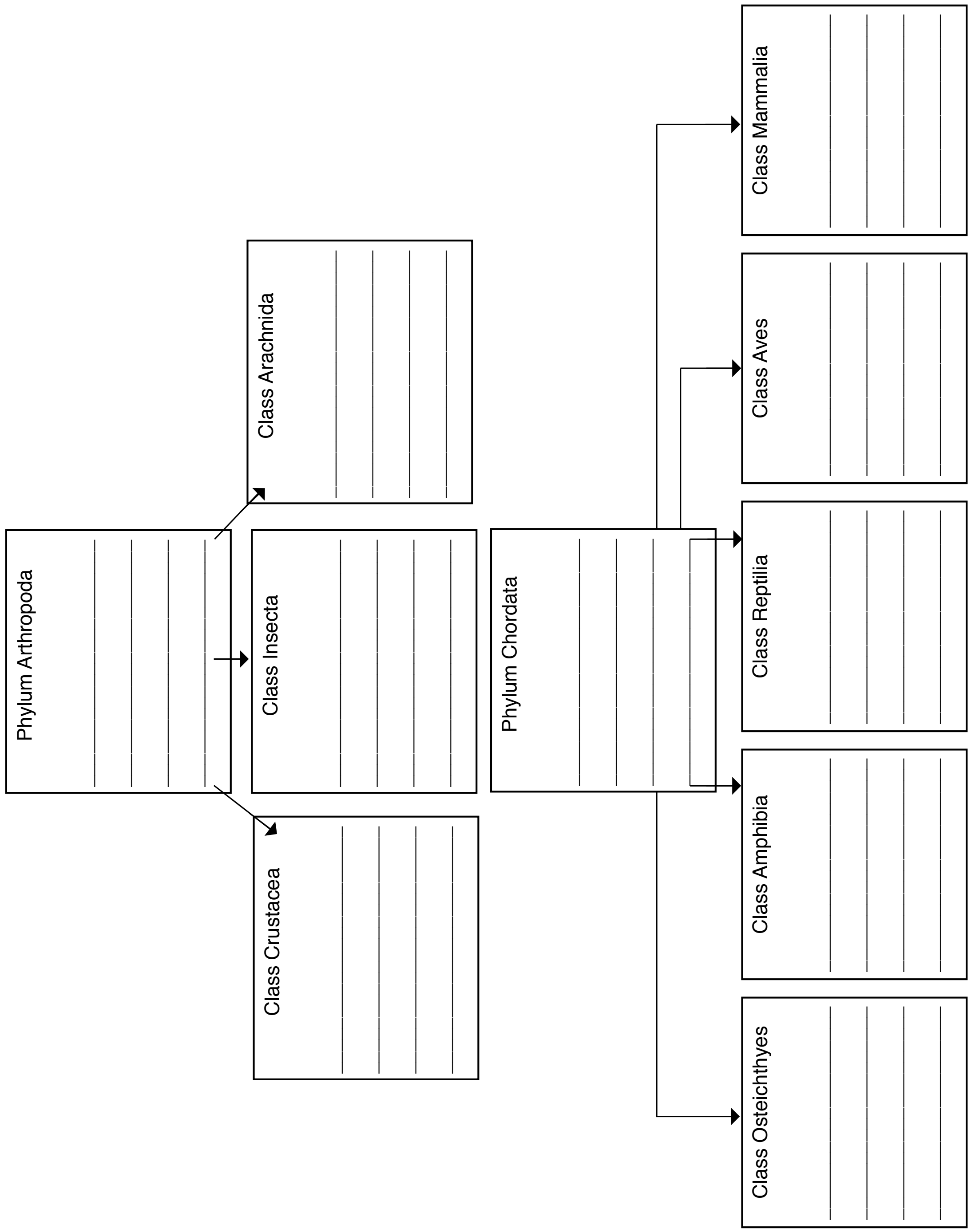
Phylum Zygomycota (Fungi)

Phylum Basidiomycota (Fungi)

Animal Characteristics Worksheets

Examine the group of organisms that you have keyed out. List the key characteristics seen within each phlum / class.




Phylum Arthropoda
Class Arachnida
Class Insecta
Class Crustacea
Phylum Chordata
Class Mammalia
Class Aves
Class Reptilia
Class Amphibia
Class Osteichthyes

Activity 3: Human Classification

Humans are classified as follows. Use your text to outline the characteristics for each group.

