THE INFLUENCE OF ENGAGEMENT IN PRACTICAL WORK ON MIDDLE SCHOOL STUDENTS' ALTERNATIVE CONCEPTIONS REGARDING BIODIVERSITY

by

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ABSTRACT

With traditional teaching methods prevalent in the U.S., it is crucial that science teachers understand methods that result in authentic changes in classroom instruction. Alternative conceptions that students bring to the classroom present a roadblock to them becoming scientifically literate. Practical work presents a promising approach to developing an engaging and minds-on science classroom that lends itself to students digging deeper into the science content and becoming scientifically literate citizens. Although the research has been inconclusive regarding the effects of practical work, it can be used as a tool in the science classroom to help students confront their alternative conceptions. This study used an exploratory case study design to explore how a unit that contained practical work could influence students' alternative conceptions concerning biodiversity.

The researcher approached analysis from both individual and holistic perspectives. From an individual perspective, each participant's thinking fluctuated concerning the different alternative conceptions during the unit. From a holistic perspective, there were meaningful changes regarding biodiversity terminology. As a result, vocabulary during a unit can be influenced with use of practical work. Another conclusion from the study was students must have opportunities to confront alternative conceptions directly through instruction to ensure that new scientific information not only merges with their thinking but also shifts their thinking toward the scientific knowledge. Ongoing research is required to understand the implication of practical work in the classroom and how it can influence students' scientific thinking.

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CHAPTER ONE: INTRODUCTION

Background of Study

Science education has moved to a focus on students' integration of science knowledge and the application of that knowledge. Several initiatives such as No Child Left Behind (NCLB, 2002), the K-12 Framework for Science Education (National Research Council, 2012), and the Next Generation Science Standards (NGSS Lead States, 2013) have emphasized the movement to a more student-centered approach to learning. Due to this emphasis, rather than knowing disconnected facts, the major goal of science education is to produce scientifically literate students (National Research Council, 2012).

A scientifically literate student knows not only the basic concepts of science but also how to ask questions for testing their ideas, manipulate science equipment, and complete scientific procedures (National Research Council, 2012). In addition, this student understands that science is a way of knowing about the natural world and associated phenomena (Aydin, 2015). The National Research Council (2006) defined scientific literacy such that a person has the determination to find answers associated with experiences, whereby an explanation or description can be deduced from natural phenomena that also may be predicted and tested. To summarize, scientific literacy can be described as follows.

> The recognition of scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express

> positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately. (National Research Council, 2006, p. 22)

As indicated in this quote, scientific literacy not only encompasses a student being able to state scientific facts but also includes a student's ability to apply scientific knowledge to a given situation. Incorporating scientific literacy within the curriculum supports the development of informed citizens (National Research Council, 2012).

Current State of Science Education

In comparison to other nations, U.S. students appear to be underperforming on international assessments of science. Results for U.S. students on the Programme for International Student Assessment (PISA) in 2018 showed 15-year-old students in the United States performed a little above the average mark in overall performance (National Center for Education Statistics, 2018). The PISA has six levels of scientific literacy, with one being the lowest level and six being the highest level (National Center for Education Statistics, 2018). At the highest level, students can consistently identify, explain, and apply scientific knowledge to a variety of life situations. Of the students in the United States taking the assessment, 9% scored at the proficiency level of five and above. These students can creatively and autonomously apply their knowledge of and about science to a wide variety of situations, including unfamiliar ones (National Center for Education Statistics, 2018). In the United States, 19% of students performed below a level two, which is below the baseline for proficiency. These statistics demonstrate that the United States has a need for progress to be made for students to be on par with other education systems internationally.

When comparing test results for the United States, another internationally reported assessment is the Trends in International Mathematics and Science Study (TIMSS, National Center for Education Statistics, 2018). The most recent TIMSS test in 2015 showed that in fourth-grade science, the United States was among the top 10 scores; however, by eighth grade the United States had fallen from the top 10 among the 56 education systems included, down to the top 15. The development of U.S. students' declining scores prompted stakeholders to examine science education more closely.

