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Effect of Process-Oriented Guided-Inquiry Learning (POGIL) on Preservice Elementary Teachers’ Understanding of Biological Classification

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EFFECT OF PROCESS-ORIENTED GUIDED-INQUIRY LEARNING (POGIL) ON PRESERVICE ELEMENTARY TEACHERS’ UNDERSTANDING OF BIOLOGICAL CLASSIFICATION

By
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A Thesis Submitted in Partial Fulfillment of the Requirements for Master of Arts in Teaching In Educational Studies: K-12 and Secondary Programs

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This thesis is submitted as part of the required work in the Department of Educational Studies, K-12 and Secondary Programs, KSP 610 Scholarly Writing, at Minnesota State University Mankato, and has been supervised, examined, and accepted by the professor.

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Abstract

This study examined preservice elementary teachers’ biological classification conceptions and whether process-oriented guided-inquiry learning (POGIL) or traditional pedagogies affect preservice elementary teachers’ understanding of biological classification conceptions. A literature review was completed to determine common biological classification conceptions that exist among all researched populations, what misconceptions are present regarding biological classification, and whether POGIL was an appropriate pedagogy to use in the experimental study. The findings from the literature review were used to develop a mixed-method research study. Both quantitative and qualitative data was gathered through the use of pre- and posttests and post-instruction clinical interviews. Participants (n = 47) were preservice elementary teachers enrolled at the Minnesota State University, Mankato in the BIOL 480 course during the fall semester of 2012. The traditional (n = 22) and POGIL (n = 25) groups received their respective instructional methods, completed Classification Conceptions Inventory and Classification pre- and posttests, and participants (n = 8) completed a post-instruction interview. Overall, results indicated that there was no significant difference between treatment groups, but there was a significant difference between sections for specific instruments. The qualitative data showed some evidence that POGIL was more effective than traditional pedagogy, but not enough to conclude POGIL was more effective. This study concluded that more research must be conducted.
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Chapter One

Introduction

There are many topics and problems in today’s society that incorporate science. In order to identify solutions to these problems, science must be understood and used correctly. Having members in our society that are able to comprehend science is necessary in order to make decisions about societal issues involving science (Wozniak, 2012). Scientifically literate individuals can assist in making informed decisions, offer ideas, and help problem solve for issues involving topics such as climate change, food, energy sources, and health (Crowell & Schunn, 2015; National Research Council [NRC], 2012). These issues in society require people to have the adequate background knowledge to help solve them, but according to the NRC (2012), not enough people do.

Obtaining the necessary scientific background information, one must have scientific literacy, and scientific literacy originates from the quality of science education. Research performed by Crowell and Schunn (2015) involved employees of various occupations taking a survey asking various questions about environmental conservation. They found that the number of college science courses taken by an individual does not necessarily mean they can apply that knowledge. It is the quality of science education received that is important for solving societal problems (Crowell & Schunn, 2015). To make society more scientifically literate, they are turning to science educators to improve the quality of K-12 science education (NRC, 2012). In order to improve the quality of science education, the educators must first assess the quality of their teaching methods.

Teachers not only need to assess their teaching methods of scientific material, but
they also need to teach new educators before they enter into the school systems. In order to start improving the quality of K-12 science education, Kindfield and Singer-Gabella (2010) state that one must first make sure preservice elementary teachers know the content and how to teach it. Preservice teachers commonly prefer to teach using methods that they were taught with in school (Laronde, & MacLeod, 2012). If preservice elementary teachers were taught using traditional teaching methods, they will likely prefer to teach using traditional methods. Traditional teaching methods are teacher-centered lectures where students come to class only to hear about a topic. Multiple studies have indicated that traditional methods are not working to improve science literacy (Akınoğlu & Tandoğan, 2007; Barthlow & Watson, 2014; Brown P., 2010). Therefore, if preservice teachers are using traditional teaching methods they were taught with, and traditional methods are not working to improve science, society is not improving their scientific literacy to solve problems. According to the National Center for Education Statistics (NCES, 2011), the Trends in International Mathematics and Science Study reported eighth grade average science scores to have increased slightly from 1995 to 2011. However, there was no significant difference in scores between 2007 and 2011. The Program for International Student Assessment (PISA) compares results of 15-year-old students’ average science scores on the science literacy scale of across the globe (National Center for Education Statistics [NCES] 2012). The United States showed minimal improvement in scientific literacy from 2006 to 2009, but scores slightly decreased from 2009 to 2012 (NCES, 2009, 2012). Without scientific literacy, one’s conception of a topic could be incorrect causing the formation of incorrect solutions to a problem.
Incorrect solutions may be prevented by insure that teachers provide students with an education without errors in their conceptions. Student conceptions are defined as a student's idea or understanding of a science concept which may be correct, or contain errors due to constraints in the student’s reasoning (Yen, Yao, & Mintzes, 2007). The errors in student conceptions are called misconceptions. Students’ misconceptions in science are not decreasing with traditional teaching methods. One topic that contains student misconceptions is biological classification. Biological classification, according to Yen et al, (2007), is a taxonomic system that focuses on categorizing living organisms based on ecological, evolutionary, and morphological foundations. To help with the removal of misconceptions in topics such as biological classification, the American Association for the Advancement of Science (AAAS) and the National Science Foundation (NSF) in 2007 sought out better ways to approach biology education for undergraduate studies, which in turn, impacts the education of preservice elementary teachers (American Association for the Advancement of Science [AAAS], 2009). How preservice elementary teachers teach can decrease the amount of errors in student conceptions in sciences such as life science.

The goal for life science instruction, as well as the other sciences, is to be student-centered. This approach can be helpful in decreasing misconceptions, such as in biological classification (Ballen & Greene, 2017). According to AAAS (2009), “student-centered classrooms tend to be interactive, inquiry-driven, cooperative, collaborative, and relevant” (p. 6). Inquiry is when students seek answers to questions about the natural world comparable to how an actual scientist would. It encourages students to develop their own conceptual understanding about a topic (Gillies & Nichols, 2015; National
Cooperative learning is when students work in groups of three-four and exchange ideas, answer questions, and make clarifications about a topic (Gillies & Nichols, 2015; Johnson & Johnson, 2002). The NRC (2012) encourages instructors to embrace these student-centered teaching methods in the classroom because they assist with the formation student conceptions and amend misconceptions. If preservice elementary teachers are taught biological concepts such as biological classification with student-centered teaching methods, they will likely teach their own students using the same methods.

One possible student-centered teaching method instructors could use is process-oriented guided-inquiry learning (POGIL). POGIL is a student-centered teaching method that uses guided-inquiry and cooperative learning to discuss biological concepts found in topics such as biological classification (POGIL, 2012). Studies have indicated that POGIL successfully reduces misconceptions and increases content knowledge for both K-12 and college students (Barthlow & Watson, 2014; Brown S., 2010; Eberlein et al., 2008; Hale & Mullen 2009; Johnson, Cagle, Jackson, & Lee, 2010, 2011). Therefore, POGIL may possibly be just as effective for preservice elementary teachers in identifying and reducing misconceptions in biological classification, as well as increasing content knowledge. There have been many studies regarding chemistry and other science topics using POGIL, but biological classification has not been thoroughly researched. In addition, most studies found regarding POGIL mostly consist of participants who are not preservice elementary teachers. This paper is a master’s thesis that will quantitatively and qualitatively compare two teaching strategies, traditional and POGIL, in a college laboratory setting. Student understanding and conceptions will be measured with a
pretest, posttest, and an interview.

**Statement of the Problem**

POGIL is drawing attention among teachers in science education. Many studies have been conducted researching the effectiveness of using POGIL instruction in chemistry classrooms. Biological sciences, however, have been neglected. During research of POGIL practices, only five have been found pertaining to biological science, while 20 have been found related to chemistry, biochemistry, organic and inorganic chemistry, foreign languages, nursing, atmospheric science, engineering, pharmacy and marketing (Barthlow & Watson, 2014; Brown, S., 2010; Drossman, Benedict, McGrath-Spangler, Van Roekel, & Wells, 2011; Hale & Mullen 2009; Hein, 2012; Johnson, et al., 2010, 2011; Minderhout & Loertscher, 2007). The push for educators to use POGIL in biology classrooms has minimal data supporting their decision. Of the POGIL research studies relating to biological sciences, anatomy and physiology and nursing were the main subject studied (Brown, P., 2010; Mattheis & Jensen, 2014). Only one study has been found by Wozniak (2012) which is a master’s thesis pertaining to the use of POGIL in biological classification. Additional research must be conducted to determine POGIL’s effectiveness on science topics such as biological topics.

POGIL needs to be examined more thoroughly in biology courses, especially regarding biological classification. Biological classification is a taxonomic system that focuses on categorizing living organisms based on morphological, evolutionary, and ecological foundations (Yen et al., 2007). Common misconceptions specifically in the classification of animals include using habitat and locomotion instead of anatomical structures (Burgoon & Duran, 2012; Kattmann, 2001; Yen, Yao, & Chiu, 2005; Yen et
al., 2007). Biological classification conceptions could potentially decrease with the addition of POGIL student-centered teaching strategy.

Biological classification often is associated with various misconceptions. There is a need for a different teaching method design to help reveal and remove misconceptions in classification (Yangin, Sidekli, & Gokbulut, 2014). In chemistry, POGIL has had success with reducing students’ misconceptions (Barthlow & Watson, 2014). Therefore, POGIL may be a more effective teaching method for biological classification than other teaching methods. By examining the effects of POGIL on students’ knowledge in classification using quantitative and qualitative measures, current life science teachers and preservice teachers can choose with more confidence whether POGIL is the right method for their classroom.

The purpose of this study is to investigate the effect of a teaching strategy, process-oriented guided-inquiry learning (POGIL), on preservice elementary teachers’ understanding of biological classification. The research questions for this thesis are:

1. What are preservice elementary teachers’ misconceptions about common classification errors for mammals, birds, insects, arachnids, amphibians, and reptiles?
2. How does the use of process-oriented guided-inquiry learning (POGIL) affect preservice elementary teachers’ understanding of biological classification when compared to traditional instructional methods?

**Importance of the Study**

As previously stated, it is important that scientific literacy is obtained so that societal problems can be solved with accurate information. Today, there is a deficiency in
scientific literacy, and the quality of science education is key to overcoming it (Crowell & Schunn, 2015; NRC, 2012). Education starts with the instructor. Ricketts (2014) and Zembal-Saul (2009) both indicate that to improve the quality of science education, attention must be paid towards the education of preservice elementary teachers. Preservice elementary teachers must be able to communicate scientific knowledge to their students. For this to take place, preservice elementary teachers themselves need to have correct conceptions about biological classification and use student-centered teaching methods such as guided-inquiry and cooperative learning (Kindfield & Singer-Gabella, 2010; NRC 2012). The following research studies summarize the common misconceptions of animal classification found among elementary teachers and students in both K-12 and college.

Common misconceptions in biological classification tend to be based of animals and their characteristics. Yen, et al. (2007) studied nearly 2,000 Taiwanese elementary, middle, high school, and university students in a cross-age designed study. Students were from both private and public schools and universities in Taichung, Taiwan. The purpose was to uncover student misconceptions in animal classification and what factors guided them to their decisions. Students completed three subtasks: define what an animal is in an interview, sort animals into groups, design a dichotomous key composed of 10 animals, take a 12-question instrument composed of free response and multiple choice (Yen et al., 2007). Results indicated that most student misconceptions exist in the classification of vertebrates, invertebrates, reptiles and amphibians. Student reasoning was commonly based on habitat, movement, and external morphology.
Similar results were found in a study done with elementary teachers. Burgoon and Duran (2012) performed a mixed-method study to determine what the common misconceptions were held by elementary teachers. Forty-four elementary teachers in third through sixth grade took a pretest and posttest before and after a professional development project called NWO TEAMS (Northwest Ohio Teachers Enhancing Achievement in Mathematics and Science) (Burgoon & Duran, 2012). Six teachers participated in an interview to identify common misconceptions. Results showed that elementary teachers’ conceptions were based on locomotion and habitat, which are similar to the student’s misconceptions in the study performed by Yen et al. (2007). The most common misconceptions among the elementary teachers were classifying vertebrates, invertebrates, reptiles, and amphibians (Burgoon & Duran, 2012). Researchers also determined that elementary teacher misconceptions match students’ common misconceptions. If elementary teachers have misconceptions about animal classification, they will, in turn, teach their students those misconceptions. Therefore, teacher misconceptions must be addressed when they are preservice elementary teachers, or sooner.

Preservice elementary teachers often teach using methods that were used to teach them. Using and modeling more student-centered teaching styles to preservice elementary teachers could turn teaching style preferences away from traditional teaching methods. As previously mentioned, POGIL is a student-centered teaching method that incorporates guided-inquiry and cooperative learning (POGIL, 2012). Studies have shown that POGIL works in reducing misconceptions and increasing content knowledge for subjects such as chemistry and anatomy and physiology, but there is a gap in the
research as to whether POGIL can help reduce preservice elementary teachers’ misconceptions and increase content knowledge in biological classification (Barthlow & Watson, 2014; Brown, P., 2010). The following research studies are examples of comparing POGIL to traditional teaching methods in chemistry and anatomy and physiology.

POGIL was designed originally for chemistry due to its high potential for misunderstandings. Therefore, a quantitative experimental study conducted by Barthlow and Watson (2014) compared the effects of POGIL to traditional teaching methods. Participants were 318 high school chemistry students from four different suburban high schools during the second semester of the 2010-2011 school year (Barthlow & Watson, 2014). During the unit of particle theory, four out of the eight classes were taught with POGIL teaching methods while the other four received traditional teaching methods. Researchers used pretests and posttests to measure the effectiveness of the two teaching methods. The results indicated a positive significant difference between the pretest and posttest scores in the POGIL experimental group, and no significant difference between the control group’s scores (Barthlow & Watson, 2014). Also, the researchers found that POGIL assisted with the reduction of misconceptions in particle theory. In addition to the reduction of student misconceptions, other researchers witnessed grades increasing.

With misconceptions decreasing, an increase of student academic performance displayed as a result. Brown, P. (2010) performed a quantitative experimental study with a total of 91 undergraduate students that took the Anatomy and Physiology II course over four semesters. During the spring semester of 2008, students were taught using traditional teaching methods, while the fall of 2008, spring 2009, and fall of 2009 were taught using
POGIL teaching methods for 50 percent of the activities (Brown, P., 2010). The
researcher compared final exam scores, and course grade distributions. Results indicated
no significant difference in final exam scores between the 2008 spring and fall semesters.
Yet, after the introduction of POGIL in the fall of 2008, the grade distribution decreased
in D/F’s and A/B’s, while the number of C’s increased. During the 2009 spring and fall
semesters, there was a dramatic increase in A and B grades, and none of the participants
received a D or F grade. Final exam grades also increased significantly in mean scores.
The results are evidence supporting the hypothesis that POGIL could be an effective
student-oriented, inquiry-based learning teaching strategy that improves student academic
understanding and achievement. The more correct conceptions being established during
the lessons, the more successful the students will be during assessments.

Animal classification conceptions, both correct and incorrect, have been revealed
among students and elementary teachers, but preservice elementary teachers’ conceptions
have yet to be identified. POGIL has been successful with identifying and removing
misconceptions for high school chemistry students (Barthlow & Watson 2014).
Therefore, POGIL could also be effective in determining and removing preservice
elementary teachers’ misconceptions, as well as increase their content knowledge.

Methods

The demand for more inquiry-based learning in the science classrooms has been
encouraged for the improvement of scientific literacy in society. POGIL started out as a
student-oriented teaching strategy in the chemistry department. The research questions of
this thesis started with a search of POGIL being used in courses from all disciplines. The
search began with the Minnesota State University, Mankato’s library databases. Their
databases included ERIC, EBSCO, and JSTOR using terms like “process-oriented guided-inquiry learning AND biology” as well as “inquiry-based learning OR POGIL” and “biological classification OR animal classification.” All sources were evaluated using Creswell’s (2015) checklists. All quantitative and qualitative studies were examined for accurate and relevant information. All research articles were obtained from the university’s library databases with a publish date within the past 15 years for POGIL specific articles and up to 20 years for biological classification research. The general information regarding POGIL came from the POGIL Project’s official website. A literature note-taking log was used to analyze and organize the research articles. The literature long included notes of the methodology, results, quotes, and summaries. The literature review was used to direct the experimental design and analysis of the results.

**Summary of Experiment**

This study was designed to address the following research questions:

1. What are preservice elementary teachers’ misconceptions about common classification errors for mammals, birds, insects, arachnids, amphibians, and reptiles.

2. How does the use of process-oriented guided-inquiry learning (POGIL) affect preservice elementary teachers’ understanding of biological classification when compared to traditional instructional methods?

The effect of POGIL instructional methods compared to traditional methods on preservice elementary teachers’ conceptions of biological classification were elicited with the use of pre- and posttests along with a post-instruction interview for both traditional
and POGIL instructional methods. Permission for this study was obtained from the university IRB in June, 2016.

**Setting and Population**

First, participants were preservice elementary teachers divided into four sections of the BIOL 480 course, Biology Laboratory Experiences for Elementary Educators, during the Fall 2012 term at Minnesota State University, Mankato. Participants were divided into the different sections via registration based on their schedules. Before registration, each section was assigned a professor and a teaching method. Two professors equally divided the sections; teaching two sections a piece and were determined by the flip of a coin which section they taught and which teaching method each section received. Post registration resulted in sections one and two as the control groups; section one had eight participants, section two had 14 for a total of 22. Sections four and six were the experimental groups; section four had 14 participants, section six had 11 for a total of 25.

**Experiment Design and Data Collection**

The researcher used a mixed-methods approach to measure the effect of POGIL on preservice elementary teachers’ understanding of biological classification. This study was a nonequivalent control-group design with pretest and posttest assessments measuring quantitative data and post-instruction clinical interviews collecting qualitative data. Quantitative data was collected via pretests and posttests. The assessments were made entirely of multiple choice questions. Classification Conceptions Inventory
Pretests and posttests and Classification Quiz pre- and posttests were used to quantitatively measure participants’ content knowledge and student conceptions about biological classification. Pre- and posttests were identical.

Two sections received biological classification instruction via traditional teaching method (control group), while the other two sections were taught via POGIL (experimental group). Each professor taught one section via POGIL instruction and the second was with traditional instruction. Before instruction took place, students first took both Classification Conceptions Inventory, and Classification Quiz pretests. The second step in the procedure was to have the participants participate in a two-day lesson about biological classification. The control group participants had the option of working individually or in a group. The experimental group were required to be in small groups of four. Each member was assigned a role to complete each of the tasks.

The third step took place post-instruction. Students took both Classification Conceptions Inventory, and Classification Quiz posttests. The pretest and posttests scores were statistically analyzed using Statistical Package for the Social Sciences (SPSS) comparing the control and experimental groups’ content knowledge in biological classification. The data collected was to answer if POGIL was more successful.

The final step was collecting the qualitative data. Qualitative data was collected via interviews after the biological classification instruction and both posttests took place. Eight participants, four from the control group and four from the experimental group, were selected for the interviews. Posttest scores of both assessments were combined and were chosen from the top 75% of the class to determine the participants for the interview. From each section, one student from the top 25% were picked, and one from the middle.
50% were picked for a total eight. The researcher analyzed the data by transcribing, coding, and determining the themes that involved classification misconceptions (Creswell, 2015). Interviews were used to identify the preservice elementary teachers’ conceptions and reasoning regarding biological classification. It was also used to determine if POGiIL was more effective than the traditional teaching method.

**Limitations of the Study**

One limitation of this study was the use of convenience sampling for the quantitative data. Since random sampling was not possible for this study, the results of this study can only apply to the participants. The researcher is unable to make generalizations about the entire preservice elementary teacher population. Limitations in the qualitative data will exist in the sampling procedure. Participant sampling was not random preventing the results from being generalized towards the entire population. Other limitations include threats to validity. History is a threat because the administration time may be close enough between the pretest where participants may remember their responses to the pretest when they take the posttest. The timing of the posttest conflicted with schedules. Therefore, the timing of the posttests taken for each of the sections were different which may have affected the validity of the results.

**Definition of Terms**

**Biological classification.** Is also referred to in this study as “classification.” It is a taxonomic system that focuses on categorizing living organisms based on ecological, evolutionary, and morphological foundations (Yen et al., 2007).

**Cooperative Learning.** Students work together in groups of 3-4 to answer questions or complete an activity. Group members share ideas, assist in understanding of concepts,
and attempt to remove misconceptions (Gillies & Nichols, 2015; Johnson & Johnson, 2002).

**Inquiry.** Also referred to in this study as “Guided-Inquiry.” Like a scientist, students ask questions regarding the natural world; how it works, why it works, and seeks answers to their own questions. Inquiry assists in the formation of their conceptual understanding (Gillies & Nichols, 2015; National Science Teachers Association, 2004).

**Process-Oriented Guided-Inquiry Learning (POGIL).** A student-centered teaching method that involves a combination of guided-inquiry and cooperative learning to discuss biological concepts. Students work in groups of 3-4 where roles are divided amongst the members. Minimal class time is used for lecture and the instructor is only a facilitator. The instructor only assist students as needed, and answer questions with questions. This is to encourage the students to come up with the answer on their own (Eberlein et al., 2008; POGIL, 2012).

**Student Conceptions.** Student’s idea or understanding of biological classification concepts, which may be correct, or have errors due to constraints in student reasoning (Yen, et al., 2007). Errors in the students’ conceptions are referred to as “misconceptions” in this study.

**Traditional Instruction.** Teacher-centered teaching method that involves presenting material in a lecture format where students only hear the biological concepts. After the lecture, students proceed into a classification lab where they apply what they heard to models, and figures. The instructor answers students’ questions directly.

**Overview**
Chapter Two includes a literature review exploring previous research regarding POGIL teaching strategies effecting student conceptions and achievement. Chapter Three discusses the methodology that took place along, while Chapter Four discusses the results of the experiment determining if POGIL was effective in identifying preservice elementary teachers’ conceptions of biological classification and whether the teaching method had better results than the traditional method. A summary will be provided at the end discussing the research, conclusions, limitations, and possible suggestions of future research of POGIL. This will be in Chapter Five: Conclusion.
Chapter Two

Review of the Literature

Introduction

This study examines the need for more research on how process-oriented guided-inquiry learning (POGIL) affects preservice elementary teachers’ understanding of biological classification. The literature review of this study is used to demonstrate how POGIL is a teaching strategy that improves scientific literacy by increasing achievement across science disciplines and improving conceptions of science topics. It shows that there is a need to determine what conceptions exist in biological classification. Secondly, there is limited research on preservice elementary teachers’ conceptions regarding scientific topics, especially in biological classification. Thirdly, POGIL is a teaching strategy that has not been used or researched regarding biological classification and preservice elementary teachers’ conceptions and achievement in this topic. This lack of research must be addressed in this area to ensure students in the classroom are leaving with correct conceptions to teach future students.

There are two research questions addressed in this literature review. The first question investigates what are preservice elementary teachers’ misconceptions about classification of mammals, birds, insects, arachnids, amphibians, and reptiles? The second question regards how the use of process-oriented guided-inquiry learning
(POGIL) affect preservice elementary teachers’ understanding of biological classification when compared to traditional instructional methods? The literature researched focuses on these questions and why they needed to be addressed in the study.

This chapter is a literature review that focuses on reporting what research is present and draws attention to what is missing in the research. First, this chapter addresses the literature regarding biological classification conceptions across different groups. Second, there is a review of preservice teachers’ conceptions across all science disciplines. Third, is research regarding what POGIL is and how it affected student achievement and conceptions in different scientific disciplines. The final section involves the instrumentation used in this research study to implement and measure the effects of POGIL on preservice elementary teachers’ understanding of biological classification. As a result, the attention is drawn to where research is lacking, the basis of this study.

Common Misconceptions in Biological Classification

There is a need to discern preservice elementary teachers’ misconceptions. Common biological misconceptions have been researched at the elementary, middle, secondary, university/college student levels, and inservice elementary teacher level (Chiung Fen, Tsung-Wei, & Mintzes, 2007; Jambrina, Vacas, & Sanchez-Barbudo, 2010; Kattmann, 2001; Yen et al., 2007). The following studies examine what conceptions exist among these groups.

The most common misconceptions involving biological classification regard vertebrates and invertebrates. Yen et al. (2007) conducted a qualitative cross-age study with Taiwanese elementary, middle, high school, and university students. There were
three tasks students performed. Task one was a 20-minute interview to name animals, and put them into classification groups. Task two involved making a dichotomous key with 10 different animals, and the final task was a 12-question multiple-choice instrument followed by a 60-minute interview with 40 students at each level. Purpose of the study and each task was to identify any misconceptions that exist.

The results were very clear regarding what common conceptions exist among the variety of students. The study conducted by Yen et al. (2007) resulted in students mostly incorrectly labeling invertebrate and vertebrate animals. The next most common conception involved students incorrectly labeling amphibians and reptiles. Lastly, students of all ages struggled to determine what characteristics divided animals into their groups. Characteristics used for their classification of organisms involved locomotion, whether the animals were heterotrophic or autotrophic, morphology, and habitat. Students in high school and at universities also added whether animals were warm or cold blooded. The researchers concluded that how classification is taught must be addressed in order to remove these common misconceptions.

Another qualitative study was conducted to determine the conceptions of biological classification at the elementary to high school levels in addition to university age levels. Chiung Fen et al. (2007) conducted a convenience sample of 1,962 student participants: 592 elementary, 710 middle, 562 high school, and 98 university students. There were three tasks that were completed by students; a 20-minute interview where participants name five animals and define what the word animal means. The second task involved presenting the students with 20 pictures of vertebrate and invertebrate animals and had students classify the organisms into one or more groups. The groups were
vertebrates, invertebrates, fish, amphibian, reptile, bird and mammal. The third and final task involved a multiple-choice instrument followed by a 45-60-minute interview identifying misconceptions.

The results were similar to what was found in the previously mentioned studies. Task one resulted in students listing names of vertebrates, specifically mammals and birds. The definition of “animal” was commonly referred to as ability to move, be viable (alive), reproduce, predation, wisdom, and a few listed respiration and nutrition as their response (Chiung Fen et al., 2007). Conceptions of a vertebrate was determined by students to be “animals possessing well-defined head and limbs” (p. 543), while invertebrates were “limbless animals with soft or lengthy bodies” (p. 543). In addition, habitat was a large factor that was used to form student decisions of classifying the organism into groups. The second task showed classification maps of elementary and middle school students basing their maps off of habitat and what the animals eat. High schoolers added a morphology, locomotion, and other biological functions such as warm and cold blooded. Out of all the students that completed task two, 50-90% of students designed their maps using habitat, morphology, and locomotion as their top influences (Chiung Fen et al., 2007) The third task revealed student misconceptions regarding a penguin, octopus, and a whale based on morphology, habitat, locomotion, and physiological adaptations. The majority of the students indicated penguins were mammals thinking that they give milk to their kin. The octopus was most commonly labelled as a fish because of its habitat. The whale was mostly labeled as a mammal, but of those that labeled it as a fish was due to its aquatic habitat. These misconceptions were found at all grade levels studied.
Habitat and locomotion misconceptions were also commonly found in other research studies involving biological classification at the student level. Kattmann (2001) completed a mixed methods study involving 536 students from grades four, five, seven and eighth grades from various schools in Germany. Students were presented with animals on the questionnaire and needed to group them in whichever way that made sense to them. Researchers found that animals were divided by habitat, locomotion, morphology, and anatomy. Classifying by habitat was the most common choice of animal division. For example, students placed all animals that live in aquatic environments into one group despite whether they were similar in morphology or anatomy which is the correct way to classify organisms. The second most common misconception found was grouping organisms by locomotion. Descriptors such as ‘flyers’ and ‘creepers’ were used by students to divide by locomotion. Morphology and anatomy was the least used of the three grouping mechanisms by students. Morphology and anatomy answers commonly referred to the ‘number of legs’ an organism had (Kattmann, 2001). These conceptions are not only found at the student level; they are also found at the preservice teacher level.

One study was found on the biological classification conceptions of preservice elementary teachers. Jambrina et al. (2010) conducted a mixed methods design at the University of Salamanca’s School of Education in Spain. Participants were 40 preservice elementary school teachers that primarily taught children aged three to six. Students were taking a course called ‘Knowledge of the Natural Environments and its Teaching’ in the 2007-2008 academic year. Participants took an open-ended questionnaire about the different animal groupings and then the researcher focused the study towards the
direction of spiders and their common misconceptions. Participants had to draw a spider and answer questions regarding its ecology and morphology.

The questionnaire again brought forth the same result regarding student knowledge on invertebrates and vertebrates. Similar to the previously reviewed studies by Burgoon and Duran (2012) and Yen et al. (2007), Jambrina et al. (2010) found that participants knew very little about invertebrates. For example, the classification of mammals and birds were answered almost perfectly by all teachers, but 70% of participants labeled reptiles as invertebrates which is incorrect because reptiles have a backbone classifying them as a vertebrate. Worms were thought as an insect by 7.5% of the participants and 20% also thought spiders were insects. Results clearly show that there are flaws in preservice elementary teachers’ conceptions regarding biological classification. Conclusions drawn from this study identified preservice elementary teachers’ struggles to correctly classify animals. Only with spiders did they focus on what their conceptions were concerning how they were classified into their group Arachnida (Jambrina et al., 2010). Although this study brings forth some information about preservice elementary teachers’ conceptions of biological classification regarding spiders, it lacks detail of their conceptions of other classification groups. Since this study had a small sample size of 40 preservice elementary teachers from Spain, it has a limitation that prevents the conclusion of this study from applying to the entire preservice elementary teacher population, which supports the need to conduct more research about preservice elementary teacher’s conceptions of biological classification.

Preservice elementary teachers’ conceptions of biological classification need further research because the common misconceptions regarding invertebrates,
vertebrates, reptiles and amphibians were found at the inservice elementary teacher level. A study conducted by Burgoon and Duran (2012) researched inservice elementary teachers’ conceptions of biological classification. Their study was a mixed methods design of 44 inservice elementary teachers in grades third through sixth. Teachers completed pre- and posttest instruments, completed two items, and finished with a semi structured interview that allowed researchers to explore the teachers’ conceptions as needed. Item A required teachers to list groups of animals that belong to the vertebrate classification group, and Item B presented six pictures of animals that teachers were to classify into the different taxonomic groups. The interview with six volunteers took place a month after the study was conducted.