			CHARACTERISTICS
1.	Kingdom	Animalia	
2.	Phylum	Chordata	
3.	Subphylum	Vertebrata	
4.	Class	Mammalia	
5.	Order	Primates	
6.	Family	Hominidae	limb anatomy lends itself to standing and walking upright on two legs

7. What is the scientific name (genus and species) of the human organism?

_______________________________ _______________________________

Biology 100
Laboratory: Classification I & II

Websites:
http://animaldiversity.ummz.umich.edu/site/index.html

In advance:

-Check availability of specimens and order new if necessary.
-Arrange with Brent Pearson for the animals you want to use and for him to make classroom visits to show certain animals to students (set up with him a week or two in advance). He'll take larger animals out of cases so students can get a close look at them.
-Arrange with Margret Durkee to have 2-4 petri dishes of Rhizopus started (2 wks ahead at room temp, 4 weeks ahead in frig). Need to be sealed with parafilm to prevent spores from escaping dish.
-Start bread mold (2 wks ahead); collect moss sample (north & east sides of buildings/walls; across street south end Trafton and midway along wall of Taylor Center ~ halfway between north doorways; place on bed of pea rock, water with distilled water, cover to prevent desiccation)

Materials:
Representatives of each of the following groups:

Bryophyta
Pterophyta
Pinophyta
Anthophyta
Anthophyta -- Monocotyledonae
Anthophyta -- Dicotyledonae
Zygomycota
Basidiomycota
Cnidaria
Echinodermata
Mollusca
Mollusca -- Gastropoda
Mollusca -- Bivalvia
Mollusca -- Cephalopoda
Annelida
Platyhelminthes
Arthropoda
Arthropoda -- Crustacea
Arthropoda -- Insecta
Arthropoda -- Arachnida
Chordata
Chordata -- Osteichthyes
Chordata -- Amphibia
Chordata -- Reptilia
Chordata -- Aves
Chordata – Mammalia

Handouts/Supplies:

- Vocab Powerpoint
- Phylogentic Tree:Paper/Pencils
- Room diagram (Organism Map)

Safety/Health:

- Treat mounts, organisms w/ care & respect
- Wash hands after handling organism

Objectives

1. Develop awareness of the diversity of life on earth.
2. List key characteristics of animal and plant phyla and classes.
3. List key characteristics of fungi phyla.
4. Explain how the current scientific classification system for organisms is organized and list the taxonomic categories in sequence.
5. Classify organisms into the appropriate kingdom, phylum, and class using observable physical characteristics.
6. Define the term "dichotomous key" and be able to use one to identify unknown organisms.
7. Write a scientific name in the proper format and list the taxonomic categories used in a scientific name.
8. Classify humans into all taxonomic categories from kingdom to species and list the key characteristics of each group.

Pre-Laboratory Reading: LM p. 53-55
Pre-lab activity: Taxonomic Categories (KPCOFGS) p.54 This is a good 5 point assignment.
Lab Activities:

Schedule for Brent Pearson/General Plan:

Depending which week Brent will be in your class aim to follow the guidelines below to keep you class on schedule:

Week 1 with Brent: Activities 1 & as much of 2 as possible then
Week 2 without Brent: Complete activity 2 and do 4

Week 1 without Brent: Activities 1 & 2 (should be close to complete) then
Week 2 with Brent: Complete 2 quickly and do 4

Classification – <u>WEEK 1</u>:

Intro & Activity 1:

- Close prep room door, no one from the other lab may enter during this time
- Quiz # 4 (10 mins)
- During quiz walk around the room to check that pre-lab activity was completed. You choose whether or not to count it for 5 points.
- Introduce Lab: scientific naming, *Genus species* with both underlined or italicized and genus capitalized, species lower case. (1 min.)
- Review taxonomic categories LM p. 54-55 (1 min.)

Activity 2: LM p. 56-69

- Go over the vocabulary on p. 56. PowerPoint available if you deem necessary.
- Do an example of how to key an organism using the keys on LM p. 64 & 65.
- **Tell students for #48 to look the adult specimen to key it.**
- **Also tell them for #33 to use Protista key p.35.**
- **Explain that our keys are simplistic because they work with our materials in the lab. This is okay in biology when a key is meant to help us identify organisms we encounter.**
- **Explain what a key characteristic is with an example (see LM p. 56, top).**

Open the prep room door when it is okay for students in the other lab to come in

- Students key out all organisms using keys on LM p.64 & 65 to fill out LM p. 57-63, "floating" as necessary to the other lab and to hallway.
  - Be sure students complete all stations and key out all organisms. They cannot divide up the organisms, each doing 10 and then swap answers. They can work as pairs going through and keying out each. Orient students by giving the locations of all station numbers. Sometimes a lab room is not in chronological order, and the wolf is in the hallway.
- Once they've classified all organisms, students need to complete Characteristics Worksheets for plants, and fungi (p. 66 and 67) (NO PROTISTS)., and animals (pp. 68 and 69)
- If students do not finish p. 66-69, have them do it for homework or next week depending on your scheduled Brent time (see recommended schedule above). This will help them during next week's lab.

Activity 2+: (NOT IN LAB MANUAL)

If during either week you have additional time after completing mandatory activities please perform this activity.