Due to previous years' TIMMS test data, stakeholders are identifying and implementing ways to reform science education (National Center for Education Statistics, 2018). As international scores reveal areas of concern in American education, one context for examining science education is during the middle school years, where students are transitioning from the elementary curriculum and preparing for high school (Wigfield, Lutz, & Wagner, 2005).

Middle School Science

Middle school years are transitioning points in the K-12 educational setting and often begin the decline of students' success in science courses, as observed in international standardized tests (National Center for Education Statistics, 2018; Weinburg, Basile, & Albright, 2011). The National Science Teachers Association (NSTA) published a position statement in 2016 specifically addressing the role of science at the middle school level.

> NSTA recommends a strong emphasis on middle level science education, which can be achieved by staffing middle schools with teachers who are qualified to teach science and are trained and dedicated to working with students at this important period in their lives. Science concepts must be presented in an age-appropriate, engaging way so students can build on their prior knowledge and attain the necessary background to participate successfully and responsibly in our highly scientific and technological society. (para. 1)

This position statement demonstrates that the NSTA is committed to an emphasis on the middle school curriculum differentiated from the high school. Whereas most high school science courses have a lecture and a laboratory component, many middle school science classes miss the opportunity to incorporate a laboratory component due to various reasons such as space, resources, or estimated time (Toplis & Allen, 2012; Wilcox, 2009). As a result, other types of experiences are needed within the middle school classroom that engage students in the content and processes of science. Included among other types of experiences is practical work, a term used to identify the opportunities students experience while engaging with the science content (Toplis & Allen, 2012). Research has shown students must be engaged in the act of doing science (Edwards, 2015; Mestad & Kolsto, 2014; Toplis & Allen, 2012). One way to ensure engagement is to integrate practical work as a significant part of the science classroom.

Practical Work in Science Classes

Although much attention has been given to the role of laboratory experiences in the science classroom, laboratories represent but one of the several different means for engaging students in science. In recognition of this, the descriptive term "practical work" has been adopted for use in this study and other science education research, particularly in the United Kingdom (Abrahams & Millar, 2008; Osborne, 2015; Toplis & Allen, 2012). Practical work can be defined in several ways. One way is where students and/or teachers manipulate and observe real objects and materials (Abrahams & Millar, 2008). Another definition of practical work is any activity that requires the student to be active in the learning process or that mobilizes their science process skills (Ferreira & Morais, 2014). These definitions highlight different approaches to practical work, all with the goal to have students actively doing science and for their minds to also be focused on the science content. Practical work encompasses a wide scope of teaching strategies that can range from a teacher demonstration to an extensive inquiry-based laboratory experience (Abrahams & Millar, 2008). This is a method of teaching science that has many different purposes such as skill development, application of concepts, and engagement in the content (Hirvonen & Viiri, 2002).

Due to the broad range of activities that fall under its scope, practical work allows science teachers the latitude of using multiple class experiences to engage students in the science content. Practical work can be divided into four categories: practical work which develops general skills; practical work for the enhancement of the science skill of observations; practical work for inquiry of scientific concepts and principles; and practical work for illustration or verifying particular concepts (Mudau & Tabane, 2015). Practical work experiences help students gain understanding about the application of scientific processes, scientific concepts, and equipment usage. An important reason for students engaging in practical work in the classroom is for the students to be actively involved in the learning process (Toplis & Allen, 2012).