The results of the study by Burgoon and Duran (2012) were similar to those of Yen et al. (2007). Results of the Burgoon and Duran (2012) study showed that teachers were able to identify the following vertebrate categories (Item A) as having a backbone: 59% fish, 45% amphibians, 69% reptiles, 74% birds, and 95% mammals. In addition, researchers discovered that only seven percent of teachers correctly classified all six organisms (Item B). These results along with the interview data analysis caused the researchers to conclude that the most biological classification misconceptions were found regarding vertebrates and invertebrates, along with reptiles and amphibians. Researchers Burgoon and Duran (2007) stated “students often possess restricted or limited definitions of animal groups and therefore fail to identify many atypical group members,” (p. 416). As a potential reason for these alternative conceptions, also known as misconceptions. This means that if people are not exposed to animals other than the common organisms that are found in communities (i.e. cows, dogs, and cats), misconceptions are more likely
to form because their groupings will be based on their own prior knowledge (Burgoon & Duran, 2012). If these are the conceptions of educators, it is likely that they will pass those conceptions to their students.

In conclusion, there are numerous studies completed regarding student conceptions regarding biological classification. Most misconceptions found were related to invertebrates and vertebrates, reptiles and amphibians, as well as choosing habitat and locomotion to classify animals into their respective groups. These conceptions were found at the elementary, middle, and high school levels as well as at the post-secondary level. In addition, misconceptions have also been found with inservice elementary educators. It is a perpetual cycle. If inservice teachers have the aforementioned misconceptions, they had to have been ingrained when they were preservice elementary teachers. If not addressed, they could be taught to their students in which some will become teachers themselves. Therefore, it is important to explore preservice elementary teachers’ conceptions and correct them before they teach them in the classroom.

**Preservice Elementary Teachers’ Conceptions in Science**

It is necessary to learn the classification conceptions of preservice elementary teachers because when they become inservice teachers, they will teach what they know. If those conceptions are incorrect, they will likely pass those misconceptions to their students. A few studies regarding preservice teachers’ conceptions of science topics have been found. First, this literature review will discuss general conceptions in a science classroom. Then preservice elementary teachers’ conceptions regarding specific topics in Earth science, physical science, and biology (Abell, Martini, & George, 2001; Atwood & Atwood, 1997; Brown & Schwartz, 2009; Stein, Larrabee, & Barman, 2008; Trend, 2000;
Yangin et al., 2014). If we know their conceptions about science, they can be addressed before they enter the classroom.

Preservice elementary teachers’ conceptions in science is not well researched. Studies however have been conducted regarding their ideas about scientific practices. Ricketts (2014) performed a qualitative case study focusing on what preservice elementary teachers think scientists actually do when they are conducting scientific practices. Eighteen senior undergraduate elementary education majors completed a jigsaw teaching strategy learning about the scientific practices Framework. Each group of students had become an “expert” on the scientific topic and then presented their findings (Ricketts, 2014). As a result, the participants stated that they had their students “posing questions suitable of scientific investigations, but never posing questions about one another’s idea” (p. 2127), and asked whether something happened, not the ‘why or the how’ it happened (Ricketts, 2014). The participants were able to do the activities, but the “why” was inconsequential to them. The “why” is the conception, therefore, if one cannot explain the “why,” they do not fully understand the topic. As a result, Ricketts (2014) concluded the “study indicates that preservice elementary teachers may need extra support in understanding the practices of modeling and data analysis” (p. 2133). This extra support as a preservice elementary teacher would be beneficial before going into the classroom as an inservice instructor.

Science is an inquiry-based discipline in which preservice elementary teachers should practice. A mixed methods research study conducted by Tsai (2006) observed how inquiry-based pedagogy impacts both preservice and inservice secondary teachers’ views about the nature of science. Preservice and inservice teachers were in two separate
courses at a national university of Taiwan where they learned about the philosophy of science, common misconceptions in science and where they could have come from, and classroom activities that can include technology (Tsai, 2006). Students had to design a lesson, make a concept map, and share their work. The goal was to engage them into a more inquiry based science. They had to answer questions in an interview, and complete a pre- and posttest questionnaire. Results indicated that out of the 32 preservice participants, 44% claimed to have ‘changed’ their views encouraging them to approach science in a different manner; 28% indicated their views have ‘somewhat changed’ (Tsai, 2006). Inservice teachers had a more difficult time altering their perspective of science. Out of the 36 inservice participants, only 28% stated they ‘changed’ their views. “Researchers are encouraged to explore more ways to facilitate teachers’ development of appropriate views about science,” (Tsai, 2006, p. 373). Therefore, the need to draw out preservice elementary teachers’ science understanding is crucial before they become inservice teachers with seemingly less malleable perspectives of science.

When it comes to preservice elementary teachers’ conceptions in science, biological classification has been studied very little. Schoon and Boone (1998) conducted a large survey to determine what preservice elementary teachers’ conceptions were. They surveyed 619 preservice elementary teachers while in their scientific methods course. The survey instrument consisted of a section focusing on “science teaching efficacy,” and the second section was a multiple-choice test that sought out misconceptions in science (Schoon & Boone, 1998). The subjects of the questions varied across all science disciplines. The results indicated that participants with a low self-
efficacy, meaning one’s self belief in their ability to do something, commonly had the following misconceptions:

That planets can be seen only with a telescope.

That dinosaurs lived at the same time as cave-men.

That rusty iron weighs less than the iron that it came from.

That electricity is used up in appliances.

That north is toward the top of a map of Antarctica. (Schoon & Boone, 1998, p. 563)

The preservice elementary teachers that had numerous misconceptions mentioned that they, “could not see themselves as being effective science teachers” (Schoon & Boone, 1998, p. 564). Preservice elementary teachers are likely to teach science as an inservice teacher and therefore will pass on these misconceptions to their students if they are not corrected.

Earth science has been studied the most with the focus on preservice elementary teachers’ conceptions. An action research study completed by Abell et al. (2001) focused on preservice elementary teachers’ conceptions of the moon phases. There were 11 participants during a six-week period where they kept a moon observation journal and upon completion, wrote a final reflection explaining their observations. The journal was to include any patterns viewed by the participants. Post interviews were conducted regarding participants’ observations and understanding.

The project was to expose participants to a sample scientific experiment, to give a taste of what it is like to be a scientist. Participants acknowledged during the interviews that the project was an example of what scientists do to conduct their research. One
participant stated “I feel that [the moon investigation] represented [science] in several ways: it goes along with what a scientist does as far as the observations, recording data” (Abell et al., 2001, p. 1100). Students used inquiry with this experiment, and their conceptions were determined as well. Some participants had the misconception that the sun only reaches the part of the moon that we on Earth can see. Another partial misconception is that the Moon is “moving” across the sky, not taking the Earth’s rotation into account. It was concluded by Abell et al. (2001) that completing an actual inquiry-based project where the participants conduct the observations, make predictions, and provide potential explanations was beneficial in attempting to understand the “why” behind the moon phases. Misconceptions were still present, however, but participants were showing the possibility of working to correct them via questioning, and discussions among the class. For example, two students stated they saw a crescent moon when another claimed it was larger later on in time. Discussions were devised to determine if it was possible to have phase changes within a few hours’ time frame. The results of this discussion were not mentioned in the article.

An additional science topic researched involved the conceptions of day and night and what causes the seasons. Atwood and Atwood (1997) studied 51 preservice elementary teachers’ conceptions regarding the seasons and what causes night and day. The study consisted of qualitative interview data to determine if conceptions change after two hours of course instruction. The instruction was designed to address misconceptions found in the pre-assessment interview (Atwood & Atwood, 1997). During the interviews students were asked to model and verbally describe how day turns into night and how the seasons change. During the pre-assessment interview, Atwood and Atwood (1997)
concluded that 48 of the participants did not understand how the seasons took place and 14 did not know how day turned into night. Misconceptions drawn out regarding day and night were participants thinking the “Earth moved around the sun.” or “the sun moved around the Earth” (Atwood & Atwood, 1997, p. 8). Season misconceptions participants had been, the “distance between the Earth and sun,” “Rotation of the Earth on its axis” only, “Changed tilt of the Earth model,” and “sun revolves around the Earth” (Atwood & Atwood, 1997, p. 8). After completing the post-assessment interview, researchers concluded that all participants had correct conceptions of the cause of night and day, and season explanations dramatically improved to 42 participants with correct conceptions while nine participants continued to have misconceptions (Atwood & Atwood, 1997). The two misconceptions that existed post-assessment interview were, “distance between the sun and hemispheres of the Earth due to the Earth’s tilt,” and “rotation of the Earth on its axis” (Atwood & Atwood, 1997, p. 8). Researchers do claim that the model used to explain the seasons may have dramatized Earth’s distance from the sun at different times (Atwood & Atwood, 1997). They acknowledged that it may have caused some misconceptions to remain with the participants.

Other scientific conceptions were brought forth regarding geologic time. Trend (2000) studied preservice elementary teachers’ conceptions of geologic time along with specific events in Earth’s history. With the use of a questionnaire, sequence geo-event cards, and interview questions, this mixed-methods study collected information regarding 20 geoscience topics (Trend, 2000). The results were compared to inservice teacher participants who also completed the same tasks. The questionnaire had a 100% response rate where many preservice participants indicated higher interest rates between 4.00 and
2.76, the encounter rates of them were much lower. Encounter rates refer to participants actually teaching the specific topic in their classroom. Fifty-five percent of preservice participants indicated that topics will not come up in their classroom. The most common topics for both groups of participants were the formation of our solar system, earthquakes, and volcanoes. There were four topics that preservice teachers thought they were not going to teach in the classroom whereas inservice teachers reported high encounter rates in the classroom including the following topics: Rocks, minerals, fossils, and “current landforms and processes” (Trend, 2000, p. 549). These topics all tie into understanding geologic time.

Geologic time is broken up by dates of major events such as a mass extinction, not by categories of time. However, researchers concluded that preservice teachers tend to depict a geologic timeline via three categories: “extremely ancient,” “less ancient,” and “geologically recent” (Trend, 2000). A found misconception within the “extremely ancient” category was that the Big Bang took place after the Sun’s formation. The “less ancient” category contained concerns as to when the ice ages took place in relation to other geologic events such as the first volcanoes and the Atlantic opening. Although there were quite a few misconceptions in regards to geologic time, researchers did advise for 10- and 11-year-old age groups that a generalized geologic time scale should be used instead of the absolute dating geologic time scale (Trend, 2000). This may also help with preservice elementary teachers’ conceptions of geologic time.

In addition to Earth science, one study involving preservice elementary teachers’ conceptions of physical science was also researched. A study conducted by Stein et al. (2008) with 305 participants (282 of them being preservice elementary teachers) to
determine their conceptions of physical science by completing the 47 true or false statement test with the option of writing an explanation of their answers. Researchers claimed that gravity and motion topics as well as physical and chemical changes tended to be where most misconceptions lie (Stein et al., 2008). A common misconception brought forth in this study was the inability for 40% of participants to point out that gravity is not the only force that acts on an object at rest. Of those who answered correctly, written responses included that air pressure, potential energy, and the Earth’s rotation were the forces that acted on a resting object when in fact it is the normal force that balances out gravity. Another misconception found that 46.2% of participants incorrectly thought that two spheres with different masses will fall at different rates. The conception of Newton’s first law of motion, an object in motion stays in motion, Stein et al. (2008) found that 94% of participants responded “true” to the question that an applied force is needed for an object to move from resting position. However, participants’ responses to the written explanation points out that only 74.7% provided correct explanations typically when referring to laws other than Newton’s first law, or gravity causing the change (Stein et al., 2008). The physical and chemical changes portion of the assessment resulted in uncovering the following misconceptions: air is the gas that is released from boiling water instead of water vapor due to a physical change, and that mass is gained or lost during a chemical reaction defying the law of conservation of matter. Each misconception had a percent incorrect answers to the true or false questions of 75.2% and 75.9% respectfully. This remains consistent to what the researchers, Stein et al. (2008) expected. Out of all the research conducted, only one was found regarding preservice elementary teachers’ conceptions in biological classification related topic
(Jambrina et al., 2010). However, other studies regarding biological topics such as the energy cycle, plant classification, and evolution have been reviewed.

The energy cycle refers to photosynthesis and cellular respiration working together to take light from the sun and change it to usable energy for all organisms on Earth. Brown and Schwartz (2009) conducted a qualitative research study that focused on 18 preservice teachers’ science conceptions and justifications regarding the energy cycle. Participants received three traditionally taught lectures and one laboratory session. Interviews of 14 of the 18 participants took place individually post-instruction. An additional clarifying interview took place with seven participants to clarify any conceptions participants had (Brown & Schwartz, 2009). The study resulted in the following conceptions presented by the participants: Both photosynthesis and cellular respiration take place in plants and 27% of participants could not explain beyond the chemical equations of each process. They could not explain how each process was interconnected on the cellular level. Another conception pertained to the sun being the ultimate energy source to the energy cycle. Participants could not explain how the sun was the source of energy at the biochemical level; calling it “ATP” in the photosynthesis process (Brown & Schwartz, 2009). Only three participants correctly labeled carbon dioxide as the cause of cellular growth. The rest of the participants referred to carbon dioxide as being either the source of oxygen, or the product of oxygen. Only two people expressed partially correct conceptions of how the energy cycle functioned. Photosynthesis was noted as the “energy reaction” while the cellular respiration was the “gas exchange reaction” (Brown & Schwartz, 2009, p. 801). These misconceptions can affect understanding at the organismal level, specifically for plant classification.
Plant classification misconceptions can also impact conceptions of how animal biological classification is determined. For example, if two plant organisms grow in aquatic environments, the misconception that habitat determines the classification of an organisms can be carried over to animal classification. One study was found focusing on the classification of plants and the misconceptions that preservice elementary teachers possess. Yangin et al. (2014) conducted a qualitative cross-sectional study involving 162 preservice elementary teachers at the beginning (class 1) and the end (class 4) of their education program. Participants completed a questionnaire of eight open-ended questions that were designed to provide their reasoning. Responses from participants in class 1 were compared to answers from class 4 participants. Misconceptions were found regarding morphology and structure of plants between vascular and non-vascular plants, gymnosperm and angiosperms, and between plants with and without seeds (Yangin et al., 2014). In addition, mushrooms were often confused as a plant instead of a fungus. Results indicated that class 4 participants had more correct conceptions in comparison to class 1. The researchers, Yangin et al. (2014) claim this to be a limitation of their study. They cannot determine the reason for why class 4 had more correct conceptions than class 1. The results of the research by Yangin et al. (2014) resembles the study results of Jambrina et al. (2010) regarding preservice elementary teachers’ animal classification conceptions. In both studies, participants struggled with classifying organisms based on their morphology; often times participants used other factors to distinguish which category they should use to be correctly classified. One final article was found that relates to evolution which is the only other study somewhat related to the topic of classification with misconceptions research.
Evolution closely resembles classification. A majority of biological topics cannot be fully understood without the Theory of Evolution (Rice & Kaya, 2012). Classification is based on the concept of evolution. Therefore, this article exploring preservice elementary teachers’ misconceptions must be included in this literature review. Rice and Kaya (2012) completed an exploratory study answering questions about preservice elementary teachers’ acceptance and understanding of the theory of evolution. Participants of this study included 240 preservice teachers answering 13 conceptual evolution questions; questions were true/false, multiple choice, and participants were encouraged to write comments explaining their responses although they were not required to (Rice & Kaya, 2012). Evolution is a controversial subject, and this study’s results are no exception. The question concerning human evolution resulted in 57.5% of 106 participants that had previously taken an advanced science course accepted evolution, and only 58.2% of the 134 participants that had not taken a previous advanced science course accepted evolution. The overall results indicated that almost 60% of participants agreed with the theory of evolution. Of these participants, their conceptions were more correct than the participants that did not agree with the theory of evolution (Rice & Kaya, 2012). Misconceptions regarding evolution is often dependent on one’s personal beliefs. If these misconceptions exist, they can also impact how biological classification is taught because it is based on the theory of evolution.

In conclusion, preservice elementary teachers tend to have a lot of flaws in their conceptions across a variety of science disciplines and topics. There are misconceptions regarding Earth science, physical science, and some biology topics. However, only one study involves preservice elementary teachers’ biological classification conceptions.
Literature has consistently shown that preservice elementary teachers, inservice elementary teachers, and students k-12 through university have misconceptions about the same biological groupings. Specifically, how each aforementioned group routinely incorrectly classifies each grouping based on habitat and locomotion. In present literature, there are no contradicting studies to these findings. These preservice elementary teachers’ conceptions need to be identified in more detail and addressed. The methods to identify and remove potential misconceptions is further discussed in this literature review.

**Process-Oriented Guided-Inquiry Learning**

Process-oriented guided-inquiry learning (POGIL) is a teaching strategy that was chosen for this study to compare its effectiveness on achievement and conceptions of biological classification. First, this section of the review will discuss the components of POGIL. Next, evidence regarding the pedagogies that are incorporated into POGIL will be established. Finally, this review will explore previous studies involving POGIL across all science disciplines to see how POGIL has affected students’ achievement (test scores and grades), and conceptions.

To determine what preservice elementary teachers’ conceptions are regarding biological classification, POGIL was chosen because research has shown that it combines a variety of heavily researched evidence showing improved achievement and altering conceptions. POGIL, is a teaching strategy that acknowledges that there are two pieces to education, ‘content and process’ (Hanson, 2006; Wozniak, 2012). According to the official POGIL website, it is a “student-centered, group-learning instructional strategy and philosophy developed through research on how students learn best,” (POGIL, 2012,
What is POGIL?) It focuses on the students working as a team to inquire about a topic themselves, as opposed to a traditional teaching strategy where direct instruction is exclusively used. POGIL was first designed for a high school chemistry classroom to help with guiding students to their own conclusions via the scientific method (POGIL, 2012). Since then, it has branched out to a wide variety of disciplines (Barthlow & Watson, 2014; Brown, P., 2010; Drossman et al., 2011; Hale & Mullen 2009; Hein, 2012; Johnson, et al., 2010, 2011; Minderhout & Loertscher, 2007). The design of POGIL moves away from teachers being the focal point to only acting as a facilitator. Its purpose is to challenge the students to take responsibility for their own learning and work as a team to obtain the answer with correct conceptions (POGIL, 2012). The design of POGIL involved the use of student-centered, guided-inquiry pedagogies as well as the use of cooperative learning (Shadle, Liu, Lewis, & Minderhout, 2018). Next, this review will discuss the three main pedagogies that make up POGIL which supports the decision of picking POGIL as the pedagogy for this study.

The first pedagogy that POGIL incorporates is student-centered material. Teachers become the facilitators while students take charge of their own learning. Patchen and Smithenry (2013) conducted a mixed methods research study that involved students working in groups to solve the problem, “If a ping pong ball and a golf ball were dropped from the same height at the same time in this room, which ball would hit the floor first?” (p. 808). Participants were 140, 11th and 12th graders in a high school physics course. The teacher could not help solve the problem, but could answer general questions. The purpose was to see how students would take control of their own learning. Students were split into groups and the students were to determine how to design and conduct an
experiment to answer the question (Patchen & Smithenry, 2013). There were three main group types that formed. One example of group formation involved less than half of students participating, with no one taking on a leadership role, resulted in an experimental design that was not made and naturally, no success in solving the problem given to them. Another example of group formation were groups that took partial ownership of their learning and had someone take on a leadership role in their group, however, there was a struggle to determine what experimental design was to be used for their experiment. There were more student contributions to the group; however, there was still some recorded chaos (Patchen & Smithenry, 2013). Chaos referred to moments where group members did not know what they were doing and they were not working functionally together. The groups that experienced the most success in the Patchen and Smithenry (2013) study were the ones that had nominated group leaders and an experimental design was drawn out with contributions of over two thirds of the class. Groups who collaborated and communicated were more successful than groups that did not. Patchen and Smithenry (2013) concluded that collaboration and communication are beneficial strategies to use in student-directed inquiry learning pedagogy. (Patchen & Smithenry, 2013). POGIL is a student-centered teaching strategy, but it recognizes the need for collaboration and communication student skills, amongst others. The next study discusses the importance of cooperative learning.

POGIL requires the use of self-managed teams. Groups are made up of three to four people and each member is assigned a task. POGIL divides these roles into a team manager, spokesperson, recorder, and reflector (POGIL, 2012). These roles are divided so that all members are responsible for each other’s success. Gillies and Nichols (2015)
conducted a qualitative research study in Australia with sixth grade students and nine teachers who all had received four days of training about how to implement cooperative and guided-inquiry learning strategies into their classrooms. Teachers then taught inquiry science about living versus non-living things as well as genetically modified organisms (GMOs) (Gillies & Nichols, 2015). Students had to make questions, make lists of what qualified something to be considered living versus non-living. In addition, the same structure was made for the GMO unit. Each unit was taught over a two-week timeframe. Results were overwhelmingly positive. Teachers commented that both inquiry and cooperative strategies were highly beneficial, stating they provided students with more ‘voice’ and ‘power’ in the classroom (Gilles & Nichols, 2015). One teacher commented, post-instruction interview, regarding collaboration, “Yeah, I loved it. I think it gave them (students) a lot of ownership of the unit and, being that co-operative, they could sort of persuade which way it was going to go” (Gilles & Nichols, 2015, p. 180). The discussions involved more participation from students and therefore resulted in more productivity (Gilles & Nichols, 2015). The pedagogy POGIL used research such as this to design its strategies. The success story of using collaboration further supports the use of POGIL as the main teaching strategy in this study. The last component however, tends to be the most important regarding teaching and learning about science. So far we have talked about how POGIL uses student oriented strategies that incorporate collaboration from others. The last strategy POGIL integrates is the use of guided-inquiry.

Guided-inquiry, the final main pedagogy that makes up POGIL, is vital in improving student success rates. Gilles and Nichols (2015) involved guided-inquiry in their study and had positive results. However, a study completed by Mcconney, Oliver,
Woods-Mcconney, Schibeci, & Maor (2014) used a quantitative retrospective analysis research design involving 15-year-old students from Australia, Canada, and New Zealand to determine if guided-inquiry instruction is being used along with how it affects interest and engagement levels. It focused on the frequency that high school science students using guided-inquiry specifically towards science topics. Researchers used Programme for International Student Assessment (PISA) science results to determine how students were affected by guided-inquiry learning. PISA is an international standardized assessment in reading, mathematics, and science (Mcconney et al. 2014). Scores are scaled to be an average of 500. Australia (n=4,209), Canada (n=5,087) and New Zealand (n=1,141) all had students claim low and high inquiry focus, 14-18% and 12-17% of the student population respectively (Mcconney et al., 2014). Students who experienced high inquiry focus in their science classrooms had higher scientific literacy performance, interest, and engagement compared to the low inquiry focus classrooms. Australia, Canada, and New Zealand students from the low inquiry focus classrooms had PISA science literacy score averages of 531, 551, and 534, respectively, and science interest averages of 441, 450, and 428 respectively (Mcconney et al., 2014). Australia, Canada, and New Zealand students from the high inquiry focus classrooms had science literacy averages of 512, 505, and 493, respectively, and science interest averages of 492, 496, and 504 respectively (Mcconney et al., 2014). The literacy and interest levels in science were much more comparative in the high inquiry focus classrooms than in the low inquiry focus classrooms. Overall inquiry-based learning showed more positive results in both literacy and engagement further encouraging the use of POGIL in Volz’s present research.
This current study being performed by Volz is comparing POGIL to traditional teaching methods to determine how each effect preservice elementary teachers’ conceptions of biological classification. With the research overwhelmingly supporting POGIL as a teaching strategy, it is important to state the evidence present in the research demonstrating the effectiveness across the science disciplines focusing on achievement first and conceptions second.

**Effect of POGIL on Student Achievement in a Science Classroom**

POGIL research has demonstrated effectiveness on achievement in science disciplines. Walker and Warfa (2017) conducted a 21 study meta-analysis quantitative study to compare how traditional lecture pedagogy (n=5,277) and POGIL (n=2,599) pedagogy impact achievement for high school and college settings in chemistry or other non-chemistry STEM disciplines. Meta-analysis results indicated that that STEM course achievement by participants improved. POGIL had a gain score of 0.29 which was statistically significant (Walker & Warfa, 2017). According to Walker & Warfa (2017), “…student performance in summative assessment measures POGIL group would be at the 62nd percentile compared to that of a student in a standard lecture group performing at the 50th percentile” (p. 6). Participation and engagement were reported as an increase as well for POGIL participants (Walker & Warfa, 2017). A limitation to this study is that it is unknown whether all teachers used POGIL endorsed activities. It is not clear as to how each educator kept strictly to POGIL activities, and as a result could have skewed the results for POGIL’s effectiveness. Other teaching strategies could have been used.

Another study was conducted at the preservice elementary teacher level. A quasi-experimental, quantitative design study by Irwanto, Saputro, Rohaeti, and Prodjosantoso
(2018) examined 48 participants that were in the second year of their education degree. The 48 participants were divided into two groups, an experimental group that was taught general science using POGIL strategies, while the other group was taught using traditional lecture methods. Pre- and posttests were used to quantify their achievement in the course. Pretest and posttest gain scores resulted in the POGIL group having higher averages than the control group, 7.88 and 4.62 respectively (Irwanto et al., 2018). The results support that the addition of POGIL into science curriculum would be beneficial towards the improvement of student achievement.

Research has demonstrated academic performance success in organic chemistry courses as well. Both De Gale and Boisselle (2015) and Hein (2012) have conducted research resulting in the increase of achievement with the use of POGIL pedagogy. De Gale and Boisselle (2015) completed a mixed-methods action research design to determine how POGIL affects academic performance. The study surveyed 22 high school students in a Trinidadian organic chemistry high school classroom. Pretests and posttests were given before and after an eight-lesson unit using POGIL pedagogy. De Gale and Boisselle (2015) found that both classes had similar completion rates however, the final grades significantly favored POGIL vs traditional teaching methods. Hein (2012) experienced similar results. In her study conducted at Winona State University involved students enrolled in the Principles of Organic Chemistry I course from 2003-2010. She compared the exam scores of POGIL instruction (n=103) which was taught from 2008 to 2010 to traditional instruction (n=158) that took place from 2003 to 2005. The American Chemical Society (ACS) Organic Chemistry Exam scores were compared and the ACS national percentile distribution showed a dramatic shift. When POGIL transitioned into
the course in 2008, Hein (2012) results indicated that POGIL participants would expect to see an increase of 10.82 percent increase over traditional instruction participants. This study did have a concern in regard to an uncontrollable change in the ACS Organic Chemistry Exam for the 2009 and 2010 academic years which may have impacted the results. Significantly less people were in the 25th percentile or lower and more participants found themselves within the 26th-74th percentile and 75th percentile and above (Hein, 2012). Both studies in organic chemistry showed positive results for using POGIL to improve achievement, however, POGIL research in the biology disciplines also needs to be addressed.

There is a lack of studies conducted indicating how POGIL pedagogy is used to improve student achievement in biology classrooms. However, these upcoming studies shed some light on this lack of literature. Three of them require biology prerequisite courses to complete: psychology, nursing, and pharmaceutical science (Roller & Zori, 2017; Soltis, Verlinden, Kruger, Carroll, & Trumbo, 2015; Vanags, Pammer, & Brinker, 2013). A quantitative, quasi-experimental designed study was completed by Vanags et al. (2013) to determine how POGIL improves long-term retention in an undergraduate psychology course at an Australian University. Participants were split into two groups, control and POGIL experimental, where 316 students took a pretest, posttest, and a follow up quiz that was two weeks after the posttest to determine how the different groups retained the information. Vanags et al. (2013) showed pretest scores for the traditional and POGIL groups were 4.3 and 3.8 out of 5.0 respectively. Posttest scores were 4.2 and 3.8 respectively. Although the data does not seem to favor POGIL from the pre- and posttest results, the follow up quiz showed the most dramatic results. The
traditional group and POGIL group had average scores of 3.7, and 3.5 respectively. The POGIL group had similar results to the posttest scores indicating there was retention of information (Vanags et al., 2013). The traditional group results showed scores that were highest for both their pretests and posttests, but their follow up was lower than both indicating retention of material was significantly less. The results of using POGIL strategies further supports the effectiveness and increase of student achievement, especially for long-term retention.

Nursing was another field that researched the effectiveness of POGIL on student achievement. Although the nursing field does not seem to be associated with biology, typical nursing program prerequisite courses involve biology courses such as anatomy and physiology and microbiology courses. Roller and Zori (2015) conducted a quantitative comparative study with 138 undergraduate nursing students during the 2014 summer and fall semester sessions comparing the effects on achievement between POGIL (n=63) and traditional lecture-based pedagogy (n=75). Data was collected via survey questions to rate content understanding and satisfaction in addition to their final course grades (Roller & Zori, 2015). Results indicated a significant difference between the final course scores for the POGIL group in comparison to the traditional group. Roller and Zori (2015) found final grade means to be 4.41 and 3.89 for POGIL group and traditional group respectively with a p-value of 0.046. Researchers did indicate that there was not a significant difference in the ATi scores (national test) which were 76.71 and 75.46 for POGIL and traditional groups respectively. This study did have limitations because study habits could not be controlled for exams and the sampling is a convenience sample preventing the generalization of the data from applying to any participants outside
of this study. Sample size also hinders the ability to generalize this data for the entire nursing population.

Like nursing, pharmaceutical science is another science topic that does not seem to be directly related to biology. Typically, pre-professional pharmaceutical prerequisite courses include general biology, microbiology, biochemistry, anatomy and physiology as well as chemistry courses. A pharmaceutical science study also supports the use of POGIL to improve student achievement of test scores and overall grades. A three-year quantitative study from 2011 to 2013 was performed by Soltis et al. (2015) which took place during a pharmaceutical introductory level one course titled, “Introduction to Pharmaceutical Sciences.” The academic years, 2011 and 2012, were taught using traditional teaching methods while in 2013 POGIL was introduced. Therefore, 2011 and 2012 participants were the traditional control groups, while 2013 participants were the POGIL group. POGIL participants received a short introductory lecture, and then were randomly assigned into POGIL groups of four. Soltis et al. (2015) collected data from four, 50 multiple-choice question exams from 2011 to 2013. Results showed that POGIL strategies increased exam percentage points by 7.0 in comparison to the traditional group. Researchers Soltis et al. (2015) stated,

When POGIL was implemented throughout the course in 2013, there were no grades of D or below and half as many grades of C (27% of the class vs 13%). The distribution of grades of A and B increased from 20% to 25% and 52% to 61%, respectively. (p. 3)

Since the final grade distribution of the POGIL group resulted in no Ds or Fs, it represented significant improvement in achievement further supporting POGIL. A
potential limitation was that 2011 and 2012 had two instructors compared to 2013 that only had one (Soltis et al., 2015). It is possible that the instructor’s teaching styles could have differed and POGIL could have been taught differently. This could have altered the 2013 results.