- Give students an "Organism Map".
- Stations will be grouped in fours and will be at tables in both rooms, around the rooms or out in hallway displays. In each group of 4, either 0, 1 or 2 organisms will not belong with the others.
- Students are to examine each group and determine which organisms don't belong. They are to CIRCLE numbers of organisms which don't belong and provide a BRIEF (1-3 words) reasoning for selection.

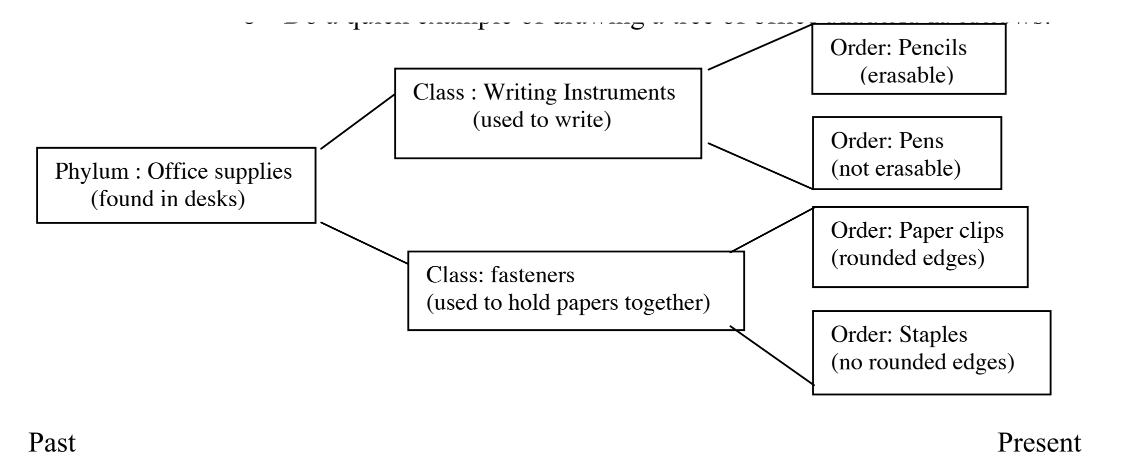
Activity 3: Human classification (LM p. 70)

-Have students go online (http://tolweb.org/tree/) or use their textbook to complete this exercise as HOMEWORK or if time permits, ask them to complete in class.

Classification – WEEK 2

Intro/Plan: (15 minutes)

- Describe Phylogenetic Tree
  - Use colored pencils, regular pencils, large sheets of paper and rulers to draw an evolutionary tree of the plants, fungi and animal phyla and classes found in the lab. Students use the keys in the lab manual and their characteristics worksheets to help them. Do not put #48 Brittle Star on the tree.
  - Explain how to draw a phylogenetic tree. Trees have time going across the bottom from left (long time ago) to right (more recent time). Each time a tree branches, each branch should be labeled with the class/phylum name and its key characteristic(s). Student should be flexible and start with the left or right side of the tree. They may need to erase.
  - Do a quick example of drawing a tree of office supplies as follows:



Activity 4: Plant/Fungi/Animal Phylogenetic Tree (40-50 minutes) (NOT IN LAB MANUAL)

- Students work on their trees.
- Collect the trees at the end of class. There are different correct variations of the trees. One has been provided as an answer key for you.

Key to Organisms (Activity 2)