Due to the different implementations of practical work in the science classroom, the reviews on its effectiveness have varied (cf. Abrahams & Millar, 2008; Haslam & Hamilton, 2010; Osborne, 2015; Toplis & Allen, 2012). Despite practical work actively engaging students in the learning process, practical work has received critical comments about its effectiveness in the classroom (Hodson, 1990; Toplis & Allen, 2012). For example, it is believed that science teachers use practical work mindlessly and not intentionally by incorporating low-thinking level work and procedural practical work activities (Ferreira & Morais, 2014; Hodson, 1990; Toplis & Allen, 2012). Low-level practical work activities can also include activities where students are actively engaged, but not participating in the thinking behind an activity. Osborne (2015) suggested that practical work receives a negative connotation because it has been so loosely defined in the United Kingdom. The lack of understanding about what encompasses practical work has led researchers in the UK to believe that practical work has been implemented incorrectly (Osborne, 2015).

Another reason for criticism of practical work is the role that practical work can play in the classroom: it must aid students in understanding the content while at the same time help students to think and/or manipulate equipment like scientists (Hirvonen & Viiri, 2002). This double role can be difficult to translate to student learning. If practical work is only utilized to clarify content, it might restrict students' freedom to model scientific investigations. For example, many students know the formula for photosynthesis but do not have the scientific thinking to explain the formula. This would be an example of students having a superficial knowledge of the content and not being able to manipulate or apply their knowledge. To be a scientifically literate student, a student must be able to understand the science, how to explain it, and how to apply the content (Hirvonen & Viiri, 2002).

Despite the criticism, practical work, when appropriately implemented, has had some positive research results on its usage in the science classroom (Toplis & Allen, 2012). Practical work can foster students' conceptual understanding and experimental skills (Hirvonen & Viiri, 2002). It can engage them in the doing of science and foster a deeper understanding of the content (Hirvonen & Viiri, 2002; Pringle, 2006). It aids students in understanding the nature of science (Abrahams & Millar, 2008). Therefore, practical work should have a prominent role in science classes and could assist students in learning difficult content. Incorporating practical work in the classroom helps to address students' prior conceptions since practical work can provide opportunities to confront alternative conceptions (Hirvonen & Viiri, 2002).

Alternative Conceptions in Science

Students construct conceptual understanding in science based upon prior knowledge and yet often hold incorrect or alternative conceptions (American Association for the Advancement of Science [AAAS] Project 2061, 2016; Hewson & Hewson, 1983; Lucero & Petrosino, 2017). When practical work augments class instruction, it aids students' thinking about science concepts (Ferreira & Morais, 2014). Students need quality instruction, such as practical work, to help change alternative conceptions that are difficult to understand or are abstract (AAAS Project 2061, 2016; Sinatra, Brem, & Evans, 2008).

Alternative conceptions are defined as ideas that differ from the accepted scientific views (Stein, Larrabee, & Barman, 2008). Many alternative conceptions are formed before formal science learning has occurred such as in early childhood (Poehnl & Bogner, 2013; Wandersee, Mintzes, & Novak, 1994). Alternative conceptions are common in the area of life sciences because students interact with many of these topics daily outside the classroom (Poehnl & Bogner, 2013). For example, young children think trees can move their leaves, but do not consider that wind is causing this movement (Tanner & Allen, 2005). An example for older children is that students think the biomass in plants comes from nutrients in the soil and do not consider that most of it comes from the carbon dioxide in the air (Tanner & Allen, 2005). Examining students' thought processes has been of interest to science educators advocating for a scientific literate society (National Research Council, 2006; Stein et al., 2008). Science educators must examine the thoughts that students bring to the classroom before instruction occurs. "The single most important factor influencing learning is what the learner already knows: ascertain this and teach him accordingly" (Ausubel, 1968, pg. vi).

Knowing what conceptions students bring to the classroom has been extensively studied in several science disciplines (AAAS Project 2061, 2016; National Research Council, 2006; Poehnl & Bogner, 2013). In life science, the scientific explanation for diversity of life on earth has been challenged by those holding alternative conceptions (AAAS Project 2061, 2016). The basics of biodiversity are taught during the middle school years. For example, in the middle school disciplinary core ideas, the Next Generation Science Standards (NGSS Lead States, 2013) state that students should construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment. To teach these abstract concepts, a teacher must take ideas that students are familiar with and restructure them scientifically. To build conceptual understanding about biodiversity, teachers must not only confront students' alternative conceptions regarding this topic but also encourage them to process new information (Hewson & Hewson, 1983; Poehnl & Bogner, 2013).