There were two sources found that used POGIL to improve achievement in a biology course. Both of them were completed at King College with participants being undergraduate students taking Anatomy and Physiology II (Brown, P., 2010). This experimental design study compared traditionally taught 2008 spring and fall final grade scores to the 2009 spring and fall semesters which received POGIL instruction. Results uncovered by Brown, P. (2010), denotes the grade distributions. Researchers observed grade distributions for traditional groups between the spring and fall of 2008 semesters results indicated 41.17% of participants received an A or B, 52.94% received a C, and 5.88% earned a D or F (Brown, P., 2010). Grade distribution for both semesters that received POGIL instruction increased to 80% of students received an A or B, and 0% of students received a D or F. Final exam scores specifically showed a difference between traditional and POGIL groups. In 2008, average scores were, 68.08 ±16.21 and 79.88 ±14.48 for the spring and fall semesters respectively (Brown, P., 2010). In 2009, when POGIL was implemented, average scores were 86.22 ±11.83 and 88.33 ±12.16 in the spring and fall semesters, respectively. This is strong evidence supporting that POGIL can be very beneficial in a biology classroom, however this study admits that material in the anatomy and physiology course tends to be very factual (Brown, P., 2010). An example of factual material in anatomy and physiology would be learning the different muscles in the human body. This type of material is more factual than conceptual.
Therefore, only 50% of the course was taught using POGIL. The continued support of POGIL in both chemistry and biology settings to improve achievement highly encouraged the decision to choose POGIL as the pedagogy for the student conducted by the current researcher.

Effect of POGIL on Student Conceptions in a Science Classroom

While the majority of studies found regarding POGIL are based on student achievement, very few have POGIL studies that have focused on science conceptions. This literature review will now discuss studies that have used POGIL to identify conceptions in chemistry and biology courses. As previously mentioned, Barthlow and Watson (2014) conducted a study using experimental design to observe 318 secondary chemistry students. Four out of the eight classrooms were taught using POGIL pedagogy while the other half received traditional lecture-based lessons. The pre- and posttests included a 20-multiple choice question Particulate Nature of Matter Assessment Version 2. All the questions in this assessment were designed to pertain only to misconceptions in an attempt to identify them in student conceptions. The POGIL group had mean pretest and posttest scores of 11.85 ± 3.868 and 14.60 ± 3.573 respectively (Barthlow & Watson, 2014). The traditional group pretest and posttest mean scores were 11.49 ± 4.298 and 11.64 ± 3.798 respectively. Using ANCOVA to test results, the POGIL group compared to traditional lecture group posttests was F[1, 312]=15.224, p<.0001. POGIL had a mean and standard error of 14.866 ± .419 (Barthlow & Watson, 2014). The traditional lecture group posttest mean and standard error was 11.923 ± .569 which was significantly lower than POGIL. Results were significant indicating that POGIL was effective in reducing misconceptions in comparison to traditional lecture.
Only a master thesis has been found that discusses how POGIL affects conceptions in a biology classroom. Wozniak (2012) conducted an experimental mixed-methods research design with undergraduate students who had taken a 100-level general biology course called Our Natural World. She focused on both student achievement and conceptions of biological classification. Participants were non-biology majors between the ages of 18 and 21 years old and were taking the course during the summer of 2012. Participants completed two pre- and posttests of two different instruments and six randomly selected individuals completed a post-instruction interview. The instruments were used to identify student conceptions as well as report how POGIL impacts student achievement in the general science course. The results of this study were reported to be insignificant between the POGIL group (n=10) and traditional groups’ (n=6) pre- and posttest scores for both assessments. Even though the POGIL group had higher posttest score than the traditional group, 8.830 ± .477 (p = .084) and 8.333 ± .333 (p = .099) respectively, the p-values were insignificant (Wozniak, 2012). This quantitative data was then triangulated with qualitative data.

The qualitative data did point out a few differences in biological classification conceptions. Differences found between the two groups indicated POGIL students used correct vocabulary more often than the traditional group, and POGIL groups explained molecular evidence and its use in biological classification more effectively compared to the traditional group who did not explain it at all. The researcher (Wozniak, 2012) stated that this is likely a result of POGIL groups receiving molecular evidence instruction while the traditional groups did not. Basing classification on habitat was a misconception found in POGIL participants’ conceptions but were replaced with correct morphological and
anatomical characteristics after POGIL instruction took place (Wozniak, 2012). POGIL was also able to completely remove locomotion as a misconception post-instruction as well. Wozniak’s (2012) study was the only study found to have analyzed both achievement and conceptions regarding biological classification with the use of POGIL pedagogies. While the aforementioned literature aims to describe how to improve student achievement using POGIL pedagogy, there are flaws that must be acknowledged.

**Concerns with POGIL as a Pedagogy**

Not all studies involving POGIL addressing conceptions and achievement are as effective as they claim. The biggest concern and evidence against POGIL’s effectiveness is the sampling process. The majority of the studies completed and reported in this literature review used non-random convenience sampling. This is a limitation that prevents these studies from applying to an entire population and instead can only pertain to their own selected groups (Barthlow & Watson, 2014; Brown, P. 2010; De Gale & Boisselle, 2015; Gillies & Nichols, 2015; Hein, 2012; Irwanto et al., 2018; Patchen & Smithenry, 2013; Roller & Zori, 2017; Soltis et al., 2015; Vanags et al., 2013; Walker & Warfa, 2017; Wozniak, 2012). Another concern involves sample sizes, a few studies had limited number of students available in the course which can influence results to make them inaccurate (Barthlow & Watson, 2014; Brown, P. 2010; De Gale & Boisselle, 2015; Gillies & Nichols, 2015; Hein, 2012; Irwanto et al., 2018; Mcconney et al., 2014; Patchen & Smithenry, 2013; Roller & Zori, 2017; Soltis et al., 2015; Vanags et al., 2013; Walker & Warfa, 2017; Wozniak, 2012). One final concern is that POGIL cannot be used as a pedagogy for all science concepts. For example, as previously mentioned by Brown, P. (2010), anatomy and physiology are mostly factually based content. It does not fully
consist of concepts that could have misconceptions. For example, when labeling the bones in the body, these are not conceptions, but instead memorization of facts. Therefore, these types of courses may only be able to incorporate POGIL for some topics, but not all. Subjects like this may only be able to use POGIL for a smaller portion of the class if this is the case.

In conclusion, POGIL was chosen because it was designed with well researched pedagogies and it has demonstrated through research its effectiveness with achievement and leading to fewer permanently ingrained and perpetuated misconceptions. Although there are concerns with some of the research in regard to sampling and topic limitations, the overall evidence overwhelmingly supports POGIL. Now that the pedagogy has been determined to use for the current study, the final step in this review is to discuss instrumentation.

**Instrumentation**

There are very few instruments found in research that concern conceptions of biological classification. Three studies have been found that contain instruments worth reviewing (Chiung-Fen et al., 2007; Kattmann, 2001; Yen et al., 2007). All of these researchers completed research with participants at all ages testing their conceptions of biological classification. They all specifically focused on classification misconceptions regarding habitat, locomotion, and morphology and anatomy. Kattmann (2001) and Yen et al. (2007) both used multiple choice test items, a two-tiered, 12 questioned multiple-choice assessment was used by Chiung-Fen et al. (2007) where a statement was provided, and then a set of reasons. Participants were allowed to provide a free response. None of these instruments used in previous research were aligned with the learning outcomes
POGIL Classification Activity. Therefore, they were all ruled out by the researcher as possible instruments.

Only one study contained instruments that aligned with POGIL Classification Activity learning outcomes. The study completed by Wozniak (2012) used two multiple choice assessments for pre- and posttest. The first one administered was an 11-multiple choice question test that was designed to include correct and incorrect anatomical structures, and common misconceptions such as habitat and locomotion. Wozniak (2012) also used a second pre- and posttest classification quiz which consisted of 20-multiple choice questions. These questions also included misconceptions but went a step further by added on questions regarding classification and molecular evidence such as the Cytochrome C protein DNA evidence. The first assessment instrument had Cronbach’s Alpha of 0.845 indicating the instrument’s strong validity (Wozniak, 2012). This validity for the instrument and is important for the present study because this instrument was used to measure the quantitative data. The second assessment instrument did not have a reported Cronbach’s Alpha. Interviews were also performed pre- and post-instruction. Each interview was approximately 30 minutes in length. Questions were open-ended to allow for the each participate to elaborate and explore biological classification conceptions. Questions were consulted with taxonomist expert, Dr. Alison Mahoney to insure the design and structure of the tasks in the interview were precise. In conclusion, due to there being a lack of instruments available regarding conceptions of biological classification, pretests, posttests, and interview questions from Wozniak’s research were chosen.

Summary
The purpose of this literature review was to examine all the research associated with the following two research questions: What are preservice elementary teachers’ conceptions of biological classification, and how does POGIL affect their understanding of biological classification compared to traditional instructional methods? This study was conducted because students of all ages, including inservice elementary teachers, have displayed misconceptions regarding biological classification (Chiung Fen et al., 2007; Jambrina et al., 2010; Kattmann, 2001; Yen et al., 2007). Those misconceptions tend to surround the classification of invertebrates and vertebrates, reptiles and amphibians, as well as habitat, locomotion, and morphological and anatomical components. Only one piece of literature was done researching preservice elementary teachers’ misconceptions. That study found similar results, but it focused on spiders and insects more than classification as a whole (Jambrina et al., 2010). It also did not address potential pedagogies that could help remove these misconceptions. The research also indicated that preservice elementary teachers have other misconceptions in other science topics in biology, such as misunderstandings in the connection between photosynthesis and cellular respiration. However, the research is very minimal in regard to biological classification and needs further study.

POGIL could be a potential resolution to misconceptions in biological classification. Research has shown support for POGIL over traditional lecture-based teaching pedagogy for improving student achievement and conceptions in the science classrooms for chemistry, physics, and biology subjects. Limitations have presented themselves in the sample sizes, and sampling processes in the research studies. They are not being ignored, but rather, explored further due to the lack in research of preservice
elementary teachers’ conceptions in biological classification and using POGIL as the pedagogy. The instrumentation found in the research has not been applicable to this study’s purpose because this study uses the POGIL Classification Activity learning outcomes (see appendix A). The researcher of this study has chosen to use the two assessments and the post-interview questions used in Wozniak’s (2012) research. It matches the POGIL Classification Activity learning outcomes, and has demonstrated validity.

The next chapter discusses the methodology used for this study. First, the mixed-methods research design of this experiment conducted will be explained. The setting of the study along with the participants of the study will be reviewed, followed by how the two pedagogy curriculums and materials were administered. Finally, both the quantitative and qualitative data will be described further explaining how it was collected and analyzed.
Chapter Three

Methods

Research Design

This chapter explains the research design, setting, participants, instrumentation, curriculum, procedures, and data analysis. A mixed methods approach was used to determine whether process-oriented guided-inquiry learning (POGIL) teaching strategy was effective on preservice elementary teachers’ understanding of biological classification.

Two types of data were collected and triangulated to identify preservice elementary teachers’ conceptions and common classification errors as well as determine the effect of POGIL teaching strategies compared to traditional instructional methods. The data collected and triangulated came from the following sources: 1) pre- and post-instruction student assessments measuring content quantitatively, and 2) post-instruction clinical interviews eliciting conceptions qualitatively.

The purpose of using a mixed method approach was to counteract the concerns found in each method (Creswell, 2015). Considering both qualitative and quantitative methods together provides a clearer understanding while reducing concerns of disadvantages. For example, both the pre- and post-assessments are multiple choice questions, which provide the opportunity for students to guess. The interviews aim to bring forth students’ true understanding of biological classification. This is the goal of using a mixed method research strategy.
The mixed method design of the quantitative research was a Nonequivalent (pretest and posttest) Control-Group Design. There were two treatment groups that four sections of classes were divided into. Two instructors were assigned to teach two sections each. Each instructor taught one section using the POGIL teaching strategy (experimental group) and one section using traditional instructional strategies (control group).

Participants were assigned to research groups and instructors via registration. The participants enrolled in BIOL 480 course were placed into the POGIL experimental group and traditional control group by the students based on their own schedules. Participants in both groups took the pretest to determine their content knowledge before their assigned instruction took place, and then took a posttest after instruction occurred.

The qualitative data was collected by having a post-intervention clinical interview. The purpose was to bring forth student conceptions about biological classification. Eight participants in the student interviews were selected using stratified sampling based on test scores. Two names were chosen from each student roster for a total of eight. The interview took place after the completion of the lesson. It was a 30-minute interview that required students to provide feedback about their learning while eliciting their student conceptions.

The decision to use the aforementioned methodology was based on another study. Wozniak (2012) completed her study during the summer semester of 2012. This study’s methodology was reviewed and then altered and repeated. Some of the things that changed were time of year, length of semester, group of students targeted, sample size, instruments and procedures. The current thesis data was collected in the fall 2012.
semester by Dr. Bethann Lavoie, Dr. Brittany Smith and Stephanie Zojonc. The data was later analyzed by the current researcher from 2018 to 2019.

**Setting**

This study was conducted at Minnesota State University – Mankato; a public, semester-based university system. The university has a population of over 18,000 students (Minnesota State University, Mankato, 2012, accessed 2/20/19). This number also accounts for students attending from more than 90 countries. Of these students, 76% are full-time, 23% part-time, 54% are female, 45% male, and 14% of students are of color. Students can choose degrees from 130 undergraduate programs, and 85 graduate programs (Minnesota State University, Mankato, 2012, accessed 2/20/19). The largest programs are nursing, psychology, elementary education, and law enforcement.

BIOL 480, Biological Laboratory Experiences for Elementary Teachers, is a course for preservice elementary teachers to gain laboratory practice in the field of biology. The course emphasizes the importance of building knowledge and skills in all general biological concepts (Minnesota State University Mankato Department of Biological Sciences, 2019). This course is offered in both Fall and Spring semesters.

The participants in this study are all preservice elementary teachers that took the BIOL 480 course in the Fall of 2012. These participants were non-biology majors who were taking the course as a requirement for their licensure. Four sections of the course were offered; Section 1 was Tuesdays and Thursdays at 2:00 PM, section 2 was Mondays and Wednesdays at 10:00 AM, section 4 Mondays and Wednesdays and 12:00 PM, and section 6 was Tuesdays and Thursdays at 12:00 PM. Before assigning the students to a section, sections 1 and 2 were designated as control groups with traditional teaching
methods, and sections 4 and 6 were designated as the treatment groups receiving POGIL instruction. The two instructors were assigned one control group and one treatment group. Instructors flipped a coin to see which teacher taught which section of each pedagogy. Sections 1 and 6 were assigned to one instructor while 2 and 4 were assigned to the other. Participants were then assigned to each research group and instructor based on their own schedules.

The researcher is currently a graduate student in the K-12 Secondary Education MAT program at Minnesota State University, Mankato. The researcher graduated in 2013, initially majoring in biology and minoring in chemistry at the University of Wisconsin, La Crosse. In 2017, the researcher gained a life science and general science teaching license while attending courses at Minnesota State University, Mankato’s Graduate Teaching Licensure/Masters of the Arts in Teaching Program. During this time, the researcher taught four semesters of Biology 100, Our Natural World. This course has similar curriculum and instruction strategies used for the BIOL 480 course. This experience could lead to potential bias. To maintain objectivity, conclusions will be drawn from the data alone, which will also be analyzed by members of the researcher’s graduate committee.

**Participants**

Participants were preservice elementary teachers. They were undergraduate students at the Minnesota State University, Mankato and took BIOL 480 during the Fall 2012 semester as a requirement for obtaining their elementary education licensure. There were 47 total participants. The 47 students were registered for the Fall 2012 semester. Participants were assigned based on their own schedules and availability. Section 1 of
BIOL 480 had eight participants, section 2 had 14, section 4 also had 14, and section 6 had 11 participants.

To determine how the interviewees were chosen, posttest, combined scores for both tests were used to identify the top 25%, the middle 50%, and the bottom 25%. Then, the instructors crossed off names of people who most likely would not have been able to describe their answers due to lack of effort or speaking capabilities. From the people left on the list, one top student and one middle 50% student were selected from each section. The bottom 25% were students that either skipped class or did not turn assignments in, so it was clear they would not provide valuable information. Students were invited to participate in the interview. If the student chose not to, the next person on the list was asked, until eight people agreed. Students were pulled out during class to conduct the interviews. Interviews were performed by Dr. Bethann Lavoie on December 5th, and 6th, 2012. Students received a local food restaurant gift card for five dollars for completing the interview. Students did not miss any course content while participating in the interview, because they were doing a previous lab takedown and cleanup. Eight participants were selected—two students from each of the sections—to take part in the student interviews. Four interviewees had received traditional instruction while the other four had received POGIL instruction.

The four sections of the BIOL 480 course were divided between two instructors. Each instructor taught one section using traditional teaching methods while the other section used POGIL instructional methods. One instructor was assigned sections 1 and 6 while the other instructor taught sections 2 and 4.

Instrumentation and Curriculum Materials
Instruments

The instruments used were two tests and post-instruction interviews. The purpose of each item was to determine participants’ content knowledge and conceptions of biological classification based on the two types of instruction. Assessments only contained organisms in the Animalia Kingdom. The purpose of using only animals instead of plants was so that students could explain their prior knowledge using familiar characteristics. It also allows for the revealing of potential misconceptions about using habitat or locomotion to classify animals. Kattmann (2001) and Yen et al. (2007) researched misconceptions. The results of their research helped in determining the design of the instrumentation used in this research (Wozniak, 2012). Kattmann (2001) and Yen et al. (2007) research also helped guide the structure of the misconception questions for both the tests and the interview.

Student Tests

Quantitative data was collected via Classification Conceptions Inventory pre- and posttests, and Classification Quiz pre- and posttests. Both Classification Conceptions Inventory pretest and Classification Quiz pretest were identical to their respective posttests (see Appendix C for Pre- and Posttests). The learning outcomes in the POGIL Classification Activity were used as guidelines in the design of the questions on the Classification Conceptions Inventory pretest and posttest (see Appendix A for POGIL Classification Activity) (Wozniak, 2012). Both student tests were formatted with all multiple-choice questions containing images of organisms so that the students could use applied knowledge.
The Classification Conceptions Inventory instrument was developed by Wozniak (2012). She drafted the instrument based on comparing “…research of student misconceptions about biological classification, expert review of the items by a taxonomist, and a preliminary test talk-aloud with students,” (p. 45). Dr. Alison Mahoney, an expert taxonomist, reviewed and modified draft test items. A few test items had been altered slightly to improve the clarity of a few questions. Only a few word changes had been made (Wozniak, 2012). The Statistical Package for the Social Sciences (SPSS) program calculated a Cronbach’s Alpha to be .845 for the final version of the pre- and posttest containing 11 questions total (Wozniak, 2012). The Classification Conceptions Inventory instrument had been slightly revised from Wozniak’s (2012) by a couple words to establish more clarity. For example, all the “what” phrases were changed to “why” phrases in attempt to make the question clearer. Also, question number nine was changed from “would you change the classification” to “should the classification be changed” to remove potential opinion answers to factual answers. So, the reliability and validity for this are not the same as the Wozniak (2012) instrument, since the instruments used by the researcher were altered slightly.

The Classification Quiz instrument consisted of 20 multiple choice questions. Students were presented with pictures or items of the organisms in question. This pre- and posttest quiz was also developed in Wozniak’s (2012) research. It contained questions requiring students to classify animals without the use of a dichotomous key. Questions included two fungi and three plant related classification questions. Three questions were about taxonomy and scientific naming. Nine questions were focused on invertebrates and vertebrates such as reptiles, amphibians, mammals, birds, insects,
arachnids, worms, and squids. The goal of the assessment was to identify any misconceptions that exist among the preservice elementary teachers’ conceptions. Question four, for example, from the Classification Quiz presented a frog and the question “this organism is in the class _____." The multiple-choice options were Amphibia, Arachnida, Crustacea, and Reptilia. The researcher used this question to see if students had the misconception of mistaking amphibians with reptiles. Wozniak (2012), did not complete a Cronbach’s statistical analysis for the classification test.

Both the Classification Conceptions Inventory and the Classification Quiz pretests were taken on October 31st or November 1st, 2012 for all sections depending on the course scheduled dates. Posttests were administered November 12th for sections 2 and 4, and November 29th for sections 1 and 6. The scores from the pretest for the Classification Conceptions Inventory were not entered into the gradebook, but students got five completion points for taking both pretests. The Classification Quiz scores were also not entered into the gradebook. However, if students did take it, they got 10 completion points. Pretests were based on completion points, so there were no repercussions against the students. Credit for the posttests were different for each section. The Classification Conceptions Inventory posttests scores for sections 2 and 4 were entered into the gradebook out of 11 points. The same was true for the Classification Quiz results, in which sections 2 and 4 students received points based on the score out of 20 questions. Sections 1 and 6 were affected by Thanksgiving break and weather closures. Therefore, their posttests did not take place until November 29th, 2012. In this case, only completion points were awarded for each posttest taken: five points for Classification Conceptions
Inventory, and five points for the Classification Quiz for a total of 10 completion points awarded.

**Student Interviews**

Qualitative data was collected through 30-minute post-instruction interviews. The interview contained open-ended questions designed for the researcher to inquire topics that may uncover any student misconceptions or correct conceptions on classification, Kvale & Brinkmann, 2009 (as cited in Wozniak, 2012). During an interview, an interviewee answered questions and completed a particular task associated with the topic of the question. The objective of the questions was to uncover misconceptions (Wozniak, 2012). Throughout the interview, the interviewee was encouraged to think aloud when performing each task, which helped to uncover their reasoning, Lee, Russ, & Sherin, 2008 (as cited in Wozniak, 2012).

The validity of the interview questions is due to cross-research between biological classification and student misconceptions; “an expert review of the questions by a taxonomist, and a preliminary talk-aloud with students” (Wozniak, 2012, p. 50). Questions regarding common misconceptions of morphology, habitat, and locomotion were designed based on research by Kattmann (2001) and Yen et al. (2007) (as cited in Wozniak, 2012). Dr. Alison Mahoney, an expert taxonomist, reviewed and modified interview questions; recommending specific word changes to maintain clarity of the questions regarding the importance of molecular data when classifying (Wozniak, 2012). The final product was used by the researcher in this study, but the product was only used post-instruction, after the posttest was taken.

**Curriculum**
Curriculum Materials

Two types of instructional methods were used for this study. Traditional instruction and POGIL instruction were the two types of intervention to determine if POGIL affected student understanding of biological classification. Both instructors received training in both POGIL and traditional methods, so both sections were taught the same content and taught as similarly as possible. Training took place October 31\textsuperscript{st}, 2012. It is important to note that the material taught to both the traditional and POGIL groups were equal. What was different was how each group was taught. For example, the same Cytochrome C charts were used for both groups, but the traditional group used more traditional lecture styled questions such as determining which two have the most differences or similarities. The POGIL curriculum addressed the Cytochrome C chart based more on inquiry based instead of factually, like the traditional groups received. This made sure that all students had a fair chance of answering the pre-and posttest content.

Traditional Curriculum

Traditional instructional materials were given over a two-day lesson, each 1 hour and 50 minutes in length, throughout the week of November 5\textsuperscript{th}, 2012 (see Appendix B). During the entirety of the instructional intervention period, students were allowed to obtain assistance from other students or the instructor. During the first 15 minutes of the intervention, the instructors gave an introductory lecture about the traditional classification system regarding hierarchal taxonomy categories, associated vocabulary, instruction on how to use a dichotomous key, and how to read a phylogenetic tree. The hierarchal taxonomy categories were Kingdom, Phylum, Class, Order, Family, Genus,
Species. Vocabulary was defined, and examples were provided. The terms regarding animal taxonomy were radial and bilateral symmetry, segmentation, exoskeleton and endoskeleton. Plant and fungi taxonomy vocabulary words explained were venation of leaves, mycelium, and fruiting body. Instructors then explained how to use a dichotomous key to classify an unknown organism. A series of two mutually exclusive statements regarding key characteristics of organisms were provided to students to place into their correct taxonomic categories. Instructors concluded their lecture with an explanation of how phylogenetic trees show the relatedness between different organisms throughout time. Visual examples of phylogenetic trees were shown to provide explanation of branching and other relevant pieces.

The remaining hour and 35 minutes of the lab time on day one was spent on the classification of organisms. Participants were allowed to work individually or in groups of their choosing. There were 62 organisms located throughout the room for participants to classify by Kingdom, Phylum and Class. Organisms were presented in a variety of ways: alive, preserved, taxidermic mounts, or in photographs. Students were allowed to use the provided dichotomous key when classifying organisms.

The following example demonstrates the process that the students go through using the dichotomous key, which was the same process in Wozniak’s (2012) study:

1) Presented with a turtle

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 (p. 64).

Day two of the traditional curriculum started out with providing the necessary time needed to complete the classification of the 62 organisms. The final component of the two-day intervention period consisted of the participants working with Cytochrome C charts and creating a phylogenetic tree using their keyed-out organisms onto a worksheet. The students were presented with a Cytochrome C chart and were told to compare a variety of organisms to determine how related they are based on the similarities in the
protein DNA. It is important to note that the Cytochrome C chart was not scientifically accurate in terms of actual number of differences in the DNA, but the numbers were accurate in providing a pattern demonstrating how similar the organisms are in comparison to others. Students were given a pair of organisms and had to determine how similar they were based on the protein’s DNA. For example, students compared a human Cytochrome C protein DNA to a monkey’s, which is 1 on the chart. The chart indicated that the smaller the number, the fewer differences there were in the DNA, therefore denoting that the two organisms are more related than a human and a tuna comparison, which was listed to have 27 differences.

During the final 25 minutes of the traditional intervention period, students again had the option to work in pairs or as individuals to create their phylogenetic trees. The participants were to make their phylogenetic trees using structural characteristics for each classification group based on the dichotomous key.

**POGIL Curriculum**

POGIL curriculum also was a two-day lesson taking place the week of November 5th, 2012 (see Appendix A). The same POGIL instructional materials and curriculum from Wozniak’s 2012 study were used with some differences based on the materials obtained. For example, some organisms had to differ due to access of the organisms. In this curriculum, the instructor served as the facilitator. This meant that they helped guide the students, but they were not allowed to give the answers away. The biggest difference between the two curriculums was that the POGIL group participants were required to work in structured groups of four to complete the tasks of the lesson. Each member chose
a role to fulfill: manager, spokesperson, recorder, and reflector. Once the roles were decided, instruction began.

There was no introductory lecture to the lab activity for the POGIL group. Students were presented with three Models from the classification activity. Model one inquired, “What characteristics do biologists use to classify organisms?” Students were then presented with organisms chosen based on familiarity to them, and they were told to separate the organisms into groups and provide reasoning. Some sample organisms were a crayfish, fish, soft shell turtle, alligator, and a frog (Wozniak, 2012). Model two focused on determining whether student classification of these organisms was correct or not. It also served the purpose of self-determination of any misconceptions held by the participants. For example, a shark, crab, and a clam could be incorrectly classified together because they all live in aquatic environments. Misconceptions such as this were addressed by first having the students divide their organisms into groups containing endoskeletons, exoskeletons, or neither. Students were then able to visibly see that groupings made of habitat, locomotion, and behaviors could not work assisting with the removal of these misconceptions. Before entering the next model, facilitators gathered the class as a whole to share conclusions and any misconceptions or correct conceptions. Model three involved the application of students’ newly gained knowledge of using anatomical structures to classify organisms to biochemical evidence; Cytochrome C protein sequences.

Cytochrome C is a protein found in organisms in a variety of kingdoms. It is found in plants, fungi, and animals, both unicellular and multicellular. The DNA that makes up the Cytochrome C protein gets randomly mutated over time (Wozniak, 2012).
This in turn results in changing of DNA sequencing which can be an exploration point for determining how related organisms are. For model 3, students were given a Cytochrome C chart. Students had to compare organisms using the data from the chart and reclassify organisms based on their DNA sequencing differences. This evidence is known as biochemical evidence. All questions to the facilitator were addressed by responding to the class as a whole. The purpose of doing this was to make sure that all groups received the same information in attempt to maintain a common understanding. This concluded the activities of day one.

Day two started out with a brief introductory lesson on how to use a dichotomous key, the same one used by the traditional group, as well as some direction on what students were to do. Students remained in their groups from the previous lesson to classify the 62 different organisms distributed throughout the room. Like the traditional group, POGIL students used the same dichotomous key to classify organisms into their Kingdom, Phylum, and Class. This took the entire class time. Students in the POGIL group did not make a phylogenetic tree like the traditional groups did.

**Procedure**

The purpose of this research project was to first identify what misconceptions exist in preservice elementary teachers’ conceptions regarding biological classification. Then the goal was to determine how POGIL impacts preservice elementary teachers’ biological classification conceptions in comparison to traditional teaching methods. To measure these questions, participants took two sets of pretests and posttests along with a post interview. Pretests and posttests were used to measure content knowledge, while the
interview data was used to measure identify student conceptions of biological classification (Wozniak, 2012). The timeline of events is listed in Table 1.

**Quantitative and Qualitative Data Collection**

Both traditional and POGIL groups were administered the Classification Conceptions Inventory and the Classification Quiz pretests October 31\textsuperscript{st}, and November 1\textsuperscript{st}, 2012. The laboratory and lecture components that took place during the week of November 5\textsuperscript{th}, 2012, when intervention took place. The quantitative data was collected via the Classification Conceptions Inventory and the Classification Quiz, while the qualitative data was collected through post-intervention clinical student interviews.

**Pretest.** Students were administered two assessments, the Classification Conceptions Inventory and the Classification Quiz pretests. These were completed prior to any instruction. Instructors read the following script used from Wozniak’s (2012) study, “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.” These multiple-choice assessments were completed individually and students were awarded five points for completion.

**Intervention.** Preservice elementary teachers taking BIOL 480 course, Biology Laboratory Experiences for Elementary Educators, experienced pedagogy intervention starting the week of November 5\textsuperscript{th}, 2012. Classes were held twice a week for 1 hour and 50 minutes each session. Lesson schedules were based on whether students were in the POGIL or traditional group. Intervention completed at the end of week of November 5\textsuperscript{th}, 2012.
Posttest. Both Classification Conceptions Inventory and Classification Quiz posttests were administered post intervention. However, they did not take place during the same week for all sections. Sections 2 and 4 completed both posttests on November 12th, 2012. Sections 1 and 6 took their posttests on November 29th, 2012. Sections 2 and 4 posttests were both graded and students received the points earned for each assessment. Since sections 1 and 6 were postponed until November 29th, due to unforeseen events, they received five completion points per assessment for a total of 10 points.