1. geranium
   Plant, Anthophyta, Dicot
2. pine
   Plant, Pinophyta
3. moss
   Plant, Bryophyta
4. spider plant
   Plant, Anthophyta, Monocot
5. tarantula
   Animal, Arthropoda, Arachnida
6. Giant Water Scavenger Beetle
   Animal, Arthropoda, Insecta
7. pillbug
   Animal, Arthropoda, Crustacea
8. jellyfish
   Animal, Cnidaria
9. honeybee
   Animal, Arthropoda, Insecta
10. crickets
    Animal, Arthropoda, Insecta
11. snapping turtle
    Animal, Chordata, Reptilia
12. Super mealworm & beetle
    Animal, Arthropoda, Insecta
13. octopus
    Animal, Mollusca, Cephalopoda
14. crayfish
    Animal, Arthropoda, Crustacea
15. black widow spider
    Animal, Arthropoda, Arachnida
16. Skunk
    Animal, Chordata, Mammalia
17. bat
    Animal, Chordata, Mammalia
18. catbird
    Animal, Chordata, Aves
19. cedar waxwing
    Animal, Chordata, Aves
20. cockroach
    Animal, Arthropoda, Insecta
21. black bread mold & Rhyzopus
    Fungi, Zygomycota
22. button mushrooms
    Fungi, Basidiomycota
23. bracket fungus
    Fungi, Basidiomycota
24. Fern
    Plant, Pterophyta
25. squid
    Animal, Mollusca, Cephalopoda
26. praying mantis
    Animal, Arthropoda, Insecta
27. snail
    Animal, Mollusca, Gastropoda
28. little bluestem
    Plant, Anthophyta, Monocot
29. corn
    Plant, Anthophyta, Monocot
30. cattails
    Plant, Anthophyta, Monocot
31. snake plant
    Plant, Anthophyta, Monocot
32. worm
    Animal, Annelida
33. *Euglena*
    Protista, Euglenophyta
34. leech
    Animal, Annelida
35. fish
    Animal, Chordata, Osteichthyes
36. tick
    Animal, Arthropoda, Arachnida
37. scorpion
    Animal, Arthropoda, Arachnida
38. spruce
    Plant, Pinophyta
39. oak
    Plant, Anthophyta, Dicot
40. cactus
    Plant, Anthophyta, Dicot
41. owl
    Animalia, Chordata, Aves
42. mouse
    Animal, Chordata, Mammalia
43. armadillo
    Animal, Chordata, Mammalia
44. iguana
    Animalia, Chordata, Reptilia
45. coastal carpet python
    Animalia, Chordata, Reptilia
46. African Clawed Frog
    Animalia, Chordata, Amphibia
47. hermit crab
    Animal, Arthropoda, Crustacea
48. brittle star
    Animal, Echinodermata
49. clownfish
    Animalia, Chordata, Osteichthyes
50. Yellow Damsel
    Animal, Chordata, Osteichthyes
51. Mudpuppy
    Animal, Chordata, Amphibia
52. Tiger Salamander
    Animal, Chordata, Amphibia
53. Blue Tongued Skink
    Animal, Chordata, Reptilia
54. Bearded Dragon
    Animal, Chordata, Reptilia
55. Softshell turtle
    Animal, Chordata, Reptilia
56. Rabbit
    Animal, Chordata, Mammalia
57. Leopard bellied toad
    Animal, Chordata, Amphibia
58. alligator
    Animalia, Chordata, Reptilia
59. grey wolf
    Animal, Chordata, Mammalia
60. (mirror)
    Animal, Chordata, Mammalia

Key to Organisms (Activity 2+)

Group A:
1. geranium (greenhouse)
2. pine (clip from outside; cone also)
3. moss (shelf in 256)
4. spider plant (greenhouse)

Group B:
5. tarantula (live; Brent)
6. giant water scavenger beetle (plastimount, special)
7. pillbug (live; Brent)
8. jellyfish (plastimount)

Group C:
9. honeybee (plastimount)
10. crickets (live; Brent)
11. snapping turtle (large tank)
12. super mealworm & beetle (live)

Group D:
13. octopus (plastimount)
14. crayfish (live; Brent)
15. black widow spider (plastimount)
16. Skunk

Group E:
17. bat (stuffed; prep room)
18. catbird (S151)
19. cedar waxwing (S151)
20. cockroach (live; Brent)

Group F:
21. black bread mold & Rhizopus (prep room)
22. button mushrooms (grocery store)
23. bracket fungus (prep room)
24. fern (greenhouse; distilled!)

Group G:
25. squid (plastimount)
26. praying mantis (live; Brent)
27. snails (live; Brent)
28. little bluestem (prep room)

Group H:
29. corn (prep room)
30. cattails (prep room)
31. snake plant (greenhouse)
32. worm (live, fridge?)

Group I:
33. Euglena (need scope; TAs setup each lab)
34. Leech (plastimount)
35. fish (tank)
36. tick (plastimount)

Group J:
37. scorpion (plastimount)
38. spruce (clip from outside w/ cone)
39. oak (outside or mounted, w/ acrons)
40. cactus (greenhouse; in bloom?)

Group K:
41. owl (S151)
42. mouse (in tank on table)
43. armadillo
44. iguana (in large case 266)

Group L:
45. Coastal carpet python (case 266)
46. African clawed frog (tank)
47. hermit crab
48. brittle star (plasitmount)

Group M:
49. clownfish
50. yellow damsel
51. Mudpuppy (tank)
52. Tiger Salamander (on table)

Group N (tropical tank 266):
53. Blue tongued Skink (tank)
54. bearded dragon (corner case)
55. softshell turtle (large tank)
56. Rabbit

Group P:
57. Leopard bellied toad (tank 262)
58. alligator (lrg tank 262)
59. grey wolf (large case)
60. human (mirror)

Bolded organisms don't belong.