Purpose of the Study

Although some literature has indicated practical work is beneficial to the classroom, the influence of practical work on students' alternative conceptions has not been studied (AAAS Project 2061, 2016; Robbins & Roy, 2007). To examine middle school students' alternative conceptions about biodiversity while engaged in practical work, research needs to examine whether the messages about the content are received by students. The purpose of this qualitative study was to examine middle school students' alternative conceptions regarding biodiversity while engaged in a unit of study that included practical work activities. The following research question guided the current study: What is the influence, if any, of engagement in practical work on middle school students' alternative conceptions regarding biodiversity?

Significance of Study

Research has shown that students hold many alternative conceptions about biodiversity (Robbins & Roy, 2007). Effectively aiding in restructuring students' alternative conceptions regarding biodiversity is one way to improve science literacy. Therefore, the significance of this study lies in its ability to inform teachers as they address students' alternative conceptions regarding biodiversity.

Definitions

In this study, the term “alternative conception” was used to describe an idea that shows a misalignment with the scientifically accepted response (Aldahmash & Alshaya, 2012; Karagoz & Cakir, 2011). Alternative conceptions differ from misconceptions in the sense that misconceptions imply that a student is wrong or has done something wrong, whereas alternative conceptions are original ideas that are held that are just not aligned with the scientific thinking.

Practical work was defined as “learning experiences in which students interact with materials or with secondary sources of data to observe and understand the natural world” (Mestad & Kolsto, 2014, p. 1056). Practical work is a broader term that differs from active learning by being not only a process where students participate or interact with the learning process but also one in which their minds are activated about the content. Practical work was chosen as the focus of this study because students not only have to manipulate the materials but also must be engaged in thinking behind the activity.

Chapter Summary

This study sought to understand whether practical work influenced students’ alternative conceptions regarding biodiversity. In this chapter, an overview of science education, the study’s purpose, the research question, and the significance behind the study were provided. The upcoming chapters will review the literature on the different topics, the methodology used in this study, and the results found from the data.

CHAPTER TWO: LITERATURE REVIEW

Introduction

Producing scientifically literate students is the goal of science education (National Research Council, 2012). To reach that goal, alternative conceptions must be examined and addressed. Alternative conceptions about biodiversity are held by students of all ages (AAAS Project 2061, 2016). How these alternative conceptions develop and how they can be modified through instruction are subjects of research that remains limited (Andrews, Kalinowski, & Leonard, 2011; Baumgartner & Duncan, 2009; Gregory, 2009; Lucero & Petrosino, 2017). This study examined how a unit on biodiversity that included practical work could influence students' alternative conceptions in the science classroom.

Although practical work is frequently used in the science classroom, its effect on students' alternative conceptions has not been well studied at the middle school level (Hirvonen & Viiri, 2002; Hodson, 1990; Mudau & Tabane, 2015). The purpose of this study was to examine middle school students' alternative conceptions regarding biodiversity while engaged in a unit of study that included practical work activities. This chapter will draw on previous research on practical work, alternative conceptions, and conceptual change to develop a representation of how they interact, if at all, in the classroom.

Practical Work

The goals of science education can be divided into three categories: learning science (i.e., content); learning about science (i.e., nature of science); and doing science (i.e., engaging in problem solving and inquiry) (Haslam & Hamilton, 2010). Science curricula has always had an emphasis on engaging in science content (Haslam &

Hamilton, 2010; National Research Council, 2000). The concern is to ensure that in the process of engaging in science that content knowledge is gained. One major challenge that the science education community faces is the need to focus on meaningful learning, while at the same time producing conceptual understanding of science content (Kibuka-Sebitosi, 2007). To develop conceptual understanding in science, it is important that students are engaged in content (Haslam & Hamilton, 2010). One way students can be involved in content in the science classroom is through practical work (Haslam & Hamilton, 2010).