Post interview. The eight participants that agreed to conduct the interviews took place December 5th and 6th, 2012. The clinical interviews were conducted by Dr. Bethann Lavoie. Interviews took place a week after all students completed the posttest assessments. Interviews were 30-minutes in length. Participants were given a five-dollar gift card to a local restaurant for completing the interview.

Ethical Considerations

The experiment was designed to avoid ethical issues. This research was based on Wozniak’s (2012) research design which received IRB approval who assesses the risk to participants. The researcher of this study maintained most of Wozniak’s (2012) design to ensure that ethical concerns were avoided. All participants are anonymous, and everything was reviewed by the University’s Institutional Review Board for this research study to ensure safety for everyone.

Data Analysis

SPSS was used for statistical analysis of all quantitative data. Descriptive statistics and p-values were calculated for Classification Conceptions Inventory and Classification Quiz pretest and posttest scores. Mean scores, standard errors, and gain
scores were determined for all components of the pre- and posttests. The following tests were also used to compare mean gain scores between groups: box plots, Sharpiro-Wilks of normality, Levene homogeneity of variance, one-way ANOVA, post hoc Tukey, Kruskal-Wallis H Test, and Mann Whitney U Tests. Fisher’s exact test (2x4) was used to identify significant differences between the two groups in student answers on each item of the Classification Conceptions Inventory and Classification Quiz.

Qualitative data was gathered via recorded interviews. Interviews were transcribed, and analyzed for themes present. The data were then coded focusing on preservice elementary teachers’ conceptions of biological classification. After the interviews were transcribed verbatim, themes were analyzed, finalized, and then interpreted (Wozniak, 2012). The data from the two quantitative assessments and the qualitative data were then triangulated to determine preservice elementary teachers’ conceptions in biological classification. They were also used to determine whether POGIL affected their understanding of biological classification in comparison to traditional instructional methods.

Summary

Chapter Three explained the methodology behind the experiment conducted. It described the collection of the quantitative data via pre- and posttest assessments, along with how qualitative data were collected via post-instruction clinical interviews. It also explained how both quantitative and qualitative data were analyzed and how they were triangulated to provide a clear depiction of the results of this experiment. Next, Chapter Four will report, in detail, the results of the experiment conducted. The quantitative data will be reported, followed by the qualitative data, to answer the research questions: what
are preservice elementary teachers’ misconceptions about common classification errors for mammals, birds, insects, arachnids, amphibians, and reptiles, and how does the use of process-oriented guided-inquiry learning (POGIL) affect preservice elementary teachers’ understanding of biological classification when compared to traditional instructional methods?
Chapter Four

Results

Introduction

This study was conducted with the purpose of finding out what preservice elementary teachers’ biological classification conceptions are and determine if POGIL pedagogy affects their understanding of biological classification in comparison to traditional pedagogy. Preservice elementary teachers’ conceptions were measured using a mixed methods approach. Data from three different sources were combined and were triangulated. The quantitative portion consisted of pre- and post-instruction Classification Conceptions Inventory assessment and a pre- and post-instruction Classification Quiz assessment, which focused on measuring the content knowledge and conceptions.

This section is structured in the following order: Quantitative, qualitative, and then the triangulation analysis. First, the Classification Conceptions Inventory pre- and posttest scores are reported, followed by the Classification Quiz pre-and posttest scores. Fisher’s exact test 2x4 results for each of the assessments is presented as well. Secondly, the qualitative data is presented in the form of student interviews divided by themes. With all data, the traditional groups are reported first followed by POGIL groups. This section finishes with a summary of the results.

Quantitative Data

Classification Conceptions Inventory and Classification Quiz Pretests and Posttests

Both Classification Conceptions Inventory and Classification Quiz pretests and posttests were analyzed via descriptive statistics. In addition, Classification Conceptions
Inventory and Classification Quiz pretests and posttests scores were combined for a complete analysis of both assessments as a whole. For all tests, both traditional and POGIL groups were analyzed. Table 2 shows the means, standard errors, and mean gain scores for each assessment by treatment and by section. Overall, the quantitative results showed there is no significant differences on the inventory, quiz or combined assessments between treatments. There were a few significant differences between sections on the Classification Conceptions Inventory and Classification Quiz, as well as on the Classification Conceptions Inventory and Classification Quiz combined scores.

In Figure 1, a one-way ANOVA was conducted to determine if the two instructional groups, POGIL (n = 25) and traditional (n = 22) groups had a difference in mean gain scores by treatment. Data is presented as mean ± standard error. Gain score for the Classification Conceptions Inventory was not statistically significantly different between the two instructional groups, $F(1, 45) = 1.281, p = 0.264$. The POGIL gain score for the Classification Conceptions Inventory (M = 1.76, SE = 0.4053) was less than the traditional group (M = 2.5909, SE = 0.63334). A Mann-Whitney U test was run to determine if there were differences in gain score between POGIL (n=25) and traditional (n=22) instruction. Gain score for the Classification Quiz was not statistically significant between the POGIL group ($Md = 3.0$) and traditional group ($Md = 5.0$), U = 243, z = -0.686, $p = 0.493$ using an exact sampling distribution for U. The POGIL gain score for the Classification Quiz (M = 3.68, SE = 0.54381) was more than the traditional group (M = 4.18, SE = 0.58). Gain score for the Classification Conceptions Inventory and Classification Quiz combined scores was not statistically significantly different between the two instructional groups, $F(1, 45) = 1.172, p = 0.285$. The POGIL gain score for the
Classification Conceptions Inventory and Classification Quiz combined scores (M = 5.44, SE = 0.67102) was less than the traditional group (M = 6.7727, SE = 1.06891).

In addition, each section for both traditional and POGIL groups were analyzed. Figure 2 shows that a one-way ANOVA was conducted to determine if Classification Conceptions Inventory mean gain score was different for different sections with different types of instruction. Participants were classified into four groups: Section 4 (n = 14), Section 6 (n = 11), Section 1 (n = 8) and Section 2 (n = 14). Data is presented as mean ± standard error. Classification Conceptions Inventory mean gain score was statistically significantly different between different types of instruction, $F(3, 43) = 11.709, p < .001$. Classification Conceptions Inventory mean gain score were traditional section 1 ($M = -0.50, SE = 0.73$), traditional section 2 ($M = 4.36, SE = 0.44$), POGIL section 4 ($M = 2.01, SE = 0.49$), and POGIL section 6 ($M = 2.07, SE = 0.49$). Tukey post hoc analysis revealed that the mean gain score increase from traditional section 1 to traditional section 2 (4.857, 95% CI [2.57, 7.15]) was statistically significant ($p = 0.000$), from traditional section 1 to POGIL section 4 (2.571, 95% CI [0.28, 4.86]) was statistically significant ($p = 0.022$), from POGIL section 4 to traditional section 2 (2.286, 95% CI [0.33, 4.24]) was statistically significant ($p = 0.016$), and from POGIL section 6 to traditional section 2 (2.994, 95% CI [0.91, 5.07]) was statistically significant ($p = 0.002$). No other group differences were statistically significant.

Figure 3 involves data that needed Kruskal-Wallis test to determine if there were differences in Classification Quiz mean gain score for different sections with different types of instruction: POGIL section 4 (n = 14), POGIL section 6 (n = 11), traditional section 1 (n = 8), and traditional section 2 (n = 14). Distributions of Classification Quiz
mean gain scores were similar for all groups, as assessed by visual inspection of a box plot. Median Classification Quiz gain scores were not significantly different between the different sections of instructional groups, $\chi^2(3) = 6.711, p = 0.082$, traditional section 1 ($Mdn = 2.50$), traditional section 2 ($Mdn = 5.50$) POGIL section 4 ($Mdn = 4.50$), and POGIL section 6 ($Mdn = 3.00$).

Finally, Figure 4 shows that a Kruskal-Wallis test was conducted to determine if there were differences in Classification Conceptions Inventory and Classification Quiz combined mean gain score for different sections with different types of instruction: POGIL section 4 ($n = 14$), POGIL section 6 ($n = 11$), traditional section 1 ($n = 8$), and traditional section 2 ($n = 14$). Distributions of Classification Conceptions Inventory and Classification Quiz combined mean gain scores were similar for all groups, as assessed by visual inspection of a box plot. Median Classification Conceptions Inventory and Classification Quiz combined gain scores were significantly different between the different sections of instructional groups, $\chi^2(3) = 16.192, p = .001$ Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted $p$-values are presented. This post hoc analysis revealed statistically significant differences in Classification Conceptions Inventory and Classification Quiz combined gain scores between traditional section 1 ($Mdn = 2.50$) and traditional section 2 ($Mdn = 9.00$) ($p = .006$) and POGIL section 6 ($Mdn = 4.00$) and traditional section 2 ($p = .005$), but not between POGIL section 4 ($Mdn = 7.00$) or any other group combination.

**Fisher’s Exact Test 2x4 Results**
Every student answer to each of the questions on the Classification Conceptions Inventory and Classification Quiz were recorded and analyzed using Fisher’s exact test 2x4. Table 3 contains student responses for Classification Conceptions Inventory pre- and posttests that were compared between the traditional and POGIL groups. After completing the analysis, there was no significant difference in student responses between groups for either the Classification Conceptions Inventory pretest or posttest.

The same process was completed for the Classification Quiz. Table 4 shows the student responses for Classification Quiz pretests and posttests compared between traditional and POGIL groups. Out of the 20 questions on the quiz, questions 16 on the posttest was the only one that was significantly different between the groups (p = 0.003). The question asked for the Class name for a stuffed bat. All students in the POGIL group answered “Mammalia” where 23% of traditional students answered “Aves,” 9% answered “Arthropoda,” and 68% answered “Mammalia.”

Displayed on Table 4 are four questions that showed a tendency towards being significant with a p-value more than 0.05 but less than 0.1. Question one asked about fungus characteristics and resulted in traditional students answering more correctly than POGIL on the posttest (p = 0.079). Question two asked about the bracket fungus Phylum name. Both pre- and posttests showed a tendency to be significant (p = 0.078 and p = 0.092, respectively). The pretest for question two had more students from the POGIL group answering correctly while the posttest resulted in the traditional group answering more correctly. Student responses to Question 10 about the Kingdom and Phylum of the classification of a jellyfish plastimount pretest resulted more traditional students answering correctly than the POGIL group on the pretest (p = 0.088). Finally, question 12
on the posttest resulted in traditional students answering the question correctly more than the POGIL group ($p = 0.054$). The question asked for the Phylum of a snail presented in a plastimount. It is important to note that question 12 had an error where none of the multiple-choice answers were correct in response to the question. The question asked for the correct Phylum and the option contained the Class “Gastropoda” instead of the Phylum “Mollusca.” The question’s answers were not altered from pretest to posttest.

**Qualitative Data**

**Student interviews**

Qualitative data was gathered to investigate student conceptions and the effectiveness of POGIL pedagogy on preservice elementary teachers’ understanding of biological classification in comparison to traditional teaching pedagogy. Eight students were selected to participate in post-instruction clinical interviews. Themes were drawn from the collected data from both groups.

The first theme brought to attention was the grouping of animals made. Table 5 is a summary of the correct physical characteristics and vocabulary used by all participants (see Table 6 for answer key). Both POGIL and traditional students made groups and provided reasoning for those groups. Reasoning was based on physical characteristics and vocabulary. The second theme involved the presence of habitat and locomotion misconceptions preventing correct conceptions of biological classification. Habitat and locomotion misconceptions mainly involved aquatic organisms and unfamiliar organisms. The POGIL students were shown to have fewer misconceptions. The third theme is about Cytochrome C conceptions that both groups have. The final theme involves the justification of teaching strategies and how they affected student
understanding of biological classification. The comparison between the two pedagogies were based on vocabulary, depth of explanations, and claims of which one helped them learn.

**Traditional students have some correct conceptions; mainly mammals and birds.** Both POGIL and traditional students display classification conceptions when grouping organisms. Traditional students had correct groupings of mammals and birds with the correct physical characteristics being used. For example, students from the traditional group stated the following. The following passage lists all the correct conceptions for traditional students post interviews.

*Traditional Participant 425:* “Okay for this, for the birds, thought Aves, and for the chipmunk and beaver and seal, umm Mammalia. And then for the millipede, ants, and fly, Insecta. For the fish, it was the osteo, something.” When asked, what characteristics did they use to know this all, the participant said, “feathers” for birds, “Umm, fur and, I guess fur,” for mammals, the insect response was “well, for the ant and the fly, I kind of went by their legs.”

*Traditional Participant 922:* This participant made the following correct groupings, mammals because “they have fur,” birds because “they have feathers instead,” and insects “they have three legs, how, I don’t, umm. I don’t know. I just thought they were all insects.” The three legs were clarified to be three sets of legs later on in the interview. The millipede got its own group. “But, then this [millipede] does not have three legs. I don’t know. I can’t remember if that one has its own group or not though.” After some clarification that they had never seen the millipede before, the student decided not to include the millipede in the insect group.

*Traditional Participant 646:* Participant had the most correct groupings and physical characteristics. This participant made eight different groups. Referring to bird group, “I just, just because all of the feathers.” “The fly and the ant I decided are insects because of their legs. They have three pairs of legs.” “And then I put these all as mammals, because I know none of them lay eggs and seems that they all have some sort of fur.” “The starfish has radial symmetry. Which doesn’t seem to go with any of these other ones.” Therefore, the student put the starfish in their own group.

*Traditional Participant 849:* Participant stated that the physical characteristic for birds was “feathers” and “hair” for mammals.
Student conceptions were not always correct. Some students incorrectly labeled or didn’t know the groupings of some organisms. Examples include mislabeling a crab as a mollusk or a millipede as an insect. The following passages are all incorrect physical characteristics of organisms in the post-instruction interviews. This does not include habitat and locomotion misconceptions.

*Traditional Participant 849:* Student put the oyster, crab, starfish in one group and stated “I just put the Crustaceans together.” This student also put the millipede with the insects because “They’re both insects and they have segmentation.”

*Traditional Participant 425:* This student also incorrectly classified the millipede as an insect. “Well, for the ant and the fly, I kind of went by their legs. Yeah, I guess the millipede just because I think it’s [millipede] an insect.” Later on, the student incorrectly classified the snail, crab, worm, and insect. The student said, “The snail I would put with these ones, the crab and the clam and stuff. And um, maybe the worms with the insects.”

*Traditional Participant 922:* This student struggled and incorrectly classified the ant and the millipede together “because they’re segmented.”

*Traditional Participant 646:* The physical characteristics were partially correct when grouping the mammals. Student stated “I put these all as mammals, because I know none of them lay eggs and seems that they all have some sort of fur. And by not laying eggs, they give birth to a live animal.” This student correctly grouped the mammals together because of fur, but they also used live birth as a characteristic. Not all mammals give live birth and lay eggs. This student also incorrectly grouped the millipede with the earthworm as an Annelida. “Because it [millipede] has a lot of segments. And I think it falls under Annelida, or something like that.” Later on, the student combined the millipede and ant because “Our mealworms look similar to the millipede but that was an insect. So, I don’t know, maybe along the evolutionary trail, they branched off. That’s the only, I don’t know how else to say that. Just they both look like, worms in a sense, or grubs or whatever.”

**Almost all traditional students have habitat and locomotion misconceptions.**

Student conceptions in the traditional group heavily focused on habitat and locomotion misconceptions. Aquatic organisms often were grouped by habitat, because their actual
classification physical characteristics were unknown. For example, the starfish, oyster, crab, and fish were often considered together because they all live in aquatic environments. Another example of the use of habitat and locomotion was when students compared the duck to the goldfish and crocodile.

*Traditional Participant 646:* When this student was asked if the goldfish and duck Cytochrome C DNA differences were surprising, they responded with “No. Well, I mean, I guess if you thought about how they both lay eggs, that would be surprising. But, they just seem like two different animals to me. One has feathers and one doesn’t. One lives under the water, and one flies.” This student used both habitat and locomotion to justify the Cytochrome C DNA differences.

*Traditional Participant 425:* When trying to group the fish, starfish, crab, and oyster, the student said, “These ones are kind of tough. Um, I guess I don’t know why because they’re all in the water. I don’t know why but those ones…” student trailed off. Later they stated, “I guess just that they are all in the water.” They did not know the characteristics for these animals and therefore resorted to using habitat.

*Traditional Participant 849:* When asked to make groups, the bird, duck, cardinal, and the ostrich were related because “they all have feathers. They have claws. They have wings. A beak. Bird-like characteristics I guess. Mainly the feathers and the claws.” However, when asked to explain the grouping of the starfish, oyster, crab, and fish, the participant responded, “Just like, water creatures, I guess.” The participant used habitat to group the organisms. When comparing the crab to a millipede, they said they would not be grouped because “This one [crab] is typically in water whereas, like, the ant and the millipede are not found in water.” The student incorrectly classified the millipede as an insect due to habitat instead of a crustacean with the crab. Later on, the same student compared a duck to a crocodile using habitat. “Then the duck and the crocodile I would say because of their feet. And they are part water and part land.” Later in the interview, the comparison between a duck and a crocodile and between a duck and a goldfish was made. The closeness in cytochrome C DNA was deemed surprising. “A little bit with the duck and the crocodile. Just because they are more closely related then you originally think, because one has feathers and the other has scales I guess. But the goldfish and duck, not really, because they breathe differently and one’s a water animal and the other one’s…” the student trailed off. The goldfish and the duck were justified by habitat conception.

**Half of traditional students had incorrect Cytochrome C protein conceptions.**

Instruction for both traditional and POGIL groups involved an activity that worked with
Cytochrome C protein charts comparing the Cytochrome C protein DNA between different animals. The interview included questions to determine student conceptions of the Cytochrome C chart and how said chart is used to classify organisms. Half of students demonstrated incorrect Cytochrome C conceptions, while the other half correctly used the chart. The following are student statements about Cytochrome C conceptions.

*Traditional Participant 646:* This student had correct conceptions about Cytochrome C. They stated that the duck, crocodile, and ostrich all go into a group together. Student stated, “reptiles and dinosaurs, or maybe it’s just dinosaurs, they are descended from, or birds are descended from them. The number on there [cytochrome C chart] is pretty close. So, you can go with that too. The genetic difference.”

*Traditional Participant 922:* The cytochrome C conceptions for this student were correct. They stated that the ostrich and duck were related, “based on the number of differences in the DNA.” The student struggled to include the duck, crocodile, and ostrich together in one group, “because I don’t know if it went like: the ostrich is way down here and the duck is in the middle and then the crocodile is way over here. Or so like, I don’t know if they’d get grouped together.” Overall they knew how to use cytochrome C chart. It is unknown whether they were able to explain the reasoning behind the numbers, except for the fact that they are more closely related. For example, the student could not understand why the duck and crocodile are so close. “There’s not that many differences between them in DNA. Because, like a duck is a bird, and a crocodile is a reptile, so…”

*Traditional Participant 849:* This participant stated that they learned “how similar things are that you didn’t think were similar” from the cytochrome C chart activity. They mentioned later that cytochrome C involved DNA differences when comparing the ostrich and the duck. “Both birds and their DNA is closest related.” However, when trying to apply this to the duck and the crocodile, the student tried to make sense of the similarities between them using habitat. “Duck and the crocodile, I would say because of their feet. And they are part water and part land.” They also said that the high cytochrome C number between the fish and duck makes sense because “they breathe differently and, one’s a water animal and the other one’s…” and the student trailed off and never finished their thought.

*Traditional Participant 425:* Student started out by saying that they learned that cytochrome C protein means “um, that the closer, um, the numbers are I guess the smaller the number between two different organisms, the closer, the more closely related they are.” They correctly stated that the ostrich and the duck are the most closely related, “because they have fewer DNA differences.” They were surprised by the comparison between the duck and crocodile, and between the goldfish and
the duck. “Um, a little bit [surprised], yea, because, they none of them really seem to be related in characteristics. I’m surprised that a duck and crocodile are that closely related.” Beyond that, there were no other explanations or attempts to group organisms together.

Overall, the conceptions of traditional students contain correct and incorrect physical characteristics, including habitat and locomotion misconceptions. When students tried to come up with explanations, it often seemed that they were trying to find any justification for classification groupings. There are similarities in conceptions between traditional students and POGIL. However, there are also clear differences.

**POGIL students have more correct conceptions than traditional students.**

POGIL students’ biological classification conceptions were analyzed in the qualitative data. There are quite a few differences between POGIL and traditional groups regarding their conceptions of animal groupings. All POGIL students knew that birds’ key characteristic is feathers and that a starfish had radial symmetry. All but one POGIL student knew that mammals’ key characteristic is fur. The following are statements made by the POGIL participants describing their different groupings.

*POGIL Participant 445:* This student started off grouping with the starfish. “Okay. Well, so this one [starfish] here has radial symmetry, so I’d probably put that in a group. The two birds, I’d put with, grouped together. Both birds obviously fall under the Aves group.” The student then continued with the crab, and oyster “This one, I would go Crustacea, the crab. And then, this here I would put in the mollusk, or bivalve, or whichever one. The fish, I feel they’d be classified, obviously with the fish. I can’t think of the name, the one with the ‘O’, osteo…, yeah, I’ve never been able to pronounce that.” The student later stated that birds are grouped due to “feathers” and that fish “had the appendages adapted as fins. That kind of thing.” Also, the student stated, “The fact that oysters have two halves. So, that’s the Bivalvia. The Mollusca was, um, I can’t remember the classification of it. I just knew that if fell under the Mollusca.”

*POGIL Participant 960:* This student knew that birds have “feathers,” “starfish has radial symmetry,” and that mammals have “fur.” Insects were said to have “two sets [of legs], or three sets of two.” The oyster is stated to be a mollusk because “his shell. And he’s got a soft inside or whatever.”
POGIL Participant 103: When describing their groups, this student said the following about birds and mammals respectively, “I guess these, the feathers and the wings,” and “fur, I think just mainly fur.” The student grouped the guppy in a group and the crab and oyster in a different group based on “the scales and the endoskeleton maybe. And then these two, they have like a hard-outer shell. I think that’s what that is? I don’t know what that is.” The student knew that the starfish has “radial symmetry” and that the fly and the ant “have like exoskeletons and then their legs…that there’s three on each. And then this one, I didn’t know where to put,” referring to the millipede. “so, this one is just by itself.” The student later does place the oyster and the snail together because “the soft body and then the hard covering.”

POGIL Participant 835: Student stated that mammals “have fur and four legs, and, even though, we don’t I guess. It shows that they had a baby in here, so it shows they have mammillary glands.” Birds were grouped because “they have wings, and they have feathers.” The starfish was stated to have “radial symmetry.” The fish was placed in its own group because it “wasn’t like anything else,” and “it has fins.” The oyster was grouped as a mollusk, but physical characteristics were not described.

Just like the traditional group, POGIL student conceptions were not always correct. Some students incorrectly labeled or didn’t know the groupings of some organisms. The following passages are the incorrect conceptions revealed in the post-instruction interviews. This does not include habitat and locomotion misconceptions.

POGIL Participant 445: This student struggled with classifying the mammals. “Um, these two here, the seal and otter, err, the beaver. Yeah, that’s what I’m thinking. The chipmunk, I would probably end up putting, we will come back to that.” Later in the interview, the participant struggled with placing the chipmunk and beaver with the seal. The participant stated, “The chipmunk I would probably put it with the beaver and the, actually I wouldn’t. Just because it [the seal] has legs and is adapted as fins.” This student did not know that fur and mammillary glands are the key characteristics for mammals. The student also struggled with the grouping of the millipede with the insects. They stated that millipede has an “exoskeleton, the same as the ant and the fly,” and the two were previously placed in a group called “Insecta.” The student did say that the insects were grouped because of their “pairs of legs,” however, they were unsure if the millipede actually fit with the group. Later, they placed them together.

POGIL Participant 960: Initially, this student correctly placed the millipede outside of the Insecta group. However, the student later tried to group the earthworm with the millipede, because they both are “segmented,” but they would
subdivide after legs evolved into the group. In addition, the student later combined the crab with the oyster, because “they both have shells.” The student correctly labeled the crab as a “crustacean” because of “his shell,” and because “he has legs” differentiating it from the oyster being a “mollusk” because of “his shell. And he’s got a soft inside or whatever.” They correctly labeled each animal; however, they grouped them for incorrect reasoning.

POGIL Participant 103: Student incorrectly placed the earthworm with the millipede because they both have “segments” and “the worm-like body.”

POGIL Participant 835: The student correctly placed the crab in its own group; however, the physical characteristic used to place it on its own was incorrect. “Well, it has, um, claws, so that’s why I put it separate. Cause I think I remember something about having like, something with claws I think?” This student did provide correct key characteristics to classify mammals and birds, but they did add some incorrect physical characteristics. They said that mammals have “fur and four legs” and “mammillary glands.” Four legs is not a key characteristic. The final incorrect grouping involved the insects and the millipede. Later in the interview, the student was asked to group either the millipede with the ant or the crab. “Well, I would say probably these two [ant and millipede], because I think I remember when we learned, I don’t remember if these are similar to mealworms, but they had like the thorax, the abdomen, and then all that. And it seems to correlate with the ant. But with this, I can’t really tell. Because I think this has an antenna too, even though it has a lot of legs.” The student used the mealworm example to place the millipede in with the insects.

Majority of POGIL students do not have habitat and locomotion misconceptions. A distinguishable difference between the traditional group and the POGIL group is the amount of habitat and locomotion misconceptions present in the preservice elementary teachers’ descriptions of their animal groupings. Out of the students interviewed from the POGIL group, only one participant had these misconceptions.

POGIL Participant 960: When trying to classify the crab and the oyster, the student said “I feel like, at some point, he [crab] could have been with him [oyster] because they both have shells, but he [crab] has legs, so I think that makes him different. Because this is considered a mollusk or something? But then, I don’t know. Ok. But I think they have to be separated, because he’s free moving. Eventually, he would get his own group, because he can move.” The student correctly determined that they are in two groups and correctly called the
crab a “crustacean;” however, they used locomotion to make the decision instead of the crab’s exoskeleton and five pairs of legs or more.

The same student also had a habitat misconception. When trying to explain why the goldfish and the duck cytochrome C number didn’t surprise them, they stated, “Um, no, for the fact that a goldfish lives underwater and like, breathes a completely different way than a duck and crocodile does. So, that doesn’t surprise me that that would be that different.” The student continued with their explanation, “I mean, it surprised me that the duck and the crocodile are so similar, but the basics of a duck and crocodile are more similar than a duck and a goldfish so. I mean like legs. And they eat. And they breathe outside of the water. And they are, like, they’re mobile like with extremities rather than a fish moves through the water and breathes through gills.” This student has not only habitat misconceptions, but they also have the misconception of using locomotion instead of physical characteristics or DNA.

**Most of POGIL students had correct Cytochrome C protein conceptions, and some correctly used the chart to group animals.** When students were challenged to describe their conceptions of how the Cytochrome C activity applies to classification, a few misconceptions were revealed along with some correct conceptions. The following are statements made by POGIL students regarding the Cytochrome C activity.

**POGIL Participant 445:** This student demonstrated how to appropriately use cytochrome C chart for classification. The student incorrectly grouped the mammals, so they did not include the seal, because they thought seals “had adapted fins as appendages.” When looking at the cytochrome C chart, the student made the following conclusion, “I would put the chipmunk with the seal. Characteristics are close together compared to a chipmunk and a beaver, probably.” The student correctly used the chart to fix their incorrect grouping to include the seal with the chipmunk and the beaver.

**POGIL Participant 103:** This student correctly demonstrated that they know how to use a cytochrome C chart. First, they answered the question of whether they think scientists ever change the way they group their living organisms. They responded with, “Like, like when we learned about the cyto… or like the DNA and stuff. I think, I think that they would change, like if they saw how closely related, like, two things that seemed like really opposite, or I think they would change it to group it with something more related, if that makes sense.” The student describes that the DNA is important with the classification of organisms. The student continues later on to explain that the ostrich and the duck are closely related “because they have the least amount of differences” on the cytochrome C chart. The student also acknowledges between the small number between the duck
and the crocodile that “they are closely related, but they wouldn’t be classified together” under the same class. Student still grouped them as “Aves and reptiles,” but they knew that they are still closely related somehow. This is a correct conception.

**POGIL Participant 835:** This student made a similar statement to participant 103. When answering whether scientists would change their classification of an organism, they responded, “I think they would if they judge something based on characteristics, and then later when I have the technology to figure out DNA, they realized that somethings are more like other things than what they look like. So, closer like DNA relation that physical traits.” The student uses this correct conception to group the ostrich, crocodile, and the duck together. “Maybe the crocodile and the ostrich, because the ostrich and the duck have little similarities and the duck and the crocodile have little similarities, so maybe they would be more alike since they’re so different. Or they’re so much alike to the duck. So maybe the crocodile and the ostrich…could go together.” When asked what they based their conclusion on, they said, “the number of differences, in their DNA.” The student acknowledges that, when stuck between the physical characteristics and DNA, they “would say DNA,” because “DNA is more important that the physical characteristic.”

**POGIL Participant 960:** The student acknowledged that the smaller DNA number means that the “DNA is the closest” between the organisms. This student incorrectly explained why it was not surprising that the duck and the goldfish were very different in “DNA.” The student stated the following, “Um, no. For the fact that a goldfish lives underwater and breathes differently than a duck and crocodile does. So, that doesn’t surprise me that that would be that different.” The student uses habitat misconceptions to make sense of the DNA differences. The student added to their explanation by adding locomotion, “I mean like legs. And they eat. And they breathe outside of the water. And they are, like they’re mobile like with extremities rather than a fish moves through the water and breathes through gills.”

When asked what scientists would use to classify organisms—DNA or the physical characteristics—this student responded, “I think the features, just because that would make the most sense to the most variety—the mass of people. The majority of people will be able to see the physical characteristics that are the same rather than the DNA samples that are the same. Because on a day to day basis, you’re not comparing DNA with other DNA. But you can see that the two things both have wings. Or who things have feathers.” This student incorrectly chose physical characteristics as the most important, because characteristics are visible to the eye.

Overall, there are errors in both traditional and POGIL students’ conceptions.