Abbreviated List of Organisms for POGIL Lab Day 2

Organism	Kingdom	Characteristics Present	Phylum	Characteristics Present	Class	Characteristics Present
geranium	Plant	chloro. present	Anthophyta	lrg, roots/stems, stem abv grnd, seeds	Dicot	net-veined, flw 4's or 5's
pine	Plant	chloro. present	Pinophyta	lrg, roots/stems, stem abv grnd, seeds, lvs needle/ scale, cones		
spider plant	Plant	chloro. present	Anthophyta	lrg, roots/stems, stem abv grnd, seeds	Monocot	parallel-veined, flw 3's
moss	Plant	chloro. present	Bryophyta	sml, no roots/stems		
fern	Plant	chloro. present	Pterophyta	cmpd lvs, stem undergrd, spores		
Rhyzopus	Fungi	Chloro. absent	Zygomycota	mycelium		
button mushrooms	Fungi	Chloro. absent	Basidiomycota	non-visible mycelium, fruiting bodies		
jellyfish	Animal	radial	Cnidaria	body soft, tenticles		
worm	Animal	bilateral	Annelida	wormlike, skeleton abs, cylindrical, segmentation		
octopus	Animal	bilateral	Mollusca	body not wormlike, soft w tentacles	Cephalopoda	shell reduced, arms w suckers
snail	Animal	bilateral	Mollusca	body not wormlike, soft w tentacles	Gastropoda	hard shell, no arms, one shell, tentacles on head
tarantula	Animal	bilateral	Arthropoda	body not wormlike, skeleton, paired jointed append., (if limbs)	Arachnida	
mealworm/ Beetle	Animal	bilateral	Arthropoda	body not wormlike, skeleton, paired jointed append., (if limbs), exoskeleton	Insecta	3 pair legs, 1 pair antennae, can have wings
cockroach	Animal	bilateral	Arthropoda	body not wormlike, skeleton, paired jointed append., (if limbs), exoskeleton	Insecta	3 pair legs, 1 pair antennae, can have wings
crayfish	Animal	bilateral	Arthropoda	body not wormlike, skeleton, paired jointed append., (if limbs), exoskeleton	Crustacea	5+ pair legs, 2 antennae
iguana	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Reptilia	naked skin, dry, scales, claws w append.
coastal carpet python	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Reptilia	naked skin, dry, scales, claws w append.
soft shell turtle	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Reptilia	naked skin, dry, scales, claws w append.
African clawed frog	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Amphibia	naked skin,moist, usually no claws
mudpuppy	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Amphibia	naked skin,moist, usually no claws

Organism	Kingdom	Characteristics Present	Phylum	Characteristics Present	Class	Characteristics Present
cedar waxwing	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Aves	skin covered feathers, wings
owl	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Aves	skin covered feathers, wings
clownfish	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Osteichthyes	fins, may have scales
yellow damsel	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Osteichthyes	fins, may have scales
bat	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Mammalia	skin w hair, mammary glands
mouse	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Mammalia	skin w hair, mammary glands
human	Animal	bilateral	Chordata	body not wormlike, skeleton, paired jointed append., (if limbs), endoskeleton	Mammalia	skin w hair, mammary glands
euglena	Protista					

Appendix C: Instruments

- Pretest/Posttest
- Student Interview Questions
- Instructor Reflection Questions
- Classification Quiz

1. Do you consent to participating in the Biology 100 research study which will use your answers from this pretest the posttest, and a possible student interview?

a. Yes
b. No

2. Are you at least 18 years old?

a. Yes
b. No

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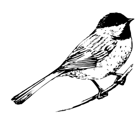
3. Considering characteristics that scientists use to classify organisms, which should be grouped together? What characteristic did you use for this grouping?
a. Bird & Ant lay eggs
b. Housefly & Ant have hard outer coverings on their bodies
c. Housefly & Bird live in the air and on plants
d. Housefly & Bird fly

Housefly	**Bird**	**Ant**
		

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4. Considering characteristics that scientists use to classify organisms, which two should be grouped together? What characteristic did you use for this grouping?

a. Owl & Penguin have feathers
b. Owl & Bat fly
c. Penguin & Bat have wings
d. Owl & Bat live in the forest

Owl	**Penguin**	**Bat**
		

5. Considering characteristics that scientists use to classify organisms, which two should be grouped together? What characteristic did you use for this grouping?

a. Dog & Lizard have four limbs
b. Lizard & Snake have a tail
c. Dog & Snake have an inner skeleton
d. Lizard & Snake have scales

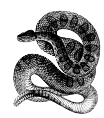
Dog	Lizard	Snake
		

Table 1. The number of differences between a comparable DNA sequence of turtles and three animal species.

Animal	Number of differences from Turtle
Turtle	0
Chicken	45
Toad	67
Large mouth bass	125

6. Considering characteristics that scientists use to classify organisms, which animal from Table 1 should be grouped with the turtle? What characteristic did you use for this grouping?

a. Turtle & Chicken DNA sequences differ the least.
b. Turtle & Toad both live on land.
c. Turtle & Large mouth bass both swim.
d. Large mouth bass & Turtle their DNA sequences differ the most.

Table 2. The number of differences between a comparable DNA sequence of selected pairs of animals.

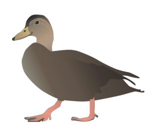
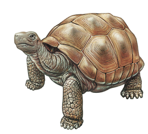
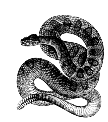
Animal Pairs	Number of Differences
Dog & Penguin	14
Dog & Turtle	13
Turtle & Penguin	8

7. Out of the pairs of organisms in Table 2, which are <u>most closely related</u>? What characteristic did you use for this?

a. Dog & Penguin DNA sequences differ the most.
b. Dog & Turtle both have 4 legs.
c. Turtle & Penguin DNA sequences differ the least.
d. Turtle & Penguin both live in the water.

Table 3. The number of differences between DNA sequences of selected pairs of animals.

Animal Pairs	# of Differences
Duck & Tortoise	10
Duck & Snake	22
Tortoise & Snake	15

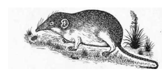
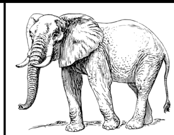
Duck	Tortoise	Snake
		

8. Based on the information above, which two organisms should be grouped together?

a. Duck & Tortoise both have inner skeletons and their DNA sequences differ the least.
b. Duck & Snake their DNA sequences differ the most.
c. Tortoise & Snake they both have scales and while their number of DNA sequences differ more than Duck & Tortoise, the sequences are still similar.
d. Tortoise & Snake live on land.

Use Table 4 to answer questions 9 & 10.

Table 4. The number of differences in the DNA sequences between the Giant Elephant Shrew and four other species.

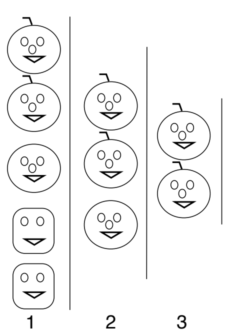
	Giant Elephant Shrew	**Common Shrew**	**Manatee**	**Elephant**	**Mouse**
Picture					
Number of differences	0	33	4	6	31

9. The Giant Elephant Shrew is a new mammal species discovered recently. Scientists named and classified this organism based on characteristics shared with the Common Shrew. Then scientists compared the DNA sequence of the Elephant Shrew along with 4 other organisms. Would you change the classification of the Giant Elephant Shrew based on this new DNA data? Why or why not?

a. No, don't change its classification. The original classification with the Common Shrew is most accurate because they look the most similar.
b. No, don't change its classification because the DNA data show it to be most closely related to the common shrew.
c. Yes, change its classification because the DNA data show that the Giant Elephant Shrew is least related to the Common Shrew.
d. Yes, change its classification because it has a trunk-like structure similar to the elephant.

10. Based on Table 4, which organism should the Giant Elephant Shrew be classified with?

a. The Common Shrew
b. The Common Shrew & Mouse
c. The Elephant & Manatee
d. The Mouse



11. As you move from column 1 to column 3 in Figure 1 what happens to the number of members in each group?

a. They increase
b. They decrease
c. They stay the same
d. None of the above

12. As you move from column 1 to column 3 in Figure 1 what happens to the number of similarities among members in a group?

a. They increase
b. They decrease
c. They stay the same
d. None of the above

13. Which 2 types of characteristics can be used to classify organisms?

a. anatomical & molecular
b. habitat & anatomical
c. locomotion & anatomical
d. locomotion & habitat

Student Interview Questions

Starting the interview:

Welcome! You are taking part in an interview that will help me measure the effectiveness of a new teaching technique being used in BIOL 100. You have marked on the pretest that you agree to participate in this interview. Please remember that you are not required to participate and can stop at any time. I will not be asking any for any personal information, your responses will be kept anonymous and will not affect your standing in BIOL 100. I am not looking for right or wrong answers. I just want to learn more about how you think about classification. Please think aloud as you answer.

Show the student the audio recorder and explain that it will be used so that I can listen closely and don't have to take notes on what was said. Once the audio is transcribed it will be destroyed.

Reminders to Interviewer:

- *list groups aloud while progressing*
- *be sure to ask why are these members of group x*

Interview questions
Getting to know the students:

What was the most interesting BIOL 100 lab so far? What did you enjoy about this lab? What did you not care for?

Questions aligned with the outcomes:

A variety of model organisms such as insects mounted in plastic, taxidermic birds and mammals, photos of organisms, and small live amphibians and reptiles in terrariums will be placed in close proximity to the student. They will be encouraged to observe these throughout the interview.

I. Student is presented with 12 different types of pasta (linguini, fettucini, lasagna, bow-tie, elbow macaroni, ridged penne, smooth penne, rigatoni, gemmelli, fusilli, cavatappi, and fusilli corti bucati)

1. How would you classify/group these?
    a. Describe what characteristics you are using.
    b. Which pasta could be placed in another group you made?
    c. Can you subdivide a group?
2. Which group or groups are broadest?
3. How are the groups similar/different to one another?
4. How many groups is X a member of? *(elbow or another type that could fit into more than one group)*

5. How is your process of grouping similar or different from the process scientists use to classify organisms?
6. How are the characteristics you've chosen similar or different from the characteristics scientist use to classify?