However, when comparing the conceptions between the two groups, one seems to display
more understanding of biological conceptions than the other. This will be discussed next when analyzing the results to answer the second research question, how does the use of POGIL affect preservice elementary teachers’ understanding of biological classification when compared to traditional instructional methods?

**POGIL groups demonstrate more understanding than traditional groups.**
Addressing the second research question requires comparisons to be made between traditional pedagogy and POGIL pedagogy. A few themes were uncovered with this portion of the qualitative analysis. The first theme involves the use of vocabulary and preservice elementary teachers’ depth of understanding when explaining their conceptions. The second theme was that POGIL students were more correct their explanations of their conceptions and understanding than traditional students. The final theme for the second research question was that walking around the room helped students learn more.

**POGIL students used characteristic vocabulary, while traditional students used “similar” in their explanations.** When the interview began with asking students what they learned from the different pieces of their respective lessons, “similarity” was a distinct term constantly being used by the traditional students. The term “similarities” does not explain what characteristics were similar within the groupings. The following statements are typical statements from traditional students.

*Traditional Participant 922:* “I guess you started catching on like what the things that are similar in classification like which families are—I guess we didn’t get down to families—but species that were the same.”

*Traditional Participant 646:* “I basically looked at them. And if they had similarities, you know, it’s visually.” The student also explained how the cytochrome C chart worked. “Basically, you know the closer the number was to the initial animal, I mean that was more similar. I liked that one a lot. And that
one seemed pretty straightforward.” The student did not explain what is “similar” between the organisms.

**Traditional Participant 849:** When referring to the cytochrome C chart, the student stated, “how similar things are that you didn’t think are similar. Like for human, we’re pretty related, close related to like a hippo, err, yeah, a hippo. Which, to me that’s you would think it would be a 63. That we’re close to a hippo. So, you get to see how similar we actually are, when you think we wouldn’t be closely related.” The student continued to explain that a dog and a horse “you wouldn’t really compare, well, I guess you could compare the two, but they’re different but they’re more similar than you actually think.” The student kept mentioning that they are similar because the cytochrome C chart says that they are, but they did not use physical characteristic vocabulary to explain rather they just say they are “more similar than you actually think.”

**Traditional Participant 425:** This student was the only one to not use the term “similar” in their explanations. Instead, they used the term “characteristics.” “Mostly what I remember from it is the most general classification like for birds, or Aves, you know, Mammalia and then what features go with each of those major groups. Umm, and learning that, um, you know, certain characteristics, that’s what classify each animal or organism into a specific group.” They also stated about the cytochrome C chart that “the closer, um, the numbers are, I guess, the smaller the number between two different organisms, the closer, the more closely related they are.” This student used the term “characteristics” when explaining their thoughts instead of “similarities.”

It was the opposite for the POGIL students. None of the POGIL students used the term “similarities.” Instead, they used terms such as “different characteristics” and “physical characteristics.” Some students even used actual key characteristics in their explanations, such as “feathers” and “exoskeleton.” The following are typical statements made by POGIL students.

**POGIL Participant 445:** When explaining what was learned from the cytochrome C chart, the student stated, “this part I learned, well, we learned mostly that the ones that are closer together have, are more closely related to each other. That really helped, I guess, visually like it showed like different characteristics.” When explaining the walking around the room, they stated, “being able to take something that you can physically, like a stuffed animal, or a fish, or a skeleton, or some type of thing we got to see that Chordata is this type of skeleton, or Aves has wings, that kind of thing mammals separate, you get to see the different characteristics rather than just in the pictures. For example, you got to see the difference between a bird and the bat. One has hair and one has feathers.” This
student said “different characteristics,” but then continued to explain using an example with correct classifying terms between the bat and the bird.

*POGIL Participant 835:* When the student was asked to explain what they learned, they said things such as, “like what different traits animals have that they get classified by. Like feathers or endoskeleton or exoskeleton. And whether they fly, or things like that,” and when referring to the cytochrome C chart, “with this, it was the smaller numbers mean they have less differences, so they have more in common with the things that have the smaller numbers associated with them.” This student used key characteristic vocabulary terms in their explanations.

*POGIL Participant 960:* This student used the term “physical characteristics.” When explaining what they learned about walking around the room classifying organisms, they stated the following, “I mean, going around the room part was the simplest to me. It made the most sense. It made it the clearest, because you could see things that were grouped together and why. Like you get a group of organisms, like, okay, it doesn’t have feathers. Well, then it’s in, you know, this certain type of group. Or does it have tentacles with suckers on them. Like, that seemed to break it down into groups where you visually in your head could be like oh, okay. Well this, you know, has suckers on it, and so does this one, so they should be together kind of thing. Which basically just breaks it down into like, physical characteristics. Which I think are easier for the students to see the differences in then like, alright, let’s compare what a whale and a rabbit have in common [for DNA].” This student clearly used physical characteristic vocabulary in their explanations, along with the actual term “physical characteristics.”

The use of terms such as “similarities,” “physical characteristics,” and examples of characteristics, was not the only vocabulary difference between the POGIL and traditional groups. Other vocabulary differences included correctly naming groups and using key characteristics terminology to group those organisms. The following quotes are from both traditional and POGIL students comparing the use of classification vocabulary.

*Traditional Participant 849:* This student correctly stated that the birds had “feathers” and mammals had “hair.” However, they referred to the fish, crab, starfish and oyster as “water creatures” because of their habitat. The student had both misconceptions and incorrect physical characteristic vocabulary.

*POGIL Participant 103:* This student used a lot more vocabulary terms; however, they did not always use them correctly. For example, when describing birds, they said “feathers and the wings.” They did correctly name birds as “Aves” and “mammals” for animals with “fur.” This student also correctly explained that the
oyster has a “hard–outer shell,” but they incorrectly applied this explanation to the crab. They did, however, correctly label the crab as a crustacean. The student correctly named the insects as “Insecta” as well, and stated, “these have, like, exoskeletons, and then their legs, there’s three on each [side].”

*Traditional Participant 922:* Student correctly stated that “Mammals” have “fur,” while birds are “Aves” and have “feathers.” This student also pointed out that the “Insecta” group has to do something with having “three legs,” but they were thrown off by the millipede having numerous legs. They were stuck on a millipede being an insect because “I just thought they were all insects.”

*POGIL Participant 835:* This student used both correct and incorrect characteristics to explain their groupings. For example, they stated that the group “mammals” have “fur, four legs” and “mammillary glands.” This is partially correct, mammals are not characterized by having four legs. This student did try to name the phylum of the starfish because of its “radial symmetry,” but guessed incorrectly with “Cnidarian” instead of the other phylum containing radial symmetry, Echinodermata. In addition, this student did not necessarily know what to label the fish, but stated that “it has fins.” This student did correctly names the groupings of the oyster, snail, and earthworm. They said “mollusk,” “gastropod,” and “Annelida” respectively. The did not at any point refer to the oyster’s class name, or that the snail was a Mollusca. Characteristics were not listed for these animals.

*Traditional Participant 425:* This student did correctly group, name, and list off characteristics for “Aves” and “Mammalia.” However, this student used their habitat misconception determine the groupings of the starfish, oyster and crab; “I guess just that they are all in the water.” They did state that they would “separate because this [starfish] has radial symmetry.” So, they used the starfish’s correct physical characteristics to remove the starfish from their habitat grouping. They did correctly name the snail as “Gastropoda,” but they placed it with the crab, oyster, and the fish. The also correctly labeled the earthworm as an Annelida, however they grouped it still with the “Insecta” group. Not acknowledging that it does not have an exoskeleton, or appendages.

*POGIL Participant 445:* This student knew a large variety of Phylum and Class scientific names; however, the physical characteristics listed where not always correct. The group that this student struggled the most with was the mammals. They knew that they were “mammals,” but the physical characteristic used was not fur. For example, the student would not group the beaver and chipmunk with the seal because “I remember when we did the classification, like, one of the things was that legs and appendages adapted to fins. And I know, obviously, the chipmunk doesn’t have fins.” They didn’t want to place the seal with the mammals because it had “appendages adapted to fins;” completely disregarding that they all have fur. This student correctly named “Aves,” “Insecta” “Crustacea,” “Bivalvia,” “Mollusca,” and, although they could not pronounce it,
The student also knew the starfish Phylum grouping started with an “E.” The only aforementioned animal grouping that they did not know or use correct key characteristics for besides mammals were Insecta, Mollusca, and Crustacea. The student stated that Insecta have “pairs of legs” but do not mention how many pairs of legs. The oyster and crab fell under the groups “Mollusca” and “Crustacea” because, “Well, I guess I just kind of knew.”

*Traditional Participant 646:* Did not know most of the Phylum or Class names. They did know, “Insecta,” and “Mammalia;” however, their characteristics were not entirely correct for the mammals. For Insecta, the student correctly stated, “three pairs of legs.” Their description for mammals was the following, “because I know none of them lay eggs and seems that they all have some sort of fur.” This is only partially true, because there are a few mammals that do lay eggs. When explaining the crab, this student mentioned that Arachnids “have four pairs of legs” and that “things are also considered part, it says five pairs of legs.” They did not clearly state that they are referring to the crab having five pairs of legs. The only other characteristic listed was “radial symmetry” for the starfish.

*POGIL Participant 960:* This student did use more vocab but failed to classify numerous organisms correctly. They did know the following Phylum and Class names: “Insecta,” “mollusk,” “crustacean,” and “mammals.” They did correctly state that birds have “feathers” and that mammals have “fur.” They also knew that insects have pairs of legs stating, “two sets, or three sets of two.” However, the crab was grouped as a crustacean because of “his shell” and “he has legs.” Student questioned whether the crab and oyster were grouped at some point because “I think they have to be separated because he’s free moving. Eventually, he would get his own group, because he can move.” The student started to use locomotion to explain the difference between the two animals. This student also incorrectly grouped the earthworm and the millipede because they both are “segmented.” Although this is true, they are not in the same Phylum due to the earthworm not having an exoskeleton or appendages while the millipede has both.

Overall, the students from the POGIL group tended to use more biological classification vocabulary words, and they also tended to use them more correctly than the traditional group. The traditional students did use correct terminology at times, but the POGIL group was able to name more of them and use more correct physical characteristics instead of “just knowing” that they were a certain type of animal. This will be addressed in the next section.
POGIL students provided more in-depth explanations than traditional students. When students discussed their understanding of biological classification topics, there were three different ways that they provided explanations: 1) “I just know,” 2) they had a brief explanation about the topic, or 3) they demonstrated a deep understanding using a full explanation of their correct conception. The following statements are traditional student explanations regarding all topics from the interview.

*Traditional Participant 849:* This student stated the following about their understanding of grouping insects, “And then, these have, well this one [ant] has segmentation, and this one [fly] has wings, but they don’t have hair or fur. I guess I just kind of know it’s an insect.” They did not truly know the reason why they are insects; they “just knew” Later, the millipede was added to their grouping, because the ant and millipede are “both insects, and they have segmentation.” Although both do have segmentation, the student’s explanation is incorrect, and minimal.

*Traditional Participant 425:* This student did not really provide a lot of explanation for their thoughts; they just listed their answers. For example, when the student was answering the question of whether characteristics or DNA is more important when classifying organisms, they answered, “the DNA, because it’s more accurate.” They are correct, but their explanations were not in great depth.

*Traditional Participant 646:* The student expresses a few different types of explanations. There is an instant where they say that a fish was grouped as a fish because, “I mean that’s a fish. That’s the only thing I’m going off with that.” Later in the interview, the student states “like the mammal and the birds have like, inner skeletons. So, they be like Chordata. And, oh, and along with the fish.” The student did know a characteristic of a fish, but when it came to the oyster, they grouped it on its own because “it just looks different. I don’t really have a good answer for that one.”

Most of the explanations from this student were either short or incorrect. The student did try to provide more explanation for their reasoning behind pairing the millipede with the ant. “The only think I can think of is. Like, our mealworms look similar to the millipede, but that was an insect. So, I don’t know maybe along the evolutionary trail they branched off. That’s the only, I don’t know how else to say that.” They tried to explain with a comparison to another worm-like organism that has legs. Unfortunately, they were unaware that the key characteristic to be an insect is only having three pairs of legs. Another example of when they provided an explanation was when they said the following about the cytochrome C activity comparing the duck to the crocodile: “Well I mean. I guess
if you thought about how they both lay eggs, that would be surprising. But they just seem like two different animals to me. One has feathers and one doesn’t. One lives under the water, and one flies.” This student revealed having both habitat and locomotion misconceptions in their understanding.

Traditional Participant 922: This student had the most correct classification conceptions out of the traditional group. However, most of their explanations were straightforward. For example, when asked which pairing was most closely related, the answered “The ostrich and the duck, because it has the least number of differences.” They didn’t explain much beyond the simple answers.

Generally traditional students provided either brief explanations, or no explanations at all. The most common topics where students “just knew” the answer were insects and fish. There were only a few moments where they expressed a deeper understanding. POGIL students, alternatively, had demonstrated more in-depth understandings. Students still had some conceptions where they “just knew” the answer, but there were fewer of them and seemed to be related towards the key characteristics of fish, crustaceans, or mollusks. The following statements were made by POGIL students.

POGIL Participant 960: This student had the most pronounced misconceptions in their understanding out of the POGIL participants. However, when trying to explain their reasoning behind their groupings of animals, they always provided a physical characteristic. For example, when explaining their understanding of crabs being a crustacean, they responded with, “his shell. I feel like at some point he [crab] could have been with him [oyster] because they both have shells, but he [crab] has legs so I think that that makes him different.” Even though this is an incorrect statement, they still tried to use physical characteristics. They never said, “I just know;” they made an attempt and were straightforward.

POGIL Participant 103: This student had straightforward answers when classifying the different animals. Their responses were either correct, or unknown. However, when asked if scientists would ever change the way they grouped living organisms, the student had this in-depth response: “Like, like when we learned about the cyto, or like the DNA and stuff. I think, I think that they would change, like, if they saw how closely related, like, two things that seemed, like, really opposite, or I think they would change it to group it with something more related, if that makes sense?” This is a correct possible reason why scientists would change organism groupings.
POGIL Participant 445: The millipede was the most difficult organism for students to classify. This student provided an in-depth response to their grouping of it. “I guess I’d classify that, with possibly, and exoskeleton, maybe, I don’t know just kind of look at the legs and compare it, maybe look at the cylindrical body? That kind of thing. So, I’d classify the ant and the fly together, as Insecta.” The student did not include the millipede in this grouping. Regarding the crab, they knew it was a crustacean, and their reasoning was “I guess I just kind of knew.” Same with “Mollusca.” They did know that fish was grouped, “because it had the appendages adapted as fins.”

When this student was asked to explain is the number of DNA differences between the duck and the crocodile surprised them, they attempted to justify the similarities between the crocodile and the duck with physical characteristics. “The duck and the crocodile I feel like might be a little more reasonable because they both have legs and webbed feet and stuff. So, I guess characteristics you could look at might resemble each other. Have a little more characteristics than the goldfish and the duck.” Even though they used incorrect physical characteristics in their justification between the duck and the crocodile, they clearly understood that there is some kind of characteristic that ties the two organisms together.

POGIL Participant 835: Like everyone else, this student struggled with the classification of the millipede. This student used physical characteristics to try and classify it. “Well, this has like, a tone of legs and segments, so I thought that it was more of an insect. So, that’s why I put it with the ant. And then, it was confusing because the fly has wings, but yet it’s not really, it doesn’t have feathers.” Overall, it lead to the student’s conclusion, “I just stuck it with the ant because I thought it was an insect.” Later, when asked to group either the millipede with the ant or the crab, the student responded with the following: “Well, I would say probably these two [ant and millipede], because I think I remember when we learned, I don’t remember if these are similar to mealworms, but they had, like, the thorax, the abdomen, and then all that, and it seems to correlate with the ant. But, with this, I can’t really tell. Because I think this has an antenna too, even though it has a lot of legs.” They provided a more in-depth response. The student may have incorrectly grouped the millipede as an insect, but their reasoning did include some correct physical characteristics and they tried to reach the correct answer.

The student did have brief answers. For example, the reasoning behind the fish was “it has fins,” and, in a similar fashion, the student reasoned that the crab had claws. “[I] remember something about having like, something with claws I think.” Even though they were not correct about the crab, they still tried using physical characteristics instead of “just knowing.”

This student demonstrated having a deeper understanding of how DNA works in biological classification. When asked if scientists ever change how they classify things, they responded, “I think they would if they judge something based on
characteristics, and then later when they have the technology to figure out DNA, they realize that some things are more like other things than what they look like. So, closer like DNA relation than physical traits.” This showed that the student understood that the DNA is a critical component in the classification of organisms.

POGIL and traditional students had different levels of understanding. Traditional students often described their understandings either with comments like “I just know” or had a brief explanation of their understanding of a topic. POGIL students had fewer people claiming that they “just know” and more people providing at minimum a brief explanation. Three of them used more in-depth rationalizations. Not all of them were completely correct, but they at least used physical characteristics to try and provide reasoning for their answers. This shows that POGIL may have been a more effective teaching strategy than traditional pedagogy on preservice elementary teachers’ understanding of biological classification.

Both POGIL and traditional students felt walking around the room helped with their learning of biological classification. The final theme that was discovered in the qualitative data was that walking around the room classifying organisms with a dichotomous key helped with student learning of biological classification the most. Some POGIL students made comments about how the branching and Cytochrome C activities “helped” them learn about biological classification. The most common answer, however, was walking around the room. One traditional student made no comment regarding if anything helped their learning of biological classification. The following statements are from students from both groups that made comments about what helped them learn.

Traditional Participant 425: “Going around the room was helpful.” This was the summary of the student’s thoughts on what helped them. They thought the repetition of the activity was helpful. “Yeah, going around the room helped,
because we did it so many times that it just like, seared into my brain. The classifications and stuff like that, because we did it so much.”

*Traditional Participant 646:* Student mentioned how they remembered things from the dichotomous key. “Yes. Like, question number five [on Classification Conceptions Inventory assessment]. I just remember going through the packet and one of the things with insects was they have, you know, three sets of paired legs and stuff like that. I remember learning that the bat, even though it had wings, was a mammal.” They remembered key characteristics from the key. They also briefly mentioned that the cytochrome C chart helped, but going around the room was the most helpful. “Yean, I mean, going over that sheet when we went around the classroom, I could in my head basically remember most of these.” They also commented on how the continued practice allowed for the student to memorize the characteristics from the dichotomous key. “I just like the repetition. Like, when I went through that packet where we went around class. I mean, I had the background knowledge, and I just, like, reinforced it.” The student focused on the repetition of the activity for memorization practice.

*Traditional Participant 849:* This student claimed that the lecture helped with their preferred auditory learning, and that walking around the room helped, too. They stated that “talking about the characteristics [lecture] since I’m really auditory, helped a lot. Um, but I think going around the room in general was beneficial.” The student also mentioned that the cytochrome C activity from the traditional group helped. “I think when we were looking at the, the key [cytochrome C chart], like, how closely relating is the DNA, I think it kind of clicked then that, like the crocodile and the duck where they don’t seem similar, their DNA is closer together. And I think that’s when It clicked that they may not physically look the same, but they’re more related than you think.”

*POGIL Participant 835:* This student also claimed that walking around the room helped with their learning of vocabulary. “Yeah. Um. What helped me the most was probably, actually going around the room. Because it let us get familiar with the words. Like the more specific words. So, but doing that and associating an animal with the, it was like, it came to me quicker. Because I was like, oh yeah, I remember learning that. So, that helped I thought. To re-associate the words back with…” the student cut off their thought.

*POGIL Participant 103:* This student clearly found both the cytochrome C activity and walking around the room beneficial to their learning. When asked if the cytochrome C chart helped them learn anything about classification, the student responded with the following: “Um. Well this just, I guess just showed me how they’re related and then it showed me how, um, how some things you wouldn’t think would be close in DNA are. And how maybe that would help them maybe change how they classify it. So, it better fits with, like, other things that are closely related.” They also mentioned the helpfulness of the test. “well, this helped, I think it helped a lot, just cause a lot of this was on the test. The DNA
differences and then I think more so going around the room, because when we were making our own branches we didn’t know for sure if the characteristics we were using was correct.” The student also mentioned how having the dichotomous key was helpful when going around the room. “Yeah. It just helped to practice. And it, like, gave me a perspective on what each characteristic looked like I guess. Like, the differences between, like, the symmetry and all that stuff.” “So, going around the room helped me, so I could actually see, like, which ones they classified with.”

**POGIL Participant 445:** The student mentioned that all three activities helped with their learning of biological classification. “The branching activity, I figured like I learned a lot more about, like, the actual main characteristics of classification. Like, what they are and how scientists and biologists, people who deal classification go about classifying animals and how they group them together and it actually helped me see, so, by, you know, starting off with plants or animals, helped me follow the list and the branching of how you get to one spot to the next, and how you can separate those into individuals and get down closer and tell less characteristics and into more specific.”

When asked about how the cytochrome C chart helped, the student said, “this part I learned, well, we learn mostly that the ones that are closer together have, are more closely related to each other. That really helped, I guess, visually, like, it showed, like, different characteristics. But, I guess the one thing that was a little less unclear was maybe which characteristics are different, or how they, you know, are closer to each other because they’re, I guess closer in number, but what those numbers actually represent wasn’t clear.” They knew that the numbers referred to organisms being more closely related but did not know that it was protein DNA. “The chart with the differences, those really helped. With, when they gave us the actual, where was it. Like, with these different things, questions here that talked about which of the three animals are closely related. So, knowing that they’re closer, the numbers are, the number of different characteristics we’re closer than obviously that those animals were closer. That really helped. And then, just going around and actually doing the classification on the actual animals and stuff like that, that really helped too, that we had to really go around and look at each one.”

**POGIL Participant 960:** This student thought that going around the room was very helpful. “Um. Well different parts helped different ones. You know, like this section where you saw things you knew that that was off of this. And that we did a worksheet like this in class so that was kind of helping with that part of it. Um, and then definitely going around the room helped with all of these. And almost going around the room and the amount of things we had to do that day you kind of can remember things. I’m trying to think of, but I can’t remember anymore. But, like, like the bird one really stuck in my head so I was like, alright, so if it’s a bird, you know it’s in this one. Like because you were doing it over and over and over again so you were becoming more familiar. Like every spider is going to be
in the arachnid whatever.” The student continued with a reptile and amphibian example. “And, because you were doing it over and over and over again. I think especially doing like the reptiles and the amphibians, and like the way the described it. Does it have claws, or is it slimy? Or like, does it have claws and it’s dry? Or, is it slimy and doesn’t? or something. And so, that was helpful to like, to break it down to those like simple things. Does it have claws? No. Okay, and then it’s this. Like, I think that that helped definitely with these last questions.” The student also commented how the dichotomous key was helpful to their learning. “I think using the key was the most straightforward, because you were able to look at an object, go through a step-by-step process to get you an answer. And I think that was helpful.”

The student also had a comment about how working in groups with assigned roles was not helpful to them. “[Working in groups with assigned roles] was not helpful. At our age. Maybe in an elementary school classroom. I remembered doing that kind of stuff, but it was that, you know, when you assign the roles. It was more the, I like the idea of having someone writing everything down, being the recorder. Someone having to be the person to represent to the class. I do think that some of the roles are important. It was maybe more the only the one person could talk to the teacher. Because if you pick somebody who is in my group specifically unable to really understand what is going on, and you and another girl are sitting there like ‘I want to ask this question, and she’s not letting me,’ like it was very frustrating.” They seemed to have understood the purpose, but the student felt that only allowing one student from your group to ask questions was hindering their learning instead of helping.

All but one student, both traditional and POGIL, claimed that walking around the room helped with their learning. Although two traditional students and two POGIL students mentioned that their respective Cytochrome C activity helped with their learning of biological classification, and one POGIL student mentioned that the branching activity helped, the verdict was nearly unanimous that walking around the room was the most helpful for all students. Being that there was no difference of how the walking around activity was taught or conducted by students, this conclusion does not help determine which teaching strategy was more effective on student understanding of biological classification. The only difference observed was that the traditional students talked about the activity as a repetition process. The POGIL students also mentioned that there was a
lot of practice, but they made comments relating to how the benefit was the opportunity to actually look at the animals and see the characteristics in real life instead of on paper.

**Triangulation**

The final component of the quantitative and qualitative data analysis was the triangulation between the three components: 1) Classification Conceptions Inventory pre- and posttests, 2) Classification Quiz pre- and posttest, and 3) Post-instruction interview. Triangulation of the data was completed to answer both research questions. The results for the first research question, what are preservice elementary teachers’ conceptions of biological classification, will be presented first, followed by the triangulation results for the second research question, how does the use of POGIL affect preservice elementary teachers’ understanding of biological classification when compared to traditional instructional methods?

**Student Conceptions of Biological Classification**

Data from both the quantitative and qualitative analysis show preservice elementary teachers’ conceptions of biological classification. The Classification Conceptions Inventory and Classification Quiz were quantitative assessments to help determine student conceptions. When the two assessment scores were combined, results shown on Table 2, the gain scores were $5.44 \pm 0.67$ for the POGIL group and $6.77 \pm 1.07$ for the traditional group. Both groups exhibited improved scores from pretest to posttest indicating improved biological classification conceptions. Individual items on each assessment were analyzed. Both assessments support that the majority of students in both traditional and POGIL groups have correct conceptions of the classification of a mammal and a bird. For example, 86% of traditional students and 88% of POGIL students
answered Classification Conceptions Inventory question two correctly regarding the grouping of an owl and a penguin, because owls and penguins have feathers, unlike the bat. This is further supported by qualitative data.

*Traditional Participant 922:* When asked what characteristics, they knew to group mammals and birds with, they said, “that they [mammals] have fur,” and “Umm, that they have feathers instead?”

The most trouble students came across was classifying a bat into the correct Class. Question 16 on the Classification Quiz posttest resulted in 23% of traditional students claiming that the bat was in the Class Aves. All the POGIL students answered Mammalia. In the post-instruction, only one POGIL student had incorrect conceptions about mammals’ physical characteristics.

*POGIL Participant 445:* This student did not know that mammals are classified by having fur and mammary glands “Well, I remember when we did the classification, like, one of the things was that legs and appendages adapted to fins. And, I know, obviously, the chipmunk doesn’t have fins.”

Preservice elementary teachers’ biological conceptions contained misconceptions between amphibians and reptiles. Question three on the Classification Quiz pretest indicated that four people from traditional and five from POGIL thought that a frog was a reptile. Post-instruction, the posttest showed a decrease of students thinking the frog was a reptile from 14% to 5% and 20% to 8% for traditional and POGIL groups, respectively. The qualitative data did not include information about reptiles or amphibians.

Results indicated that invertebrates are difficult to classify. The Classification Quiz posttest indicated that 9% traditional and 16% POGIL students still considered a spider to be in the Insecta class instead of Arachnida. Two questions on the Classification Quiz (Questions 9 and 10) inquired about the symmetry of a jellyfish, and its Kingdom and Phylum. Results from the posttest regarding the symmetry of a jellyfish still indicated
that 18% of traditional and 4% of POGIL students thought these two animals are bilateral instead of radial. The classification of the jellyfish had even more inconsistencies. Only 50% of traditional and 40% of POGIL students answered that it was in the Kingdom Animalia and Phylum Cnidaria. This pattern was also seen in the qualitative data regarding the symmetry and classification of a starfish. The post-instruction interview showed that all POGIL students and three of the traditional students knew that a starfish had radial symmetry. However, only one person knew that it was an organism that was in the phylum Echinodermata, even though they did not remember the actual name.

*POGIL Participant 445:* This student was the only one to get close to a correct grouping: “Well, so this one here has radial symmetry, so I’d probably put that in a group.” Later on, they were asked if they knew the name, “Doesn’t it start with an ‘E’?”

The Classification Quiz continued to inquire about invertebrates in question 11. Students were asked to provide the phylum characteristics for a snail and a squid. The majority of traditional and POGIL students answered correctly on the posttest that they both have “a soft body with hard outer shell and one muscular foot or tentacles with soft body;” 95% and 96% respectively. However, when students were asked to group an oyster and a snail, very few knew the characteristics that classified them as a mollusk.

*POGIL Participant 445:* This student knew that the oyster was a bivalve, but didn’t know the physical characteristics to be a mollusk. “The face, that oysters have two halves. So, that’s the Bivalvia. The Mollusca was, um, I can’t remember the classification of it. I just knew that it fell under the Mollusca.” Later on, the student added the snail. “Take the snail and probably put it with the mollusk group. It’s got its shell, a one foot type of thing they call it.” Again, they explained the class Gastropoda’s physical characteristics but did not know what the mollusks have in common.

*POGIL Participant 960:* This student tried to place the crab with the mollusks even though they classified it as a crustacean. “I feel like at some point he [crab] could have been with him because they both have shells, but he has legs, so I think that makes him different.” This student incorrectly classified the mollusks as
all having a shell but forgot that cephalopods do not have shells and are a part of the phylum mollusks.

*Traditional Participant 922:* This student knew that the oyster and the snail should be in the same group because, “it was the soft body, or something, a muscle foot? I don’t remember.” This student was the closest in getting the correct classification physical characteristics.

When classifying and grouping organisms, the majority of student errors revolved around crustaceans and insects. On the Classification Conceptions Inventory, question two asked which out of the three presented organisms (housefly, bird, and ant) would be grouped together and why? On the posttest, 91% of traditional and 88% of POGIL students answered that the housefly and the ant should be grouped because they have a hard-outer covering on their body. Question 12 on the Classification Quiz asked which Phylum a snail belongs to. Although there were no correct answers in the options, 23% of traditional and 40% of POGIL students answered Crustacea on the posttest.

The qualitative data tells a similar story. No one who conducted the interview were able to provide the correct physical characteristics for the crab. Also, when asked to either group a millipede with an ant or a crab, everyone chose the ant. The majority of the students had a clear idea that insects were animals that had three pairs of legs, but when a millipede was presented, that confidence faltered. Everyone lacked the information about crustaceans having five or more pairs of legs, so they instead labeled the millipede as an insect. The following are typical answers from both traditional and POGIL students regarding the classification and grouping of the millipede

*Traditional Participant 646:* “I’m not sure on if this is an insect. But it’s got a lot of legs, so I’m going to say it’s not.” They say this because they say that insects “have three pairs of legs.” However, when presented with the ultimatum of grouping with an ant or the crab, they chose the ant. They tried to provide the mealworm analogy to justify their thoughts. “The only think I can think of is, like, our mealworms look similar to the millipede, but that was an insect. So, I don’t
know maybe along the evolutionary trail they branched off. That’s the only, I don’t know how else to say that. Just, they both look like, worms in a sense, or grubs or whatever”

*Traditional Participant 425:* This student stated no physical characteristics, “I would say the ant and a millipede. Because, um, I think because they’re both classified as insects.