II. Student is presented with the models/images of a goldfish, duck, ostrich, cardinal, chipmunk, seal (photo w/ hair), beaver, ant, housefly, millipede, crab, clam, starfish

**Draw your groups as you rearrange the objects.*

1. How would you classify or group these organisms?
2. Describe the characteristics you are using while doing this.
3. Can you combine any of the groups?
4. Can you subdivide this group?
5. How are the groups related to one another?
6. How do scientists classify living organisms?
7. Do scientists change these groupings?
8. Which groups contain organisms with the most similar characteristics?
9. Are _____ & _____ or _____ & _____ more closely related? Explain your thinking.

III. Student is presented with a purposefully designed cytochrome C table.

Number of DNA Differences	
Goldfish & Duck	21
Chipmunk & Seal	8
Ostrich & Duck	6
Duck & Turtle	7

1. How would you group these organisms?
2. How related are the organisms to each other?
   a. Goldfish & Duck?
   b. Chipmunk & Seal?
   c. Ostrich & Duck?
3. Which pair is most closely related?
   c. Why?
4. How do these groups fit with the groups that you made using the photos and models?
5. Does the number of DNA differences between the duck and turtle surprise you? Why?

Instructor Reflection Questions

Experience teaching POGIL lesson

1. Provide an example of how the students were able to work effectively in their structured groups?
2. How they utilize their assigned roles?
3. Did they stop at the appropriate times and wait for further instruction? If not, please provide an example as to how you handled the situation.
4. Can you give me some examples of questions that you asked different groups while facilitating?
5. Provide an example of how you encouraged the students to rely on one another to come up with answers and ideas?
6. When being asked a question, did you only interact with the manager of each group?

Both Types of Curriculum-Immediately after class: Day 1 & 2 of classification lab

1. Read lesson plan and note changes on it.
2. What do you think is learned from this lesson? Give evidence/examples/ quotes. How well did it match the lesson outcomes?
3. How well do you think students liked this lesson? Give evidence/examples/ quotes.
4. What misconceptions did students have about biological classification during the lesson? Give evidence/examples/quotes. Did these change by the end? How? Give evidence/examples/quotes.
5. How did you assist students during the lesson?
    a. Traditional: keying, phylogenetic tree, other?
    b. POGIL: Model 1, Model 2, Model 3, keying?
6. Overall, how did you like facilitating this lesson?

Classification Quiz

The biological taxonomic categories, in order from broadest to most specific, are _____.

a. Class, species, kingdom, phylum, family, genus, order
b. Kingdom, phylum, class, order, family, genus, species✓
c. Order, genus, family, phylum, kingdom, species, class
d. Species, genus, family, order, class, phylum, kingdom

A key characteristic of the kingdom to which this organism belongs is ____. (*Item: bracket fungus)*

a. lacks roots and stems
b. lacks a nucleus
c. lacks chlorophyll✓
d. has radial symmetry

This organism is in the phylum ____. (*Item: bracket fungus)*

a. Basidiomycota✓
b. Pinophyta
c. Pteridophyta
d. Zygomycota

This organism should be identified to the class _____. *(Item: frog)*

a. Amphibia✓
b. Arachnida
c. Crustacea
d. Reptilia

This sample is from an organism in the phylum _____. *(Item: moss)*

a. Anthophyta
b. Bryophyta✓
c. Pinophyta
d. Pteridophyta

A key characteristic of the phylum to which this organism belongs is _____. *(Item: fern)*

a. Spores on underside of leaf✓
b. Obtains energy by photosynthesis
c. Produces flowers
d. Produces cones

This organism belongs to the Class _____. (*Item: crustacean)*

a. Arachnida
b. Crustacea✓
c. Insecta
d. Osteichthyes

This organism has _____ symmetry. *(Item: jellyfish)*

a. Axial
b. Bilateral
c. Parallel
d. Radial✓

Classify this organism. What is its Kingdom and Phylum? *(Item: iguana)*

a. Animalia, Chordata✓
b. Animalia, Arthropoda
c. Animalia, Echinodermata
d. Animalia, Cnidaria

Tiger, lion, and the domestic cat all belong to the same family, Felidae. The scientific name of the tiger is *Panthera tigris,* the lion is *Panthera leo,* and the domestic cat is *Felis catus.* This means that

a. the domestic cat is in the same family, but different genus than the lion.✓
b. the lion is in the same family, but different genus than the tiger.
c. the lion is the same species as the tiger.
d. all three organisms are in different kingdoms.

Organisms in the phylum represented by this organism have _____. *(Item: spider)*

a. An endoskeleton and bilateral symmetry
b. An exoskeleton and paired, jointed appendages✓
c. Three pairs of legs and a pair of antennae
d. Four pairs of legs and no antennae

This organism has a _____skeleton and belongs to the Phylum _____. *(Item: turtle)*

a. endo, Chordata✓
b. endo, Reptilia
c. exo, Chordata
d. exo, Reptilia

Which of these organisms "does not belong" to the same class? *(Items: A-cockroach, B-beetle, C-tarantula)*

a. A
b. B
c. C✓
d. They are all in the same class.

This plant has leaves with (a) _____. It belongs to the Class ____. *(Item: Geranium)*

a. Needle-like structure, Monocotyledonae
b. Netted veins, Dicotyledonae✓
c. Spores on its underside, Dicotyledonae
d. Parallel veins, Monocotyledonae

This organism belongs to the Phylum ___ and Class _____. *(Item: bat)*

a. Arthropoda, Aves
b. Chordata, Aves
c. Chordata, Mammalia✓
d. Osteichthyes, Mammalia

The fungus growing on the bread in Figure 1 is composed of whitish, thread-like mycelium. Which phylum does it belong to? *(Item: bread mold)*

a. Basidiomycota
b. Monocotyledonae
c. Zygomycota✓
d. Anthophyta

Which of the following is a correct way to write a scientific name?

a. Homo sapiens
b. *Homo sapiens*✓
c. homo sapiens
d. both a and b

What is a dichotomous key?

a. a model that uses DNA comparisons to estimate the length of time that two species have been evolving independently
b. a primary division of a kingdom, as of the animal kingdom, ranking next above a class in size
c. a series of two choices of opposite characteristics used to identify organisms✓
d. none of the above

Organisms that belong to Phylum Arthropoda have a/an _______ skeleton whereas organisms that belong to Phylum Chordata have a/an _______ skeleton.

a. exo; endo✓
b. endo; exo
c. bilateral; radial
d. radial; bilateral

Classify a dragonfly (see Figure 1). What is its Kingdom, Phylum, and Class?
(Item: dragonfly)

a. Animalia, Echinodermata, Asteroidea
b. Animalia, Mollusa, Bivalvia
c. Animalia, Arthropoda, Insecta✓
d. Animalia, Arthropoda, Arachnida

Appendix D: Consent Form

- Student Consent Form

CONSENT FORM
BIOL 100 Study

Dear Biology 100 Student,

You are invited to take part in research about a new teaching technique used in biology**.** You are a potential participant because you are a student in BIOL 100 Our Natural World. The research is being conducted by Professor Bethann Lavoie and graduate student Breann Wozniak. We ask that you read this form before agreeing to the research.

PURPOSE
The purpose of the research is to find out if a new teaching technique will help non-major biology students understand biological classification. This information will be used to inform BIOL 100 instructors and other college instructors about the usefulness and academic benefits, if any, of this new teaching technique.

PROCEDURE
If you agree, the scores from an in-class pretest and posttest the week before and after your regular classification laboratory will be used. This pre and posttest should only take 10-15 minutes of your time. The score will be used for research purposes only. In addition, you may be asked to voluntarily participate in student interviews with the researchers. In this case you will be notified individually, and may choose whether or not to participate.

RISKS AND BENEFITS
You will be asked to answer questions on your understanding of biological classification. None of the questions will be personal. The information you provide will be kept anonymous. There are minimal risks while participating in this study. These may include: anxiety and nervousness while taking the tests or during the interviews. There are no penalties if you do not participate. Your scores and interview answers will not affect your grade.

CONFIDENTIALITY
If you choose to participate in this study, your test scores and interview answers will be kept confidential. Only Dr. Lavoie and Breann Wozniak will see your responses. Your name will not be used with any of the data. The researchers will transcribe the audio recording of the interviews. The recordings and transcriptions will be kept anonymous, and will be kept on a flash drive that will be destroyed by the researchers as soon as the transcription is complete. All responses and data will be kept locked in a secure file cabinet, and only the researchers will have access to these files.

VOLUNTARY NATURE OF THE STUDY
Participation in this research is voluntary. Your decision whether or not to participate in this research will not affect your current or future relations with BIOL 100 Our Natural World, the Minnesota State University, Mankato, or the staff involved with this study. Even if you check that you agree to participation on the pretest, you are free to stop participating at any time without penalty by contacting the researchers.

CONTACT
The researchers of this study are Dr. Bethann Lavoie and Breann Wozniak. You may contact them by emailing breann.wozniak@mnsu.edu or bethann.lavoie@mnsu.edu. If you have any questions or concerns regarding the treatment of research subjects' rights, contact: MSU IRB Administration Minnesota State University, Mankato, Institutional Review Board, 115 Alumni Foundation, (507) 389-2321.

To indicate that you wish to participate in the study and are at least 18 years old, mark "yes" for the questions on the pretest asking if you consent to have your answers from the pretest and interviews used for the research study.

Thank you for considering participating.
___ I agree to the audio taping of the interview session
___ I have received a copy of this consent