*POGIL Participant 835:* This participant put the fly, ant, and the millipede together because “Well, this has, like, a ton of legs and segments. So, I thought that it was more of an insect. So, that’s why I put it with the ant.” Later they continued, “Well, I would say probably these two [ant and millipede] because I think I remember when we learned, I don’t remember if these are similar to mealworms, but they had, like, the thorax, the abdomen, and then all that, and it seems to correlate with the ant. But, with this I can’t really tell. Because I think this has an antenna too, even though it has a lot of legs.”

*POGIL Participant 103:* This student took a different route and did not classify the millipede with the insect. Instead, they combined it with the earthworm because “I mean, I think it would be a similar thing,” “the segments,” “and, like, the worm-like body.” When presented with the ultimatum, the student did say with the ant, but they could not provide a reason why. “I don’t know.”

**Student Habitat and Locomotion Misconceptions of Biological Classification**

In both the quantitative and qualitative data, habitat and locomotion misconceptions were uncovered. Question one on the Classification Conceptions Inventory quiz posttest uncovered two traditional students with a locomotion misconception about the housefly and bird being able to fly. Also, two POGIL students had a habitat misconception claiming that the housefly and the bird are grouped because they live in the air and on plants. Question two also indicated that two students had a locomotion misconception in both groups and one student from both groups had a habitat misconception. Question 11 asked which two types of characteristics should be used to classify organism. Two traditional students answered “habitat and anatomical,” and two traditional and four POGIL students answered “locomotion and anatomical,” and two
POGIL students answered that “locomotion and habitat” should be used to classify organisms.

The Classification Quiz also had one question that revealed a locomotion misconception. Question 16 asked what Class a bat belongs to; 23% of traditional students answered “Aves” instead of “Mammalia.” All POGIL students answered “Mammalia.”

These misconceptions were present in the qualitative data as well. The most common misconception regarded habitat. The following statements are by two traditional students who had habitat misconceptions:

Traditional Participant 425: Student grouped the fish, starfish, crab, and oyster. “These ones are kind of tough. Um, I guess I don’t know why because they’re all in the water. I don’t know why but those ones…” student trails off. Later they state, “I guess just that they are all in the water.”

Traditional Participant 849: Student grouped the starfish, oyster, crab, and fish. “Just like, water creatures, I guess.” The participant used habitat to group the organisms. When comparing the crab to a millipede. They said they would not be grouped because, “This one [crab] is typically in water whereas, like, the ant and the millipede are not found in water.” Later on, when the duck was compared to a crocodile, they used habitat. “Then the duck and the crocodile I would say because of their feet. And they are part water and part land.”

The following traditional and POGIL student had both locomotion and habitat misconceptions.

Traditional Participant 646: “No. Well, I mean, I guess if you thought about how they both lay eggs, that would be surprising. But, they just seem like two different animals to me. One has feathers and one doesn’t. One lives under the water, and one flies.” This student used both habitat and locomotion to justify the Cytochrome C DNA differences.

POGIL Participant 960: Student grouped the crab and the oyster together. “I feel like at some point he [crab] could have been with him [oyster] because they both have shells, but he [crab] has legs, so I think that makes him different. Because this is considered a mollusk or something? But then I don’t know. Ok. But I think
they have to be separated because he’s free moving. Eventually he would get his own group, because he can move.” When trying to explain why the goldfish and the duck Cytochrome C number doesn’t surprise them, they state, “Um, no. for the fact that a goldfish lives underwater and like, breathes a completely different way than a duck and crocodile does. So, that doesn’t surprise me that that would be that different.” “I mean, it surprised me that the duck and the crocodile are so similar, but the basics of a duck and crocodile are more similar than a duck and a goldfish so. I mean like legs. And they eat. And they breathe outside of the water. And they are, like, they’re mobile like with extremities rather than a fish moves through the water and breathes through gills.”

Student Conceptions Contain Errors of Cytochrome C Biological Classification

It was also found in the quantitative data, that Cytochrome C differences were sometimes justified by incorrect organisms’ physical characteristics. For example, for question six on Classification Conceptions Inventory 14% of traditional and 16% of POGIL students answered the tortoise and snake on the posttest because they both have more similar physical characteristics, even though the Cytochrome C chart indicated that the duck and the tortoise were more closely related. However, 86% of traditional and 80% of POGIL students did select the correct answer. Questions seven and eight challenged the students to compare the giant elephant shrew DNA number of differences to other animals and determine if their classification should be changed. Eight-six percent of traditional and 84% of POGIL students answered yes because the DNA shows that it is least related to the common shrew. The other 14% of traditional and 12% of POGIL students said no because the giant elephant shrew looks the most similar to the common shrew. Interestingly enough, when asked on question eight what the giant shrew should be classified with, all but one student per treatment group stated it should be with the elephant and the manatee.

The qualitative data provided more information about student conceptions regarding the Cytochrome C activity. A common thread among the interviewees was the
need to justify the Cytochrome C difference in numbers between organisms with some form of characteristic; whether it is a shared physical characteristic, or a shared habitat or locomotion characteristic. The following statements were made by traditional and POGIL students about their conceptions of Cytochrome C.

*Traditional Participant 849:* When comparing the duck and the crocodile, they responded with the following rationalization, “And then the duck and the crocodile I would say because of their feet. And they are part water and part land.”

*Traditional Participant 425:* The student put the crocodile and the duck together, “because they have fewer DNA differences.” When asked if it surprised them, “um, a little bit, yeah, because, they, none of them really seem to be related in characteristics.”

*Traditional Participant 922:* The duck and the crocodile’s small number surprised them. “Um, that there’s not that many differences between them in DNA. Because, like, a duck is a bird and a crocodile is a reptile, so.”

Traditional Participant 646: The goldfish and the duck dissimilarity was not surprising to this student. “Well, I mean. I guess if you thought about how they both lay eggs, that would be surprising. But they just seem like two different animals to me. One has feathers and one doesn’t. One lives under water and one flies.” The crocodile and the duck is not surprising because, “crocodiles are supposedly just as old as dinosaurs, or close to that. And there’s supposed to be some sort of relationship between birds and dinosaurs.”

*POGIL Participant 960:* When asked if anything was surprising to them, the student responded, “Um, no for the fact that a goldfish lives underwater and, like, breathes a completely different way than a duck and crocodile does. So, that doesn’t surprise me that that would be that different. I mean it surprised me that the duck and the crocodile are so similar, but the basics of a duck and crocodile are more similar than a duck and a goldfish, so. I mean like legs. And they eat. And they breathe outside of the water. And they are, like, they’re mobile, like, with extremities rather than a fish moves through the water and breathes through gills.”

*POGIL Participant 445:* “The goldfish and the duck I guess, I mean, kind of surprises me, but at the same time, not so much. Because one’s a fish and one’s a bird. But, the duck and the crocodile I feel like might be a little more reasonable because they both have legs and webbed feet and stuff. So, I guess characteristics you could look at, might resemble each other. Have a little more characteristics
that the goldfish and the duck.” The student later added, “yeah, the feet and the legs, I guess.”

POGIL Participant 835: This student mostly uses physical characteristics in their justification. “No. The duck and the goldfish don’t [surprise me]. Because, the duck has feathers and the goldfish has scales. And the goldfish has fins and the duck doesn’t, has wings.” The crocodile and duck did surprise them because, “the duck has feathers and crocodile has scales. And just the size. And I guess the physical characteristics are just so different.”

POGIL Participant 103: This student had correct conceptions about how Cytochrome C DNA differences are used in biological classification. They stated “Like, like when we learned about the cyto, or like, the DNA and stuff. I think, I think that they [scientists] would change, like, if they saw how closely related, like, two things that seemed, like, really opposite or I think they would change it to group it with something more related, if that makes sense?”

Overall, Students tend to have more correct conceptions about vertebrates than invertebrates. Errors in biological classification of amphibians and reptiles have shown to be present in preservice elementary teachers’ conception along with crustaceans, arachnids, insects, and mollusks. Misconceptions regarding the use of habitat and locomotion is present in preservice elementary teacher’s conceptions for both classifying organisms and providing a rationale for Cytochrome C differences. Next, the second research question is addressed regarding which pedagogy, POGIL or traditional, had an effect on preservice elementary teachers’ understanding of biological classification.

No Significant Difference Between Pedagogy Treatments Helping Preservice Elementary Teachers’ Understanding of Biological Classification

Figure 1 compares mean gain scores by treatment for each test instrument, including Classification Conceptions Inventory and Classification Quiz Combined gain scores where both assessment scores added together. One-way ANOVA and Mann Whitney U tests were conducted and determined that there was no significant difference between POGIL and traditional groups for any of the assessments.
An item analysis was conducted using Fisher’s exact test 2x4 for both Classification Conceptions Inventory and Classification Quiz between treatments. The Fisher’s exact test did not calculate any Classification Conceptions Inventory question results to be significantly different between treatments for either pre- or posttests. The Fisher exact test calculations for the Classification Quiz pre- and posttests did report one item to be significantly different between groups, and four items showed a tendency toward being significant. Question 16 asks what Class a bat belongs to. The responses were significantly different between groups on the posttest (p = 0.003). All POGIL students answered the question correctly while only 68% of traditional students answered it correctly. Questions one (bracket fungus characteristic) on posttest, two (bracket fungus Phylum name) on both pre- and posttest, 10 (Kingdom and Phylum jellyfish classification) on the pretest, and 12 (Phylum of snail) on the posttest showed a tendency toward being significant (p = 0.079, p = 0.078, p = 0.092, p = 0.088, and p = 0.054, respectively). All of them indicated that traditional students answered more correctly than POGIL students.

The qualitative data illustrated a slightly different perspective, which is that there were differences in how students classified organisms. POGIL students tend to classify more invertebrates correctly than traditional students as well as use more biological classification vocabulary. For example:

*Traditional Participant 425:* “Well for the ant and the fly I kind of went by their legs. Yeah, I guess the millipede just because I think it’s [millipede] an insect.” Later on, the student incorrectly classifies the snail, crab, worm, and insect. The student said, “The snail I would put with these ones, the crab and the clam and stuff. And um, maybe the worms with the insects.”

*POGIL Participant 103:* The student grouped the guppy in a group, and the crab and oyster in a different group based on “the scales and the endoskeleton maybe.
And then these two they have like a hard-outer shell. I think that’s what that is? I don’t know what that is.” The student knew that the starfish has “radial symmetry” and that the fly and the ant “have like exoskeletons and then their legs…that there’s three on each. And then this one I didn’t know where to put,” referring to the millipede. “So, this one is just by itself.” The student later placed the oyster and the snail together because “the soft body and then the hard covering.”

Only one POGIL student expressed having habitat and locomotion misconceptions, while there were three traditional students that had misconceptions. For example:

*Traditional Participant 849:* Student grouped the starfish, oyster, crab, and fish, and explained, “just like, water creatures, I guess.” The participant used habitat to group the organisms. When comparing the crab to a millipede. They said they would not be grouped because, “This one [crab] is typically in water whereas, like, the ant and the millipede are not found in water.” Later on, they compared a duck to a crocodile using habitat, “Then the duck and the crocodile I would say because of their feet. And they are part water and part land.”

*POGIL Participant 960:* “I feel like at some point he [crab] could have been with him [oyster] because they both have shells, but he [crab] has legs so I think that makes him different. Because this is considered a mollusk or something? But then I don’t know. Ok. But I think they have to be separated because he’s free moving. Eventually he would get his own group, because he can move.” The same student also had a habitat misconception. “Um, no. For the fact that a goldfish lives underwater and like, breathes a completely different way than a duck and crocodile does. So, that doesn’t surprise me that that would be that different.” The student continued with their explanation, “I mean, it surprised me that the duck and the crocodile are so similar, but the basics of a duck and crocodile are more similar than a duck and a goldfish so. I mean like legs. And they eat. And they breathe outside of the water. And they are, like, they’re mobile like with extremities rather than a fish moves through the water and breathes through gills.”

POGIL students demonstrated more of an understanding of Cytochrome C than traditional students, two POGIL students even used it in an example.

*Traditional Participant 922:* The Cytochrome C conceptions for this student were correct. The stated that the ostrich and duck were more related, “based on the number of differences in the DNA.” The student struggled to include the duck crocodile, and ostrich together in one group, “because I don’t know if it went like:
The ostrich is way down here and the duck is in the middle and then the crocodile is way over here. Or so like, I don’t know if they’d get grouped together.”

POGIL Participant 445: This student demonstrated how to appropriately use Cytochrome C chart for classification. The student incorrectly grouped the mammals because the student thought seals “had adapted fins as appendages.” The Cytochrome C chart caused the student to conclude, “I would put the chipmunk with the seal. Characteristics are close together compared to a chipmunk and a beaver probably,” correctly fixing their groupings.

POGIL students often provided more thorough answers than traditional students.

Traditional student explanations often were shorter and less descriptive in comparison to POGIL students. The following are two example in-depth statements by a traditional student and a POGIL student. Both students concluded that the ant and millipede are grouped together. This is incorrect, but the depth of the justifications was significantly different.

Traditional Participant 646: “The only think I can think of is. Like, our mealworms look similar to the millipede, but that was an insect. So, I don’t know maybe along the evolutionary trail they branched off. That’s the only, I don’t know how else to say that.”

POGIL Participant 835: “Well, I would say probably these two [ant and millipede], because I think I remember when we learned, I don’t remember if these are similar to mealworms, but they had, like, the thorax, the abdomen, and then all that, and it seems to correlate with the ant. But, with this, I can’t really tell. Because I think this has an antenna too, even though it has a lot of legs.”

Both students made the mealworm comparison in an attempt to justify that the millipede is grouped the same as an ant. The difference was that the POGIL student provided a more in-depth response that included some correct physical characteristics, such as references to segmentation.

Significant Differences Were Found Between Sections Quantitatively
Although the quantitative data did not show a significant difference between treatments, significant differences were found between sections. Figures 2, 3, and 4 illustrate significant differences between the different sections of students. The Classification Quiz did not have any significant difference between the sections. The Classification Conceptions Inventory did show a significant difference in the gain scores between traditional section 1 and traditional section 2, between traditional section 1 and POGIL section 4, and between traditional section 2 and POGIL section 4. The Classification Conceptions Inventory and Classification Quiz combined mean gain scores by section indicated a significant difference between traditional section 1 and traditional section 2, and between traditional section 2 and POGIL section 4.

In summary, the triangulation results indicated student conceptions of biological classification to include the following:

1. Both treatment groups’ classification of Aves and Mammalia were mostly correct with very few errors.

2. Invertebrates such as the mollusks, insects, and crustaceans were difficult for both treatment groups to classify.

3. Habitat and locomotion misconceptions are present in both treatment groups, but in the traditional group more than the POGIL group.

4. Both treatment groups showed errors in Cytochrome C conceptions, but POGIL group had two students that displayed correct application of the Cytochrome C chart.
The triangulation resulted in an inconclusive conclusion being drawn between pedagogy treatments between preservice elementary teachers’ understanding of biological classification.

Chapter Five

Conclusions
The purpose of this study was to determine the effect of process-oriented guided-inquiry learning (POGIL), on preservice elementary teachers’ understanding of biological classification. The research questions this study was based on were:

1. What are preservice elementary teachers’ misconceptions about common classification errors for mammals, birds, insects, arachnids, amphibians, and reptiles?

2. How does the use of process-oriented guided-inquiry learning (POGIL) affect preservice elementary teachers’ understanding of biological classification when compared to traditional instructional methods?

Both questions were initially researched in the literature review in Chapter Two, and they were both accounted for in the research design mapped out in Chapter Three methodology. Chapter Four reported the quantitative and qualitative results along with a triangulation of the data collected from the study. This fifth and final chapter will consider the conclusions drawn from the results followed by a discussion of limitations and suggestions for future research.

**Preservice Elementary Teachers’ Biological Classification Conceptions of Groups**

Preservice elementary teachers’ biological classification conceptions were determined based on their animal groupings, habitat and locomotion misconceptions, and Cytochrome C DNA. Students typically did well classifying the vertebrates. Very few students inaccurately classified the mammals or birds. Throughout the interviews, students would comment how animals need feathers to be included in the Aves group, or animals would need fur to be classified into Mammalia. Most students had difficulty classifying the fish and distinguishing between reptiles and amphibians.
*Traditional Participant 646:* Typical student responses regarded the classification of a fish as a “fish” because, “I mean that’s a fish. That’s the only thing I’m going off with that.”

Question three on the Classification Quiz pretest indicated that 14% of traditional students and 20% of POGIL students thought that a frog was a reptile. Although these numbers decreased to 5% and 8% respectively post intervention on the Classification Quiz posttest, the reptile/amphibian errors were still present in a few student conceptions.

The results of this study indicated that the majority of preservice elementary teachers had the most biological classification conception errors when trying to classify invertebrates. For example, the students were usually confident that, in order to be in Insecta, animals would need to have three pairs of legs. However, once the millipede was introduced, student confidence faltered. Most students placed the millipede with the insects instead of with the crustaceans. The following is a typical student response regarding the millipede classification:

*Traditional Participant 425:* “Well, for the ant and the fly, I kind of went by their legs. Yeah, I guess the millipede just because I think it’s [millipede] an insect.”

It was not surprising to the researcher that students were unable to classify the millipede as a crustacean because no one was able to explain the key characteristics of a crustacean. The crab for example, was often called a crustacean, but no one was able to explain why. They “just knew” that’s what it was. Sometimes the crab was referred to as a mollusk because students thought the crab had a “shell” instead of an exoskeleton.

*POGIL Participant 960:* The student grouped the crab with the oyster, because “they both have shells.” The student correctly labeled the crab as a “crustacean” because of “his shell,” and because “he has legs,” differentiating it from the oyster being a “mollusk” because of “his shell. And he’s got a soft inside or whatever.”
They correctly labeled each animal; however, they grouped them for incorrect reasoning.

There were a few students that were correctly able to classify the oyster as a Bivalvia, and the snail as a Gastropoda, but classifying the group Mollusca was often unknown to the students.

*POGIL Participant 445:* “The fact that oysters have two halves. So, that’s the Bivalvia. The Mollusca was, um, I can’t remember the classification of it. I just knew that if fell under the Mollusca.”

This study’s findings coincide with the findings in the literature review. The cross-age study conducted by Yen et al. (2007) with Taiwanese elementary, middle, high school, and university students found that their students incorrectly labeled amphibians and reptiles as well. Jambrina et al. (2010) witnessed preservice elementary teachers incorrectly labeling spiders as insects; some did not know the number of legs a spider has or what criteria is needed to classify as an Insecta. Although the current study did not focus on arachnids, confusion still took place involving insects and crustaceans. The millipede’s numerous legs were often disregarded and it was placed in the Insecta group.

**Preservice Elementary Teachers’ Habitat and Locomotion Misconceptions**

Habitat and locomotion misconceptions were ever present in preservice elementary teachers’ conceptions of biological classification. During the interviews, the animals that live in aquatic environments were grouped together due to their habitat. A couple students labeled the group as “water creatures.” The following is a typical statement from students with habitat misconceptions.

*Traditional Participant 849:* Three statements made by this student confirmed an error in their conceptions regarding the starfish, oyster, crab, and fish. “Just like, water creatures, I guess.” “This one [crab] is typically in water whereas, like, the ant and the millipede are not found in water.” “Then the duck and the crocodile I would say because of their feet. And they are part water and part land.”
A couple students also demonstrated having a locomotion misconception. For example, question 11 on the Classification Conceptions Inventory asked Which two types of characteristics should be used to classify organisms. On the posttest, 9% of traditional students and 20% of POGIL students answered locomotion and anatomical. However, the qualitative data from this study found that students with the locomotion misconceptions also seemed to have habitat misconceptions. The following two quotes are from two students that had both locomotion and habitat misconceptions.

*Traditional Participant 646:* “No. Well, I mean, I guess if you thought about how they both lay eggs, that would be surprising. But, they just seem like two different animals to me. One has feathers and one doesn’t. One lives under the water, and one flies.”

*POGIL Participant 960:* “I mean, it surprised me that the duck and the crocodile are so similar, but the basics of a duck and crocodile are more similar than a duck and a goldfish so. I mean like legs. And they eat. And they breathe outside of the water. And they are, like, they’re mobile like with extremities rather than a fish moves through the water and breathes through gills.”

These misconceptions found within the preservice elementary teachers’ conceptions were also present in past research across all student levels. Yen et al. (2007), Chiung Fen et al. (2007), and Kattman (2001) all witnessed the presence of habitat and locomotion misconceptions. But, not only was it found at the student level, Burgoon and Duran (2012) also found habitat and locomotion misconceptions within inservice teachers’ biological classification conceptions.

**Preservice Elementary Teachers’ Conceptions of Using Cytochrome C Protein DNA with Biological Classification**

Student conceptions of Cytochrome C tended to be minimal. Student conceptions usually did not venture beyond the knowledge that the numbers on the Cytochrome C
chart referred to how closely related two organisms are to each other. Some students just referred to the numbers as being “similar”.

*Traditional Participant 849:* “How similar things are that you didn’t think were similar.”

Two students demonstrated a complete understanding on how to use and apply the Cytochrome C chart. The following is an example of when a student used the Cytochrome C chart to correctly classify their group of mammals.

*POGIL Participant 445:* Student previously did not group the seal as a mammal because they thought seals “had adapted fins as appendages.” After the cytochrome C chart was viewed, they said, “I would put the chipmunk with the seal. Characteristics are close together compared to a chipmunk and a beaver, probably.”

When students were asked which was more important, DNA or anatomical features when classifying organisms that display opposing characteristics, students more often than not stated the following:

*POGIL Participant 835:* “I think they would if they judge something based on characteristics, and then later when I have the technology to figure out DNA, they realized that somethings are more like other things than what they look like. So, closer like DNA relation that physical traits.”

However, not all students agreed. For example, the following student claimed that the physical features were more important because they are what you see with your eyes.

*POGIL Participant 960:* “I think the features, just because that would make the most sense to the most variety—the mass of people. The majority of people will be able to see the physical characteristics that are the same rather than the DNA samples that are the same. Because on a day to day basis, you’re not comparing DNA with other DNA. But you can see that the two things both have wings. Or who things have feathers.”

On the Classification Conceptions Inventory, Question 6 required students to use Cytochrome C DNA differences to determine if a giant elephant shrew should be
reclassified. Most students answered correctly; however, 14% of traditional and 12% of POGIL students incorrectly answered that its classification should not be changed. Those students answered that it would still be classified with the common shrew because their appearance is most similar. The DNA sequences show that it should be classified with the manatee and the elephant because they have the least number of differences. There is currently no research regarding Cytochrome C and biological classification available to either support or dispute these claims. However, according to the Minnesota teaching standards Framework, student misconceptions regarding DNA tends to revolve around inheritance. The misconception usually involves the interactions between sequences of DNA and protein which is exactly what Cytochrome C is about, according to the American Society of Human Genetics (2008) (as cited in the Minnesota Department of Education, 2019). Cytochrome C is a protein and has mutated over time. The inheritance of this protein, including mutations, shows how related organisms can be which in turn affects the classification of organisms.

**Effect of POGIL Pedagogy on Preservice Elementary Teachers’ Biological Classification Conceptions is Inconclusive**

With the preservice elementary teachers’ biological classification conceptions determined, the differences between the effectiveness of the two types of pedagogies were examined. After data analysis, it was determined that further research needs to be conducted before a conclusion can be drawn. Gain scores by treatment for each assessment resulted in no significant difference. The Fishers exact test 2x4 analysis of each pre- and posttest assessment only found one item that was significantly different between treatments ($p = 0.003$). Question 16 on the Classification Quiz was not only
significant, but it was also the only test item on both assessments in which the POGIL group answered more correctly than the traditional group. The questions that showed a tendency of being significant all favored traditional students performing better than POGIL.

The qualitative data did supply evidence supporting the effectiveness of POGIL towards preservice elementary teachers’ conceptions. The POGIL group demonstrated the use of more correct vocabulary than the traditional group. For example, the following POGIL student provided additional vocabulary regarding the classification of a starfish, bird, fish, and the oyster than any other student interviewed.

*POGIL Participant 445:* “Okay. Well, so this one [starfish] here has radial symmetry, so I’d probably put that in a group. The two birds, I’d put with, grouped together. Both birds obviously fall under the Aves group.” “This one, I would go Crustacea, the crab. And then, this here I would put in the mollusk, or bivalve, or whichever one. The fish, I feel they’d be classified, obviously with the fish. I can’t think of the name, the one with the ‘O’, osteo…, yeah, I’ve never been able to pronounce that.” The fish “had the appendages adapted as fins. That kind of thing.” “The fact that oysters have two halves. So, that’s the Bivalvia. The Mollusca was, um, I can’t remember the classification of it. I just knew that if fell under the Mollusca.”

The POGIL group also had fewer habitat and locomotion misconceptions. Only one POGIL student expressed having misconceptions, whereas three traditional students had misconceptions present in their understanding of biological classification. The POGIL student however, had both habitat and locomotion misconceptions stated below.

*POGIL participant 960:* “I mean like legs. And they eat. And they breathe outside of the water. And they are, like they’re mobile like with extremities rather than a fish moves through the water and breathes through gills.”

Based on the quantitative data, qualitative data, and the triangulation, the results were not clear enough to draw the conclusion that POGIL was more effective than traditional instruction on preservice elementary teachers’ biological classification conceptions.
All the aforementioned POGIL research in the Chapter 2 literature review illustrates that POGIL is an effective pedagogy in science-related courses. POGIL, originally designed for general chemistry instruction, has been explored in other science areas, including anatomy and physiology, nursing, psychology, and pharmaceutical science (Roller & Zori, 2017; Soltis, Verlinden, Kruger, Carroll, & Trumbo, 2015; Vanags, Pammer, & Brinker, 2013). All studies have shown results in favor of POGIL. This literature support and the results of this current study requires the need for further research into the effectiveness of POGIL on the understanding biological classification. Additional reasoning for further research of this topic is due to the errors and limitations present in the study’s design, teaching implementation, instrumentation, and data analysis.

**Limitations**

There are a few limitations associated with this study. The first limitation is the fact that the sampling technique was not random. Therefore, the results of this study cannot be generalized for the entire preservice elementary teacher population. It can only apply to this specific sample population. In addition, the smaller sample size (n = 47) could have impacted the p-value significance. Because it was small, it could potentially prevent any significance from showing.

Biology 100, “Our Natural World,” is a non-major general biology course offered at Minnesota State University, Mankato. During this course, there is a biological classification lab that includes the same lesson taught for the BIOL 480 course. This is the same lesson that was used for the traditional group instruction. The only difference was the order of the organisms presented during the “walking around the room” activity.
Out of the preservice elementary teachers who participated in this study, 14 of them had previously taken BIOL 100. Their prior knowledge could have altered the validity of this study. There are other specific limitations associated with both the quantitative and qualitative data.

**Quantitative Limitations**

Quantitative data limitations involve the instruction and instrumentation. The instruction intervention included plant and fungi classification; not just animal classification. It is possible that the plant and fungi classification could have altered students’ conceptions or amount of attention spent on classifying animals. In addition, the Classification Quiz also included plant and fungi classification questions. The amount of studying that took place regarding animal classification could have been affected by the addition of plant and fungi classification. The amount of studying students did could not be controlled and is a limitation in this research. Cronbach’s Alpha test for validity and reliability was never calculated for the Classification Quiz. Therefore, the Classification Quiz may not measure what it was intended to measure. After the Classification Quiz pretest was administered, it was found that question 12 lacked a correct answer. This also affects the validity of the assessment.

Another limitation regarding the quantitative data involves the timing of the assessment administration. The dates of the posttests for both Classification Conception Inventory and Classification Quiz did not take place during the same week for all sections. Sections 1 and 6 took their posttests 17 days after sections 2 and 4 took theirs. This could have affected the validity of both the posttest scores.
The final quantitative limitation involved a negative gain score on the Classification Conceptions Inventory for the traditional section 1 group. This could have been a result of an outlier or possibly a misinterpretation of a teaching explanation. This could have created a significant difference between sections when there truly is none, or vice versa.

**Qualitative Limitations**

The sampling technique for the clinical interviews was not random, and therefore cannot apply to all preservice elementary teachers. The recorded interviews were translated verbatim. However, there were times where participants were difficult to hear due to mumbling or other background noises, which prevented the recording from being deciphered without the potential for error. In addition, the researcher was also unable to return to the participant to ask clarifying questions about their conceptions. The recordings were not transcribed and analyzed until seven years following the interview.

**Triangulation Limitations**

There is one specific limitation related to the triangulation analysis. The multiple-choice test in comparison to the interviews were not directly aligned for eliciting student conceptions. The Classification Conceptions Inventory heavily focused on vertebrates, the Classification Quiz included questions about plants and fungus, where the interview data indicated that students struggled more with invertebrates. This hindered the ability to triangulate more of the data directly.

**Suggestions for Future Research**

This study was conducted with a small sample size (n = 47). Future research should be conducted with a larger sample size. Future research should also consider
extending the study to include more participants and multiple semesters. Future research could also add a pre-intervention clinical interview to analyze and better understand how students’ conceptions shift post-intervention. Future Research should also take into account participants’ prior knowledge and how it could affect the results of the study.

Another suggestion for future research is to study not only more preservice elementary teachers but to also study preservice secondary life science teachers. Biological classification is also taught at the secondary level. Preservice secondary life science teachers’ conceptions should be researched in addition to determining whether POGIL is an effective method of instruction to improve biological classification conceptions. Future research should include the use of POGIL to help determine other misconceptions found in other biological science topics in addition to biological classification. Other topics future researchers could use POGIL for could be for molecular biology, such as DNA double helix structure, and genetics, such as the probability of inheritance and using Punnett squares.

**Summary**

This study explored preservice elementary teachers’ conceptions of biological classification as well as examined how POGIL affects their understanding of classification. It was found that preservice elementary teachers have the same conceptions regarding vertebrates and invertebrates found in the literature. This included the presence of misconceptions between reptile and amphibian, insect and crustaceans, habitat and locomotion. In addition, the quantitative and qualitative triangulation of the data resulted in the conclusion that further research needs to be conducted regarding POGIL’s effectiveness on preservice elementary teachers’ understanding of the topic.
There was no significant difference between POGIL and traditional groups and their success and conceptions with biological classification.
References


https://doi.org/10.1023/A:1009455201314


https://doi.org/10.1371/journal.pbio.2001630


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https://doi.org/10.1007/s11165-010-9193-2


### Table 1

*Timeline of Events and Instruments of the Study*

<table>
<thead>
<tr>
<th>Section Number</th>
<th>Instructor</th>
<th>Treatment Group</th>
<th>Classification Conceptions Inventory followed by Classification Quiz Pretests</th>
<th>Intervention</th>
<th>Classification Conceptions Inventory followed by Classification Quiz Posttests</th>
<th>Post-Instruction Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dr. Smith</td>
<td>Traditional</td>
<td>November 1&lt;sup&gt;st&lt;/sup&gt;, 2012</td>
<td>November 6&lt;sup&gt;th&lt;/sup&gt; and 8&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
<td>November 29&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
<td>December 6&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
</tr>
<tr>
<td>2</td>
<td>Zojonc</td>
<td>Traditional</td>
<td>October 31&lt;sup&gt;st&lt;/sup&gt;, 2012</td>
<td>November 5&lt;sup&gt;th&lt;/sup&gt; and 7&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
<td>November 12&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
<td>December 5&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
</tr>
<tr>
<td>4</td>
<td>Zojonc</td>
<td>POGIL</td>
<td>October 31&lt;sup&gt;st&lt;/sup&gt;, 2012</td>
<td>November 5&lt;sup&gt;th&lt;/sup&gt; and 7&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
<td>November 12&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
<td>December 5&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
</tr>
<tr>
<td>6</td>
<td>Dr. Smith</td>
<td>POGIL</td>
<td>November 1&lt;sup&gt;st&lt;/sup&gt;, 2012</td>
<td>November 6&lt;sup&gt;th&lt;/sup&gt; and 8&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
<td>November 29&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
<td>December 6&lt;sup&gt;th&lt;/sup&gt;, 2012</td>
</tr>
</tbody>
</table>

**Purpose:**

1. 1<sup>st</sup> set of quantitative data, elicit prior conception, content knowledge
2. Implement POGIL curriculum and traditional curriculum
3. 2<sup>nd</sup> set of quantitative data, elicit any changes in conceptions and content knowledge
4. Qualitative data, elicit any changes in conceptions
Table 2

Test Scores of Number of Items Correct for Each Section and Type of Instruction on the Classification Conceptions Inventory, the Classification Quiz, and Classification Conceptions Inventory and Classification Quiz Combined Scores for Each Type of Instruction.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>POGIL</th>
<th>Traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Section 4</td>
<td>Section 6</td>
</tr>
<tr>
<td>Classification Conceptions Pretest</td>
<td>7.86</td>
<td>7.91</td>
</tr>
<tr>
<td>Classification Conceptions Posttest</td>
<td>9.93</td>
<td>9.27</td>
</tr>
<tr>
<td>Classification Conceptions Gain Score</td>
<td>2.07</td>
<td>1.36</td>
</tr>
<tr>
<td>Classification Quiz Pretest</td>
<td>10.86</td>
<td>11.36</td>
</tr>
<tr>
<td>Classification Quiz Posttest</td>
<td>15.50</td>
<td>13.82</td>
</tr>
<tr>
<td>Classification Quiz Gain Score</td>
<td>4.64</td>
<td>2.45</td>
</tr>
<tr>
<td>Classification Conceptions Posttest</td>
<td>18.71</td>
<td>19.27</td>
</tr>
<tr>
<td>Classification Conceptions Gain Score</td>
<td>25.43</td>
<td>23.09</td>
</tr>
<tr>
<td>Classification Quiz Gain Score</td>
<td>6.71</td>
<td>3.82</td>
</tr>
</tbody>
</table>
Table 3

Proportion of Students Who Answered Correctly on Classification Conceptions Inventory Pretest and Posttest for Traditional and POGIL Groups (n = 47) (Fishers 2x4 Exact Test)

Question 1: Considering characteristics that scientists use to classify organisms, which should be grouped together? Why?

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bird &amp; Ant lay eggs</td>
<td>0.05</td>
<td>0.00</td>
</tr>
<tr>
<td>Housefly &amp; Ant have hard outer coverings on their bodies</td>
<td>0.64</td>
<td>0.91</td>
</tr>
<tr>
<td>Housefly &amp; Bird live in the air and on plants</td>
<td>0.09</td>
<td>0.00</td>
</tr>
<tr>
<td>Housefly &amp; Bird fly</td>
<td>0.23</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Fisher’s Exact 2x4 Test (p-value)  
0.954             0.205
Question 2: Considering characteristics that scientists use to classify organisms, which two should be grouped together? Why?

<table>
<thead>
<tr>
<th></th>
<th>Owl</th>
<th>Penguin</th>
<th>Bat</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Owl" /></td>
<td><img src="image2" alt="Penguin" /></td>
<td><img src="image3" alt="Bat" /></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
<td>Traditional</td>
</tr>
<tr>
<td>√ Owl &amp; Penguin have feathers</td>
<td>0.41</td>
<td>0.56</td>
<td>0.86</td>
</tr>
<tr>
<td>Owl &amp; Bat fly</td>
<td>0.32</td>
<td>0.28</td>
<td>0.05</td>
</tr>
<tr>
<td>Penguin &amp; Bat have wings</td>
<td>0.18</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>Owl &amp; Bat live in the forest</td>
<td>0.09</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.696</td>
<td></td>
<td>1.000</td>
</tr>
</tbody>
</table>
Question 3: Considering characteristics that scientists use to classify organisms, which two should be grouped together? Why?

<table>
<thead>
<tr>
<th>Dog</th>
<th>Lizard</th>
<th>Snake</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Dog" /></td>
<td><img src="image2.png" alt="Lizard" /></td>
<td><img src="image3.png" alt="Snake" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dog &amp; Lizard have four limbs</td>
<td>0.14</td>
<td>0.00</td>
</tr>
<tr>
<td>Lizard &amp; Snake have a tail</td>
<td>0.05</td>
<td>0.00</td>
</tr>
<tr>
<td>Dog &amp; Snake have an inner skeleton</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>Lizard &amp; Snake have scales</td>
<td>0.73</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Fisher’s Exact 2x4 Test (p-value)

- Pretest: 0.251
- Posttest: 0.117
Question 4: Consider considering characteristics that scientists use to classify organisms, which animal from Table 1 should be grouped with the turtle? Why?

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

<table>
<thead>
<tr>
<th>Animal</th>
<th>Number of differences from Turtle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turtle</td>
<td>0</td>
</tr>
<tr>
<td>Chicken</td>
<td>45</td>
</tr>
<tr>
<td>Toad</td>
<td>67</td>
</tr>
<tr>
<td>Large mouth bass</td>
<td>125</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>√ Turtle &amp; Chicken DNA sequences differ the least</td>
<td>0.68</td>
<td>0.64</td>
</tr>
<tr>
<td>Turtle &amp; Toad both live on land</td>
<td>0.23</td>
<td>0.20</td>
</tr>
<tr>
<td>Turtle &amp; Large mouth bass both swim.</td>
<td>0.09</td>
<td>0.16</td>
</tr>
<tr>
<td>Large mouth bass &amp; Turtle their DNA sequences differ the most</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.825</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Question 5: Out of the pairs of organisms in Table 2, which are most closely related? Why?

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

<table>
<thead>
<tr>
<th>Animal Pairs</th>
<th>Number of Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dog &amp; Penguin</td>
<td>14</td>
</tr>
<tr>
<td>Dog &amp; Turtle</td>
<td>13</td>
</tr>
<tr>
<td>Turtle &amp; Penguin</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>Dog &amp; Penguin DNA sequences differ the most.</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Dog &amp; Turtle both have 4 legs.</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>√ Turtle &amp; Penguin DNA sequences differ the least.</td>
<td>0.91</td>
<td>0.84</td>
</tr>
<tr>
<td>Turtle &amp; Penguin both live in the water.</td>
<td>0.09</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Fisher’s Exact 2x4 Test (p-value) 1.00 0.729
Question 6: Based on the information above, which two organisms should be grouped together? Why?

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

<table>
<thead>
<tr>
<th>Animal Pairs</th>
<th># of Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duck &amp; Tortoise</td>
<td>10</td>
</tr>
<tr>
<td>Duck &amp; Snake</td>
<td>22</td>
</tr>
<tr>
<td>Tortoise &amp; Snake</td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>√ Duck &amp; Tortoise both have inner skeletons and their DNA sequences differ the least.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duck &amp; Snake their DNA sequences differ the most.</td>
<td>0.55</td>
<td>0.64</td>
</tr>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Tortoise &amp; Snake they both have scales and while their number of DNA sequences differ more than Duck &amp; Tortoise, the sequences are still similar.</td>
<td>0.41</td>
<td>0.32</td>
</tr>
<tr>
<td>0.14</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Tortoise &amp; Snake live on land.</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.772</td>
<td>1.000</td>
</tr>
</tbody>
</table>
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 four other organisms. Should the classification of the Giant Elephant Shrew be changed based on this new DNA data? Why or why not?

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

<table>
<thead>
<tr>
<th></th>
<th>Giant Elephant Shrew</th>
<th>Common Shrew</th>
<th>Manatee</th>
<th>Elephant</th>
<th>Mouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture</td>
<td><img src="image1.png" alt="Picture" /></td>
<td><img src="image2.png" alt="Picture" /></td>
<td><img src="image3.png" alt="Picture" /></td>
<td><img src="image4.png" alt="Picture" /></td>
<td><img src="image5.png" alt="Picture" /></td>
</tr>
<tr>
<td>Number of differences</td>
<td>0</td>
<td>33</td>
<td>4</td>
<td>6</td>
<td>31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>No, don’t change its classification. The original classification with the Common Shrew is most accurate because they look the most similar.</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>No, don’t change its classification because the DNA data show it to be most closely related to the common shrew.</td>
<td>0.14</td>
<td>0.00</td>
</tr>
<tr>
<td>Yes, change its classification because the DNA data show that the Giant Elephant Shrew is least related to the Common Shrew.</td>
<td>0.64</td>
<td>0.86</td>
</tr>
<tr>
<td>Yes, change its classification because it has a trunk-like structure similar to the elephant.</td>
<td>0.09</td>
<td>0.00</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.303</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Question 8: Based on Table 4, which organism should the Giant Elephant Shrew be classified with?

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

<table>
<thead>
<tr>
<th></th>
<th>Giant Elephant Shrew</th>
<th>Common Shrew</th>
<th>Manatee</th>
<th>Elephant</th>
<th>Mouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture</td>
<td><img src="image1" alt="Giant Elephant Shrew" /> <img src="image2" alt="Common Shrew" /> <img src="image3" alt="Manatee" /> <img src="image4" alt="Elephant" /> <img src="image5" alt="Mouse" /></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of differences</td>
<td>0</td>
<td>33</td>
<td>4</td>
<td>6</td>
<td>31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest Traditional</th>
<th>POGIL</th>
<th>Posttest Traditional</th>
<th>POGIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Common Shrew</td>
<td>0.05</td>
<td>0.08</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>The Common Shrew &amp; Mouse</td>
<td>0.18</td>
<td>0.20</td>
<td>0.05</td>
<td>0.00</td>
</tr>
<tr>
<td>√ The Elephant &amp; Manatee</td>
<td>0.77</td>
<td>0.72</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>The Mouse</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test</td>
<td>1.000</td>
<td></td>
<td>0.722</td>
<td></td>
</tr>
<tr>
<td>(p-value)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Question 9: As you move from column 1 to column 3 in Figure 1, what happens to the number of members in each group?

Figure 1.

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>They increase</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>√ They decrease</td>
<td>1.00</td>
<td>0.92</td>
</tr>
<tr>
<td>They stay the same</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>None of the above</td>
<td>0.00</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Fisher’s Exact 2x4 Test (p-value)

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>(p-value)</td>
<td>1.000</td>
<td>0.214</td>
</tr>
</tbody>
</table>
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?

Figure 1.

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>√ They increase</td>
<td>0.59</td>
<td>0.64</td>
</tr>
<tr>
<td>They decrease</td>
<td>0.23</td>
<td>0.08</td>
</tr>
<tr>
<td>They stay the same</td>
<td>0.18</td>
<td>0.28</td>
</tr>
<tr>
<td>None of the above</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Fisher’s Exact 2x4 Test (p-value) 0.414 0.717
Question 11: Which 2 types of characteristics should be used to classify organisms?

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>√ Anatomical &amp; molecular</td>
<td>0.36</td>
<td>0.52</td>
</tr>
<tr>
<td>Habitat &amp; anatomical</td>
<td>0.27</td>
<td>0.28</td>
</tr>
<tr>
<td>Locomotion &amp; anatomical</td>
<td>0.27</td>
<td>0.08</td>
</tr>
<tr>
<td>Locomotion &amp; habitat</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.354</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* √ indicates correct answer for each item. *p* < .01.
Table 4

Proportion of Students Who Answered Correctly on Classification Quiz Pretest and Posttest for Traditional and POGIL Groups (n = 47) (Fishers 2x4 Exact Test)

Question 1: A key characteristic of the kingdom to which this organism belongs is ____. (Bracket fungus)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th></th>
<th>Posttest</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>Lacks roots and stems</td>
<td>0.50</td>
<td>0.40</td>
<td>0.27</td>
<td>0.12</td>
</tr>
<tr>
<td>Lacks a nucleus</td>
<td>0.05</td>
<td>0.12</td>
<td>0.00</td>
<td>0.16</td>
</tr>
<tr>
<td>√ Lacks chlorophyll</td>
<td>0.41</td>
<td>0.32</td>
<td>0.64</td>
<td>0.48</td>
</tr>
<tr>
<td>Has radial symmetry</td>
<td>0.05</td>
<td>0.16</td>
<td>0.09</td>
<td>0.24</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test</td>
<td>0.508</td>
<td></td>
<td>0.079#</td>
<td></td>
</tr>
<tr>
<td>(p-value)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Question 2: This organism is in the Phylum _____. (Bracket fungus)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>✓ Basidiomycota</td>
<td>0.14</td>
<td>0.36</td>
</tr>
<tr>
<td>Pinophyta</td>
<td>0.27</td>
<td>0.08</td>
</tr>
<tr>
<td>Pteridophyta</td>
<td>0.14</td>
<td>0.28</td>
</tr>
<tr>
<td>Zygomycota</td>
<td>0.45</td>
<td>0.28</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.078#</td>
<td></td>
</tr>
</tbody>
</table>
Question 3: This organism would be identified to the Class _____. (Frog picture and plastimount of frog)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>√ Amphibia</td>
<td>0.86</td>
<td>0.80</td>
</tr>
<tr>
<td>Arachnida</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Crustacea</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Reptilia</td>
<td>0.14</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Fisher’s Exact 2x4 Test (p-value) 0.706 1.000
Question 4: The biological taxonomic categories, in order from broadest to most specific are ______.

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>class, species, kingdom, phylum, family, genus, order</td>
<td>0.09</td>
<td>0.00</td>
</tr>
<tr>
<td>√ kingdom, phylum, class, order, family, genus, species</td>
<td>0.77</td>
<td>1.00</td>
</tr>
<tr>
<td>order, genus, family, phylum, kingdom, species, class</td>
<td>0.05</td>
<td>0.00</td>
</tr>
<tr>
<td>species, genus, family, order, class, phylum, kingdom</td>
<td>0.07</td>
<td>0.00</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.658</td>
<td>0.491</td>
</tr>
</tbody>
</table>
Question 5: This sample is from an organism in the Phylum _____. (Moss)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>Anthophyta</td>
<td>0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>√ Bryophyta</td>
<td>0.55</td>
<td>0.32</td>
</tr>
<tr>
<td>Pinophyta</td>
<td>0.14</td>
<td>0.28</td>
</tr>
<tr>
<td>Pteridophyta</td>
<td>0.27</td>
<td>0.28</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.389</td>
<td>0.624</td>
</tr>
</tbody>
</table>
Question 6: A key characteristic of the phylum to which this organism belongs is ______. (Fern plastimount with spores)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest Traditional</th>
<th>Pretest POGIL</th>
<th>Posttest Traditional</th>
<th>Posttest POGIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>√ Spores on underside of leaf</td>
<td>0.82</td>
<td>0.84</td>
<td>0.95</td>
<td>0.92</td>
</tr>
<tr>
<td>Obtains energy by photosynthesis</td>
<td>0.14</td>
<td>0.16</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Produces flowers</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>Produces cones</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.837</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Question 7: This organism belongs to the Class _____. (Spider with very small palps)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arachnida</td>
<td>0.91</td>
<td>0.86</td>
</tr>
<tr>
<td>Crustacea</td>
<td>0.00</td>
<td>0.05</td>
</tr>
<tr>
<td>Insecta</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Osteichthyes</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.670</td>
<td>0.832</td>
</tr>
</tbody>
</table>
Question 8: Which of the following is a correct way to write a scientific name?

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th></th>
<th>Posttest</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>Homo sapiens</td>
<td>0.09</td>
<td>0.04</td>
<td>0.14</td>
<td>0.04</td>
</tr>
<tr>
<td>√ Homo sapiens</td>
<td>0.45</td>
<td>0.44</td>
<td>0.64</td>
<td>0.68</td>
</tr>
<tr>
<td>Homo sapiens</td>
<td>0.05</td>
<td>0.04</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Homo Sapiens</td>
<td>0.41</td>
<td>0.44</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test</td>
<td></td>
<td></td>
<td></td>
<td>0.950</td>
</tr>
<tr>
<td>(p-value)</td>
<td></td>
<td></td>
<td></td>
<td>0.585</td>
</tr>
</tbody>
</table>
Question 9: This organism has _____ symmetry. (Jellyfish)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>Axial</td>
<td>0.27</td>
<td>0.08</td>
</tr>
<tr>
<td>Bilateral</td>
<td>0.18</td>
<td>0.16</td>
</tr>
<tr>
<td>Parallel</td>
<td>0.05</td>
<td>0.00</td>
</tr>
<tr>
<td>√ Radial</td>
<td>0.50</td>
<td>0.76</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.158</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Question 10: Classify this organism. What is its kingdom and phylum? (Jellyfish)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
<td>Traditional</td>
<td>POGIL</td>
<td></td>
</tr>
<tr>
<td>Animalia, Cnidaria</td>
<td>0.27</td>
<td>0.16</td>
<td>0.50</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Animalia, Echinodermata</td>
<td>0.32</td>
<td>0.08</td>
<td>0.18</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Fungi, Cnidaria</td>
<td>0.23</td>
<td>0.36</td>
<td>0.27</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Fungi, Echinodermata</td>
<td>0.18</td>
<td>0.40</td>
<td>0.05</td>
<td>0.12</td>
<td></td>
</tr>
</tbody>
</table>

Fisher’s Exact 2x4 Test (p-value)

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.088#</td>
<td></td>
<td></td>
<td>0.276</td>
<td></td>
</tr>
</tbody>
</table>
Question 11: Organisms in the Phylum represented by these organisms have _____. (Two plastimounts of a snail and squid labeled with a J and K respectively)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th></th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>An endoskeleton and bilateral symmetry</td>
<td>0.14</td>
<td>0.16</td>
<td>0.05</td>
</tr>
<tr>
<td>An exoskeleton and paired, jointed appendages</td>
<td>0.18</td>
<td>0.04</td>
<td>0.00</td>
</tr>
<tr>
<td>✓ A soft body with hard outer shell and one muscular foot or tentacles with soft body</td>
<td>0.68</td>
<td>0.80</td>
<td>0.95</td>
</tr>
<tr>
<td>Four pairs of legs and no antennae</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Fisher’s Exact 2x4 Test (p-value)                                               | 0.343   | 1.000   |
Question 12: The organism labeled J belongs to the Phylum _____. (Two plastimounts of a snail and squid labeled with a J and K respectively)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>Annelida</td>
<td>0.09</td>
<td>0.08</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>Crustacea</td>
<td>0.36</td>
<td>0.44</td>
<td>0.23</td>
<td>0.40</td>
</tr>
<tr>
<td>√ Gastropoda</td>
<td>0.41</td>
<td>0.40</td>
<td>0.77</td>
<td>0.44</td>
</tr>
<tr>
<td>Osteichthyes</td>
<td>0.14</td>
<td>0.08</td>
<td>0.00</td>
<td>0.12</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.965</td>
<td></td>
<td>0.054#</td>
<td></td>
</tr>
</tbody>
</table>
Question 13: This organism has an _____skeleton and belongs to the Phylum ______. (Turtle skeleton and picture)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>√ Endo, Chordata</td>
<td>0.09</td>
<td>0.04</td>
</tr>
<tr>
<td>Endo, Reptilia</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>Exo, Chordata</td>
<td>0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>Exo, Reptilia</td>
<td>0.64</td>
<td>0.60</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.789</td>
<td>0.530</td>
</tr>
</tbody>
</table>
Question 14: The tiger (*Panthera tigris*), domestic cat (*Felis catus*), and lion (*Panthera leo*) all belong to the same family, Felidae. This means that _____

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest Traditional</th>
<th>Pretest POGIL</th>
<th>Posttest Traditional</th>
<th>Posttest POGIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>√ The domestic cat is in a different genus from the lion.</td>
<td>0.36</td>
<td>0.44</td>
<td>0.55</td>
<td>0.64</td>
</tr>
<tr>
<td>The lion is in a different genus from the tiger.</td>
<td>0.09</td>
<td>0.20</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>The lion is the same species as the tiger.</td>
<td>0.27</td>
<td>0.24</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td>All three organisms are in different kingdoms.</td>
<td>0.27</td>
<td>0.12</td>
<td>0.18</td>
<td>0.12</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.503</td>
<td>0.898</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Question 15: This plant has leaves with (a) ______. It belongs to the Class ______. (Dicot, Rose)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>Needle-like structure, Monocotyledonae</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>√ Netted veins, Dicotyledonae</td>
<td>0.41</td>
<td>0.28</td>
</tr>
<tr>
<td>Spores on its underside, Dicotyledonae</td>
<td>0.00</td>
<td>0.08</td>
</tr>
<tr>
<td>Parallel veins, Monocotyledonae</td>
<td>0.55</td>
<td>0.60</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.663</td>
<td></td>
</tr>
</tbody>
</table>
Question 16: This organism belongs to the Class _____. (Stuffed bat)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest Traditional</th>
<th>Pretest POGIL</th>
<th>Posttest Traditional</th>
<th>Posttest POGIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aves</td>
<td>0.14</td>
<td>0.24</td>
<td>0.23</td>
<td>0.00</td>
</tr>
<tr>
<td>Arthropoda</td>
<td>0.18</td>
<td>0.12</td>
<td>0.09</td>
<td>0.00</td>
</tr>
<tr>
<td>√ Mammalia</td>
<td>0.68</td>
<td>0.52</td>
<td>0.68</td>
<td>1.00</td>
</tr>
<tr>
<td>Osteichthyes</td>
<td>0.00</td>
<td>0.12</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.333</td>
<td></td>
<td>0.003*</td>
<td></td>
</tr>
</tbody>
</table>
Question 17: The fungus growing on the bread is composed of whitish, thread-like mycelium. To which phylum does it belong? (Rhizopus on black paper)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>Anthophyta</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>Basidiomycota</td>
<td>0.32</td>
<td>0.48</td>
</tr>
<tr>
<td>Monocotyledonae</td>
<td>0.23</td>
<td>0.16</td>
</tr>
<tr>
<td>√ Zygomycota</td>
<td>0.45</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Fisher’s Exact 2x4 Test (p-value)

0.527

0.746
Question 18: Classify a dragonfly. What is its Kingdom, Phylum, and Class? (Dragonfly plastimount)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th></th>
<th>Posttest</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>Animalia, Arthropoda, Arachnida</td>
<td>0.05</td>
<td>0.04</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>√ Animalia, Arthropoda, Insecta</td>
<td>0.86</td>
<td>0.92</td>
<td>1.00</td>
<td>0.96</td>
</tr>
<tr>
<td>Animalia, Echinodermata, Asteroidea</td>
<td>0.05</td>
<td>0.04</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Animalia, Mollusca, Bivalvia</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.861</td>
<td></td>
<td>1.000</td>
<td></td>
</tr>
</tbody>
</table>
Question 19: This organism has ______. It belongs to the Phylum _____. (Canadian Earthworm picture and plastimount)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>An exoskeleton, Platyhelminthes</td>
<td>0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>A flattened body, Platyhelminthes</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>A soft body with a muscular foot, Annelida</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>√ Segmentation present, Annelida</td>
<td>0.68</td>
<td>0.72</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>0.741</td>
<td></td>
</tr>
</tbody>
</table>
Question 20: A key characteristic of the class to which this organism belongs is _____. (Bird)

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
<td>POGIL</td>
</tr>
<tr>
<td>Cylindrical body</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>√ Feathers present</td>
<td>0.95</td>
<td>0.92</td>
</tr>
<tr>
<td>Hair present</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Two legs</td>
<td>0.05</td>
<td>0.08</td>
</tr>
<tr>
<td>Fisher’s Exact 2x4 Test (p-value)</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

*Note. √ indicates correct answer for each item. * $p < .01$. # $p > .05$ and $p < .1$. 
Table 5

Correct Physical Characteristics Vocabulary Used by Participants in Qualitative Data.

<table>
<thead>
<tr>
<th>Physical Characteristics and Vocabulary</th>
<th>Traditional Section 1</th>
<th>Traditional Section 2</th>
<th>POGIL Section 4</th>
<th>POGIL Section 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>646</td>
<td>922</td>
<td>849</td>
<td>425</td>
</tr>
<tr>
<td>Echinodermata</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Radial symmetry</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Annelida</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cylindrical body</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Segmentation</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mollusca</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Soft body, with Hard outer shell and one muscular foot</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>OR tentacles with soft body</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Gastropoda</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>One large shell, tentacles on the head, gills or lungs</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Bivalvia</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Shell in two parts, the shell has two valves</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Exoskeleton</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Insecta</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3 pairs of legs</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Arachnida</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4 pairs of legs</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Crustacea</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5 or more pairs of legs</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Chordata</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Endoskeleton</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Osteichthyes</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Appendages adapted as fins</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Many have scales as part of their epidermis</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Aves</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Feathers</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mammalia</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hair</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mammillary Glands</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 6

*Answer Key of Physical Characteristics for the Classification of the Animals in the Clinical Interview.*

<table>
<thead>
<tr>
<th>Animal</th>
<th>Phylum</th>
<th>Class</th>
<th>Correct Physical Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starfish</td>
<td>Echinodermata</td>
<td>-</td>
<td>Radial symmetry; Hard body, spines over entire body</td>
</tr>
<tr>
<td>Earthworm</td>
<td>Annelida</td>
<td>-</td>
<td>Body wormlike, skeleton absent; Cylindrical body; Segmentation Present</td>
</tr>
<tr>
<td>Snail</td>
<td>Mollusk</td>
<td>Gastropoda</td>
<td>Soft body, with hard outer shell and one muscular foot OR tentacles with soft body; One large shell, tentacles on the head, gills or lungs</td>
</tr>
<tr>
<td>Oyster</td>
<td>Mollusk</td>
<td>Bivalvia</td>
<td>Soft body, with hard outer shell and one muscular foot OR tentacles with soft body; Shell in two parts, the shell has two valves</td>
</tr>
<tr>
<td>Crab</td>
<td>Arthropoda</td>
<td>Crustacea</td>
<td>Exoskeleton; Five or more pairs of legs, two pairs of antennae</td>
</tr>
<tr>
<td>Millipede</td>
<td>Arthropoda</td>
<td>Crustacea</td>
<td>Exoskeleton; Five or more pairs of legs, two pairs of antennae</td>
</tr>
<tr>
<td>Ant</td>
<td>Arthropoda</td>
<td>Insecta</td>
<td>Exoskeleton; Three pairs of legs, one pair of antennae, can have wings</td>
</tr>
<tr>
<td>Housefly</td>
<td>Arthropoda</td>
<td>Insecta</td>
<td>Exoskeleton; Three pairs of legs, one pair of antennae, can have wings</td>
</tr>
<tr>
<td>Goldfish</td>
<td>Chordata</td>
<td>Osteichthyes</td>
<td>Endoskeleton; Appendages adapted as fins, many have scales as part of their epidermis</td>
</tr>
<tr>
<td>Crocodile</td>
<td>Chordata</td>
<td>Reptilia</td>
<td>Endoskeleton; Dry, scaly skin, claws present if appendages are present</td>
</tr>
<tr>
<td>Duck</td>
<td>Chordata</td>
<td>Aves</td>
<td>Endoskeleton; Feathers and wings present</td>
</tr>
<tr>
<td>Ostrich</td>
<td>Chordata</td>
<td>Aves</td>
<td>Endoskeleton; Feathers and wings present</td>
</tr>
<tr>
<td>Cardinal</td>
<td>Chordata</td>
<td>Aves</td>
<td>Endoskeleton; Feathers and wings present</td>
</tr>
<tr>
<td>Chipmunk</td>
<td>Chordata</td>
<td>Mammalia</td>
<td>Endoskeleton; Hair and mammillary glands present</td>
</tr>
<tr>
<td>Seal</td>
<td>Chordata</td>
<td>Mammalia</td>
<td>Endoskeleton; Hair and mammillary glands present</td>
</tr>
<tr>
<td>Beaver</td>
<td>Chordata</td>
<td>Mammalia</td>
<td>Endoskeleton; Hair and mammillary glands present</td>
</tr>
</tbody>
</table>
Figure 1. Mean gain scores from two instruments for two different types of instruction. Error bars represent standard error. Calculated with one-way ANOVA and Mann-Whitney U test for POGIL \((n = 25)\) and traditional \((n = 22)\) instructional groups.
Figure 2. Classification Conception Inventory by section and type of instruction. Error bars represent standard error. Calculated with one-way ANOVA and Tukey post hoc analysis between POGIL Section 4 (n = 14), POGIL Section 6 (n = 11), Traditional Section 1 (n = 8), and Traditional Section 2 (n = 14). Bars with different letters show significant differences between means.
Figure 3. Classification Quiz by section and type of instruction. Error bars represent standard error. Calculated with Kruskal-Wallis H Test between POGIL section 4 (n = 14), POGIL section 6 (n = 11), traditional section 1 (n = 8), and traditional section 2 (n = 14).
Figure 4. Classification Conceptions Inventory and Classification Quiz combined mean gain scores by section and type of instruction. Error bars represent standard error. Calculated with Kruskal-Wallis H Test between POGIL section 4 (n = 14), POGIL section 6 (n = 11), traditional section 1 (n = 8), and traditional section 2 (n = 14). Bars with different letters show significant differences between means.
Appendix A: POGIL Laboratory Activity

• POGIL Classification Activity: How we Classify

• Lesson Plan for POGIL Classification Activity: How we Classify

• POGIL Group Roles

• POGIL Lesson Materials
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 isolated with a rationale. Space is provided for your diagram on the next page.

Format for Grouping

- moss, mushroom, oak tree, cedar
- waxwing bird, corn, octopus
- snail, earthworm, tarantula, fish, frog, owl, bat, honeybee, snake, alligator, squirrel, caterpillar
Diagram for Model 1
2. Create a few classification procedures that could be used to classify any 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

<table>
<thead>
<tr>
<th>Classification Procedures from Model 1</th>
<th>Supported</th>
<th>Refuted</th>
<th>Supported by the class</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
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<td></td>
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<tr>
<td>B</td>
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</tr>
</tbody>
</table>

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.

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.

<table>
<thead>
<tr>
<th>human</th>
<th>duck</th>
<th>fly</th>
</tr>
</thead>
<tbody>
<tr>
<td>monkey</td>
<td>penguin</td>
<td>fungus (yeast)</td>
</tr>
<tr>
<td>dog</td>
<td>turtle</td>
<td>pig</td>
</tr>
<tr>
<td>horse</td>
<td>rattlesnake</td>
<td>hippopotamus</td>
</tr>
<tr>
<td>rabbit</td>
<td>tuna fish</td>
<td>whale</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Names of Organisms Compared</th>
<th># of Cytochrome C differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>horse &amp; pig</td>
<td>5</td>
</tr>
<tr>
<td>pig &amp; hippo</td>
<td></td>
</tr>
<tr>
<td>hippo &amp; horse</td>
<td></td>
</tr>
</tbody>
</table>

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.
References


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 of 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
POGIL LAB LESSON PLAN

- 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, Rhizopus, moss, hemlock, blue spruce, Elodea
- Table 6: button mushroom, bracket fungus, Rhizopus, 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 POGIL 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 general patterns. 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 diagramming 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 careful 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 allotted (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

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**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

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

Recorder

- Recorder ensures that everyone has the same information written down and comes to the same conclusions.
- The recorder’s report is turned in to the instructor at the end of class.

Reporter

- Presents consensual group answers to the class.
- Should be concise
- Instructor will respond to questions from the reporter only.

Reflector/Quality Control

- 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.
Appendix B: Traditional Classification Activity

- Traditional Classification Activity: Classification of Organisms
- Lesson Plan for Classification of Organisms
- Key to Organisms
Classification of Organisms

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-generic), 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 categories 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)

Biologically Speaking

KINGDOM

PHYLUM

CLASS

ORDER

FAMILY

GENUS SPECIES
(Scientific name)
Activity 2: Classification of Organisms

There are 26 stations set up with different organisms. The stations will include organisms from the plant, animal and fungal 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
   - Segmentation

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 #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: ___________________
<table>
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<th>Station #</th>
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<th>Class</th>
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### Key to the Kingdom Animalia

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

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

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Animal Characteristics Worksheets

Examine the group of organisms that you have keyed out. List the key characteristics seen within each phylum / class.
9. Label below each circle the name of the organism, the mode of locomotion (if any), whether chlorophyll is present, its association, and what magnification you used to view the organism.

10. Determine the kingdom to which each organism belongs by finding the diagram at the end of this lab.
   If it belongs to the Kingdom Protista, use the key below to determine the phylum to which it belongs.
   Label the kingdom for all organisms and the phylum for Kingdom Protista only under each circle.

**Key to Kingdom Protista**
1a. Unicellular, filamentous or globular (Kingdom Protista ONLY) .................................................. 2
1b. Multicellular (Kingdoms Fungi, Plantae and Animalia) .................................................................. Biodiversity Lab
   2a. Chlorophyll present (appears green or blue-green in color) ......................................................... 3
   2b. Chlorophyll absent ........................................................................................................................... 4
3a. Motile (actively moves by flagellum), unicellular ........................................................................ Phylum Euglenophyta
3b. Non-motile, filamentous or globular ............................................................................................. Phylum Chlorophyta
   4a. Moves by cytoplasmic extensions (pseudopodia) ................................................................. Phylum Rhizopoda
   4b. Moves by numerous hair-like extensions (cilia) ......................................................................... Phylum Ciliophora

*Note the Kingdoms Fungi, Plantae and Animalia will be studied in a later lab.

11. After viewing the organism, clean your slide and cover slip. Repeat steps 2-10 for each organism until all provided organisms have been viewed.

**Activity 2: Questions**
Cytochrome C Activity

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.

Examine the Cytochrome C data table provided. The two most closely related species have the fewest differences in amino acid sequence. Answer the questions below using the table.

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

2. Which organism is most like the human?

3. How many Cytochrome C differences are there between each of the following:
   a. human and pig
   b. duck and penguin
   c. duck and crocodile
   d. horse and tuna

4. Which of the pairs in #3 are most closely related? Least closely related?

5. What if the structural similarities and molecular data (DNA, cytochrome C) do not agree? What is most accurate - basing the classification of organisms on structures, molecules, or both? Explain.
Model 3: Number of Differences in Cytochrome C Sequences (Edited for Educational Purposes)

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<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Penguin</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
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<td>4</td>
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<td></td>
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<tr>
<td>Crocodile</td>
<td>13</td>
<td>13</td>
<td>13</td>
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<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>5</td>
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<tr>
<td>Rattlesnake</td>
<td>13</td>
<td>13</td>
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<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
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<td>10</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td></td>
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</tr>
<tr>
<td>Tuna</td>
<td>27</td>
<td>29</td>
<td>29</td>
<td>27</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>26</td>
<td>26</td>
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<td>0</td>
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<tr>
<td>Fly</td>
<td>33</td>
<td>32</td>
<td>34</td>
<td>34</td>
<td>36</td>
<td>35</td>
<td>33</td>
<td>33</td>
<td>35</td>
<td>38</td>
<td>33</td>
<td>37</td>
<td>34</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Yeast</td>
<td>63</td>
<td>62</td>
<td>64</td>
<td>64</td>
<td>65</td>
<td>66</td>
<td>62</td>
<td>62</td>
<td>65</td>
<td>61</td>
<td>64</td>
<td>61</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 Cnidaria Arthropoda -- Crustacea
Pterophyta Echinodermata Arthropoda -- Insecta
Pinophyta Mollusca Arthropoda -- Arachnida
Anthophyta Mollusca -- Gastropoda Chordata
Anthophyta – Mollusca -- Bivalvia Chordata -- Osteichthyes
Monocotyledonae Mollusca -- Cephalopoda Chordata -- Amphibia
Anthophyta -- Dicotyledonae Annelida Chordata -- Reptilia
Zygomycota Platyhelminthes Chordata -- Aves
Basidiomycota Arthropoda Chordata – Mammalia

Handouts/Supplies:
• 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.

Pre-Laboratory Reading: LM p. 57-60
Pre-lab activity: Taxonomic Categories (KPCOFGS) p.58.

Lab Activities:

Schedule:

Traditional Group
   Day 1 Activities 1 & as much of 2 as possible
   Day 2 finish Activity 2, do cytochrome C traditional activity

Classification – DAY 1:

Intro & Activity 1:
   • Bean Plant, Aquarium, Mealworm observations/measurements (10 min)
   • Introduce Lab: scientific naming, Genus species with both underlined or italicized and genus capitalized, species lower case. (1 min)
   • Review taxonomic categories LM p. 58-59 (1 min.)

Activity 2: LM p. 60-73
   • Go over the vocabulary on p. 60.
   • Do an example of how to key an organism using the keys on LM p. 68 & 69.
   • Tell students for #53 to look the adult specimen to key it.
   • Also tell them for #43 to use Protista key p.49.
   • Explain that the key used in this class for organisms is based on appearance or structural characteristics. If we look at the DNA of organisms, organisms with the most similar DNA are most related in terms of evolution. This relatedness will not necessarily match the key or structural characteristics (how the organisms look). Often, the relatedness is reflected in structural characteristics and on keys, but not always.
   • Explain what a key characteristic is with an example (see LM p. 60, top).

   • Students key out all organisms using keys on LM p.68 & 69 to fill out LM p.61-67, “floating” as necessary to the other lab and to hallway.
     o 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 on the second floor.
   • Once they’ve classified all organisms, students need to complete Characteristics Worksheets for plants, and fungi (p. 70 and 71) (NO PROTISTS), and animals (pp.72 and 73)
Cytochrome C Activity

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.

Examine the Cytochrome C data table provided. The two most closely related species have the fewest differences in amino acid sequence. Answer the questions below using the table.

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

2. Which organism is most like the human?

3. How many Cytochrome C differences are there between each of the following:
   a. human and pig
   b. duck and penguin
   c. duck and crocodile
   d. horse and tuna

4. Which of the pairs in #3 are most closely related? Least closely related?

5. What if the structural similarities and molecular data (DNA, cytochrome C) do not agree? What is most accurate - basing the classification of organisms on structures, molecules, or both? Explain.
Keys to Organisms

1. Giant Water Scavenger Beetle
   a. Animal, Arthropoda, Insecta
2. Skunk
   a. Animal, Chordata, Mammalia
3. Pillbug
   a. Animal, Arthropoda, Crustacea
4. Squid
   a. Animal, Mollusca, Cephalopoda
5. Rabbit
   a. Animal, Chordata, Mammalia
6. Little Bluestem
   a. Plant, Anthophyta, Monocot
7. Bracket Fungi
   a. Fungi, Basidiomycota
8. Cardinal
   a. Animal, Chordata, Aves
9. Honeybee
   a. Animal, Arthropoda, Insecta
10. Snake Plant
    a. Plant, Anthophyta, Monocot
11. Cricket
    a. Animal, Arthropoda, Insecta
12. Corn
    a. Plant, Anthophyta, Monocot
13. Oak
    a. Plant, Anthophyta, Dicot
14. Tick
    a. Animal, Arthropoda, Arachnida
15. Fish Skeleton
    a. Animal, Chordata, Osteichthyes
16. Leech
    a. Animal, Annelida
17. Black Widow Spider
    a. Animal, Arthropoda, Arachnida
18. Spruce
    a. Plant, Pinophyta
19. Praying Mantis
    a. Animal, Arthropoda, Insecta
20. Cactus
    a. Plant, Anthophyta, Dicot
21. Armadillo
    a. Animal, Chordata, Mammalia
22. Tarantula
    a. Animal, Arthropoda, Arachnida
23. Patriot Crabs
    a. Animal, Arthropoda, Crustacea
24. Blue-Tongue Skink
    a. Animal, Chordata, Reptilia
25. Chinese Painted Quail
    a. Animal, Chordata, Aves
26. Tiger Salamander
    a. Animal, Chordata, Amphibia
27. Snapping Turtle
    a. Animal, Chordata, Reptilia
28. Fire-Bellied Toads
    a. Animal, Chordata, Amphibia
29. Softshell Turtle
    a. Animal, Chordata, Reptilia
30. Alligator
    a. Animal, Chordata, Reptilia
31. Wolf
    a. Animal, Chordata, Mammalia
32. Human (Mirror)
    a. Animal, Chordata, Mammalia
33. Bat
    a. Animal, Chordata, Mammalia
34. Moss
    a. Plant, Bryophyta
35. Campanula portenschlagiana (purp fl.)
    a. Plant, Anthophyta, Dicot
36. Jellyfish
    a. Animal, Cnidaria
37. Worm
    a. Animal, Annelida
38. Owl
    a. Animal, Chordata, Aves
39. Octopus
    a. Animal, Mollusca, Cephalopoda
40. Pine
    a. Plant, Pinophyta
41. Rhizopus/Black Bread Mold
    a. Fungi, Zygomycota
42. Fern *pennata*
   a. Plant, Pterophyta

43. Euglena *model? microcope?*
   a. Protista, Euglenophyta

44. Crayfish *banc*
   a. Animal, Arthropoda, Crustacea

45. Button Mushroom *stirc*
   a. Fungi, Basidiomycota

46. Snail *banc*
   a. Animal, Mollusca, Gastropoda

47. Cedar Waxwing *tax.*
   a. Animal, Chordata, Aves

48. Spider Plant *pennata*
   a. Plant, Anthophyta, Monocot

49. Mealworm & Beetle *banc*
   a. Animal, Arthropoda, Insecta

50. Coast Carpet Python *luc*
   a. Animal, Chordata, Reptilia

51. Iguana *luc*
   a. Animal, Chordata, Reptilia

52. Mudpuppy *lac*
   a. Animal, Chordata, Amphibia

53. Brittle Star *plach*
   a. Animal, Echinodermata

54. Clownfish *luc*
   a. Animal, Chordata, Osteichthyes

55. Yellow Damselfish *luc*
   a. Animal, Chordata, Osteichthyes

56. Mouse *luc*
   a. Animal, Chordata, Mammalia

57. African Clawed Frog *lac*
   a. Animal, Chordata, Amphibia

58. Hissing Cockroach *plah / luh*
   a. Animal, Arthropoda, Insecta

59. Scorpion *potch*
   a. Animal, Arthropoda, Arachnida

60. Leopard Gecko *luc*
   a. Animal, Chordata, Reptilia

61. Mussel *shuh*
   a. Animalia, Mollusca, Bivalvia

62. Fluke *luc*
   a. Animalia, Platyhelminthes
Appendix C: Instruments

- Classification Conceptions Inventory Pretest/Posttest
- Classification Quiz Pretest/Posttest
- Student Interview Questions
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

3. Have you previously taken BIOL 100 at MSU?
   a. Yes
   b. No

4. Have you previously taken a college-level biology course?
   a. Yes
   b. No

5. Considering characteristics that scientists use to classify organisms, which should be grouped together? Why?
   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
   Housefly | Bird | Ant
   ![Housefly](image1.png)  |  ![Bird](image2.png)  |  ![Ant](image3.png)

6. Considering characteristics that scientists use to classify organisms, which two should be grouped together? Why?
   a. Owl & Penguin have feathers
   b. Owl & Bat fly
   c. Penguin & Bat have wings
   d. Owl & Bat live in the forest
7. Considering characteristics that scientists use to classify organisms, which two should be grouped together? Why?

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

8. Considering characteristics that scientists use to classify organisms, which animal from Table 1 should be grouped with the turtle? Why?

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

<table>
<thead>
<tr>
<th>Animal</th>
<th>Number of differences from Turtle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turtle</td>
<td>0</td>
</tr>
<tr>
<td>Chicken</td>
<td>45</td>
</tr>
<tr>
<td>Toad</td>
<td>67</td>
</tr>
<tr>
<td>Large mouth bass</td>
<td>125</td>
</tr>
</tbody>
</table>

Table 1.
Table 2. The number of differences between a comparable DNA sequence of selected pairs of animals.

<table>
<thead>
<tr>
<th>Animal Pairs</th>
<th>Number of Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dog &amp; Penguin</td>
<td>14</td>
</tr>
<tr>
<td>Dog &amp; Turtle</td>
<td>13</td>
</tr>
<tr>
<td>Turtle &amp; Penguin</td>
<td>8</td>
</tr>
</tbody>
</table>

9. Out of the pairs of organisms in Table 2, which are most closely related? Why?
   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.

<table>
<thead>
<tr>
<th>Animal Pairs</th>
<th># of Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duck &amp; Tortoise</td>
<td>10</td>
</tr>
<tr>
<td>Duck &amp; Snake</td>
<td>22</td>
</tr>
<tr>
<td>Tortoise &amp; Snake</td>
<td>15</td>
</tr>
</tbody>
</table>

10. Based on the information above, which two organisms should be grouped together? Why?
   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 11 & 12.

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

<table>
<thead>
<tr>
<th>Picture</th>
<th>Giant Elephant Shrew</th>
<th>Common Shrew</th>
<th>Manatee</th>
<th>Elephant</th>
<th>Mouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of differences</td>
<td>0</td>
<td>33</td>
<td>4</td>
<td>6</td>
<td>31</td>
</tr>
</tbody>
</table>

11. 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 four other organisms. Should the classification of the Giant Elephant Shrew be changed 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.

12. 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

13. 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
14. 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

15. Which two types of characteristics should be used to classify organisms?

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

1. A key characteristic of the kingdom to which this organism belongs is ____.
   a. lacks roots and stems
   b. lacks a nucleus
   c. lacks chlorophyll
   d. has radial symmetry

2. This organism is in the Phylum ____.
   a. Basidiomycota
   b. Pinophyta
   c. Pterophyta
   d. Zygomycota

3. This organism should be identified to the Class _____.
   a. Amphibia
   b. Arachnida
   c. Crustacea
   d. Reptilia

4. 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

5. This sample is from an organism in the Phylum ____.
   a. Anthophyta
   b. Bryophyta
   c. Pinophyta
   d. Pterophyta

6. A key characteristic of the phylum to which this organism belongs is ____.
   a. spores on underside of leaf
   b. obtains energy by photosynthesis
   c. produces flowers
   d. produces cones

7. This organism belongs to the Class _____.
   a. Arachnida
   b. Crustacea
   c. Insecta
   d. Osteichthyes

8. Which of the following is a correct way to write a scientific name?
   a. Homo sapiens
b. Homo sapiens  
c. homo sapiens  
d. Homo Sapiens  

9. This organism has _____ symmetry.  
   a. axial  
   b. bilateral  
   c. parallel  
   d. radial  

10. Classify this organism. What is its kingdom and phylum?  
   a. Animalia, Cnidaria  
   b. Animalia, Echinodermata  
   c. Fungi, Cnidaria  
   d. Fungi, Echinodermata  

11. Organisms in the phylum represented by these organisms have _____.  
   a. an endoskeleton and bilateral symmetry  
   b. an exoskeleton and paired, jointed appendages  
   c. a soft body with hard outer shell and one muscular foot or tentacles with soft body  
   d. four pairs of legs and no antennae  

12. The organism labeled J belongs to the Phylum _____.  
   a. Annelida  
   b. Crustacea  
   c. Gastropoda  
   d. Osteichthyes  

13. This organism has an _____ skeleton and belongs to the Phylum _____.  
   a. endo, Chordata  
   b. endo, Reptilia  
   c. exo, Chordata  
   d. exo, Reptilia  

14. The tiger (*Panthera tigris*), domestic cat (*Felis catus*), and lion (*Panthera leo*) all belong to the same family, Felidae. This means that ___  
   a. the domestic cat is in a different genus from the lion.  
   b. the lion is in a different genus from the tiger.  
   c. the lion is the same species as the tiger.  
   d. all three organisms are in different kingdoms.  

15. This plant has leaves with (a) _____. It belongs to the Class _____.  
   a. needle-like structure, Monocotyledonae  
   b. netted veins, Dicotyledonae  
   c. spores on its underside, Dicotyledonae
16. This organism belongs to the Class _____.
   a. Aves
   b. Arthropoda
   c. Mammalia
   d. Osteichthyes

17. The fungus growing on the bread is composed of whitish, thread-like mycelium.
   To which phylum does it belong?
   a. Anthophyta
   b. Basidiomycota
   c. Monocotyledonae
   d. Zygomycota

18. Classify a dragonfly. What is its kingdom, phylum, and class?
   a. Animalia, Arthropoda, Arachnida
   b. Animalia, Arthropoda, Insecta
   c. Animalia, Echinodermata, Asteroidea
   d. Animalia, Mollusca, Bivalvia

19. This organism has __________. It belongs to the Phylum ____.
   a. an exoskeleton, Platyhelminthes
   b. a flattened body, Platyhelminthes
   c. a soft body with a muscular foot, Annelida
   d. segmentation present, Annelida

20. A key characteristic of the class to which this organism belongs is ____.
   a. Cylindrical body
   b. Feathers present
   c. Hair present
   d. Two legs

Classification Quiz Images
Student Interview Questions

Starting the interview:
Welcome! I’m Beth Lavoie and am working with your instructor (Brittany or Stephanie) on this research project. You are taking part in an interview that will help me measure the effectiveness of a new teaching technique being used in BIOL 480. 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, and your responses will be kept confidential and will not affect your standing in BIOL 480. 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. I will also take notes on what was said. Once the audio is transcribed it will be destroyed. Transcriptions and notes will be stored in a locked file cabinet that only the researchers can access.

Reminders to Interviewer:
• list groups aloud and note them while progressing
• be sure to ask why are these are members of group x

Interview questions
Getting to know the students:

What is your favorite BIOL 480 project so far? What did you enjoy about it? Do you think elementary students will enjoy it? Learn from it? Do you think you will use what you are learning in BIOL 480 when you teach in your own classroom?

About the curriculum
1. What did you learn about the classification of biological organisms during the activities you did in class (POGIL group: POGIL models -grouping and diagramming, cyt c-, walking around the room// trad group: walking around the room, cyt C)?

2. Which activities do you think helped you more when answering the posttest questions? What about the activity was helpful?

3. What were barriers to your learning for each activity?
4. Which learning activities did you prefer? Why?

**Questions aligned with the outcomes:**

1. *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, moss, conifer, 2 flowering plants (one aquatic, one houseplant)*

   *Draw your groups as you rearrange the objects. (or interviewer draws)*
   1. How should these organisms be separated into groups?

   2. Describe the characteristics you are using while doing this.
   3. How did you decide which characteristics to use? Do scientists use the characteristics you are using? Would your instructor?

   4. Can any of the groups be combined?
5. Can any of the groups be subdivided?

6. How are the groups related to one another?

7. Which groups contain organisms with the most similar characteristics?

8. Are _____ & _____ or _____ & _____ more closely related? Explain your thinking.
9. What are the names of your groups? Names of groups these organisms belong to? What are the characteristics of organisms in groups with these names?

***add more organisms – how would you fit these into the groupings? What are their group names? Characteristics?

10. How do scientists classify living organisms?
11. Do scientists change their groupings of living organisms?

12. Show students their posttest with answers (except items related to DNA). Would you change any answers? How would you change your answers on the posttest? What made you change the answer?

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

<table>
<thead>
<tr>
<th>Number of DNA Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goldfish &amp; Duck</td>
</tr>
<tr>
<td>Chipmunk &amp; Seal</td>
</tr>
<tr>
<td>Ostrich &amp; Duck</td>
</tr>
<tr>
<td>Duck &amp; Crocodile</td>
</tr>
</tbody>
</table>

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?
   d. Duck & Crocodile

3. Which pair is most closely related?
   a. How do you know?
4. How do these groups fit with the groups that you made using the photos and models?

5. Compare the DNA differences between the goldfish & duck vs. duck and crocodile. Does the number of DNA differences between the duck and crocodile surprise you? Why or why not?

6. How are organisms grouped when DNA differences don’t match up with the features or structures of the organisms? Is one more important than the other?

7. Show students their posttest answers relating to DNA. Would you change any answers? How would you change your answers on the posttest? What made you change the answer?

For students whose pretests showed they already knew a lot about classification:
1. On your pretest (show pretest), you answered that molecular and anatomical data should be used to classify organisms. How did you know each one is important?

2. Did your knowledge of classification change during the class activities (POGIL models, cytochrome C comparisons, walking around room to classify)? If so, in what way?
3. What triggered the change?
Thank you for your time today! Here is a gift card to compensate you for your time.

Appendix D: Consent Form

• Student Consent Form
CONSENT FORM - BIOL 480 Study

Dear Biology 480 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 480 Biology Laboratory Experiences for Elementary Educators. The research is being conducted by Dr. Bethann Lavoie, Dr. Brittany Ziegler, Ms. Stephanie Zojonc, and Ms. 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 elementary education majors understand biological classification. This information will be used to inform BIOL 480 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 one to three weeks after your regular classification laboratory will be used. The pre and posttests should take 30-40 minutes of your time. The pretest score will be used for research purposes only. Even if you choose not to participate in the study, completing the pretest in class will earn you 5/5 points, and your posttest score will be used as your classification quiz grade for BIOL 480. The pretest, lab activities and posttest will be completed as normal BIOL 480 activities by all students, whether or not they are participating in the study. Once your instructor has recorded your points, your name will be removed from the tests. Your test will then be tracked with a randomly assigned code number.

In addition, you may be asked to voluntarily participate in a 20-minute student interview with the researchers. In this case you will be notified individually and may choose whether or not to participate. You will receive a $5.00 restaurant gift card to compensate you for the time you spend in the interview.

RISKS AND BENEFITS
You will be asked to answer questions about your understanding of biological classification. None of the questions will be personal. The responses you provide will be kept and used for the study after your name has been removed. 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.

CONFIDENTIALITY
If you choose to participate in this study, your test scores and interview responses will be kept confidential. Only the researchers 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 labeled with a code number, and the recordings 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 480, the Minnesota State University, Mankato, or the staff involved with this study. Even if you agree to participate by marking “yes” on the pretest and below, you are free to stop participating at any time without penalty by contacting the researchers.

CONTACT
The researchers conducting this study are Dr. Lavoie, Dr. Ziegler, Ms. Zojonc and Ms. Wozniak. You may contact them by emailing bethann.lavoie@mnsu.edu, brittany.ziegler@mnsu.edu, or stephanie.zojonc@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, write “yes” in front of the statements below.
______ I am at least 18 years of age.
______ I agree to the audio taping of the interview session.
______ I have received a copy of this consent.

Thank you for considering participating.

INSTRUCTOR CONSENT FORM
BIOL 480 Study

Dear Biology 480 Instructor,
You are invited to take part in research about a new teaching technique used in biology. You are a potential participant because you are an instructor for BIOL 480 Biology Laboratory Experiences for Elementary Educators. The research is being conducted by Dr. Bethann Lavoie, Dr. Brittany Ziegler, Ms. Stephanie Zojonc, and Ms. 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 elementary education majors understand biological classification. This information will be used to inform BIOL 480 instructors and other college instructors about the usefulness and academic benefits, if any, of this new teaching technique.

PROCEDURE
If you agree to participate in this research, we ask that you take part in a teaching technique training session before you teach the classification laboratory. This training will take two hours.

You will be asked to administer an in-class pretest and posttest the week before and one to three weeks after teaching the classification laboratories. The pre and posttests should take 30-40 minutes of class time. The students’ pretest scores will be used for research purposes only. Your students will be given 5/5 points for completing the pretest, even if they choose not to participate in the study. The students’ posttest scores will be recorded. The pretest, lab activities and posttest will be completed as normal BIOL 480 activities by all students, whether or not they are participating in the study.

In addition, you will be asked to voluntarily participate in an instructor reflection, which should take you 20 minutes, after you have taught the classification laboratories. The responses to your reflection questions will be used for research purposes only.

RISKS AND BENEFITS
You will be asked to answer questions about your experience facilitating the classification laboratories and the content that was taught. None of the questions will be personal. The responses you provide will be kept confidential. There are minimal risks while participating in this study, such as nervousness while using the new teaching technique or filling out the instructor reflection. There are no penalties if you do not participate.

CONFIDENTIALITY
If you choose to participate in this study, your reflection responses will be kept confidential. Only the researchers will see your responses. Your name will not be used with any of the responses. All responses 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 480, the Minnesota State University, Mankato, or the staff involved with this study. Even if you agree to participate by
writing “yes” below, you are free to stop participating at any time without penalty by contacting the researchers.

CONTACT
The researchers conducting this study are Dr. Lavoie, Dr. Ziegler, Ms. Zojonc and Ms. Wozniak. You may contact them by emailing bethann.lavoie@mnsu.edu, brittany.ziegler@mnsu.edu, or stephanie.zojonc@mnsu.edu. If you have any questions or concerns regarding 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, write “yes” in front of the statement below. 

_______ I have received a copy of this consent.

Thank you for considering participating.
you use that section word-for-word to explain the study and consent process, so at the top of this document is a bullet point list you could use instead if you like. Alter as needed so students understand clearly, do their best work, and have questions answered.

Abbreviated Consent Bullet Points

- Invitation to participate in research study.
- Study examines new teaching technique for biological classification
- Consent letter explains the study in detail
  - Read
  - Write yes at bottom if received letter
  - Yes if over 18
  - Yes if agree to audio taping
  - Please keep the consent letter for contact info if you have concerns about study
- Voluntary study
- Everyone in class will do the classification activities and fill out the tests as a normal part of class; only those who mark they are participating will have their scores and responses used
- No penalty or risk if you do not participate – meaning your scores and responses will NOT be used for the study but WILL BE used for the 5/5 points for the completed pretest and 5/5 points for the completed posttest (Brittany) or actual score on the posttest (Steph)
- Codes will be used after your points are recorded for confidentiality
- You may be contacted and asked to participate in a 20-minute interview during the last day of class

Any questions???

At the beginning of the BIOL 480 class and prior to the administration of the pretest (data collection), all students present will be asked to read the consent letter (attached) and write “yes” if they have received a copy of the letter, are over 18 years of age, and agree to audio taping of the interview. They keep the consent letter. The consent letter explains the study, risks, benefits, confidentiality, researcher contact information, and voluntary participation/discontinuation of participation in the study.

After students read the consent letter, Dr. Ziegler/Ms. Zojonc will explain the following:

1. **Students will mark “yes” for pretest item 1 if they wish to participate**; the data from students who marked “no” for item 1 will be excluded from the study. Students will **mark “yes” for item 2 if they are at least 18 years old**; the data from students who marked “no” for item 2 will also be excluded from the study. **Test scores and interview responses will be used only if “yes” is marked for both items 1 and 2.**

2. **Students may choose not to participate with no risk or penalty to them. Whether or not they choose to participate, they will be learning using the teaching strategies and taking the tests.** Filling out the pretest earns a student 5/5 points in the course. Students will receive 5 points whether or not they consent to participate in the study. The posttest score will be used as the classification quiz grade for BIOL 480 (Steph). Completing the posttest will earn students 5/5 points in the course (Brittany).
3. Each student will put his/her name on the front page of the test. Once students receive the 5 points in the instructor’s grade book, student names will be recorded on a piece of paper and assigned a random code number. The paper will be kept in a locked file cabinet in the PI’s office until the interviews are completed; then it will be shredded. **The code number will be written on the pretest, posttest, and interview (if applicable), and the front page of the tests with student names will be torn off and shredded** to maintain confidentiality. When data are entered and recorded, the database will contain code numbers only, no names.

Later in the semester, Dr. Lavoie will check the students’ pretest for consent and non-minor status. If consent was given and the student is over 18, the Dr. Ziegler/Ms. Zojonc will invite the students to participate in interviews conducted by Dr. Lavoie. Interviews will take place during the last BIOL 480 class meeting.