Practical work is a term frequently used in international educational settings to include a variety of teaching strategies utilized in the science classroom. Practical work is defined as “learning experiences in which students interact with materials or with secondary sources of data to observe and understand the natural world” (Mestad & Kolsto, 2014, p. 1056). Although the term practical work is not used frequently in the United States, it appropriately applies to the types of activities that occur in U.S. classrooms such as teacher demonstrations, small group work, investigations, and inquiry-based laboratories (Toplis & Allen, 2012). Practical work is an extension of the learning of material covered in bookwork or teacher-led instruction (Toplis & Allen, 2014). Justifications for using practical work in the classroom lie in the fact that it can assist students in learning science concepts and provide them experience with manipulatives, materials, or models (Toplis & Allen, 2012). Another reason for the inclusion of practical work in the classroom is the positive motivation for learners (Toplis & Allen, 2014). In summarizing the benefits of practical work, Hodson (1990) discussed 10 reasons behind using practical work in school science. Key ideas included encouraging accurate observations and recording, promoting the use of the scientific method, clarifying theoretical work to help with science comprehension, verifying concepts that have already been taught, and learning to find facts through investigations. Although the Hodson (1990) article is 30 years old, the key ideas of practical work still are major priorities in the science classroom today.

In recent years, practical work has been examined from several different perspectives to begin to understand how it can shape classroom instruction and improve science understanding in the classroom. However, research findings on practical work have been confusing or inconclusive in the past (Haslam & Hamilton, 2010; Hirvonen & Viiri, 2002; Hodson, 1990). Some of the reasoning behind the inconclusive results is the wide range of instructional strategies categorized as practical work. That is, practical work can range from a worksheet-driven laboratory activity to an open-ended student-driven project (Hodson, 1990). Another reason that some of the results have been negative is that some students have difficulty developing skills and learning new content in practical work (Haslam & Hamilton, 2010; Mestad & Kolsto, 2014). A factor attributed to this is that the cognitive load on the activity is too high (Haslam & Hamilton, 2010; Mestad & Kolsto, 2014). However, when appropriate adjustments are made, such as changing the pace of instruction or scaling back the amount of time on a task, students who initially had difficulty can benefit from the experience (Haslam & Hamilton, 2010; Mestad & Kolsto, 2014). Some of the positives of practical work include that it improves science achievement, helps with students' problem-solving skills, aids in students' restructuring of alternative conceptions, and promotes conceptual change (Haslam & Hamilton, 2010).

Several international studies have examined different perspectives related to the application of practical work in the classroom (Ferreira & Morais, 2014; Haslam & Hamilton, 2010; Hirvonen & Viiri, 2002; Mudau & Tabane, 2015). One multiple case study considered practical work in the classroom from the teacher's perspective (Mudau & Tabane, 2015). This study showed that from the teacher's perspective, practical work should be used as a teaching tool and a learning tool. Even though many of the teachers' classroom materials were focused on what learners were expected to do and not learner outcomes, the teachers still fully expected students to gain science process skills and knowledge through practical work This study indicated that learning gains that resulted from practical work seemed to happen by chance and not by design. These results lend themselves to the conclusion that when teachers design activities that purposefully lead to understanding science concepts and developing skills, practical work can be beneficial in the classroom even if these tools are used by chance.

In contrast, other researchers have examined practical work from the students' perspective. One practical-work study conducted in the high school setting examined a physics unit with student-teachers (Hirvonen & Viiri, 2002). The study was aimed at discovering the objectives that the student-teachers had for the application of practical work in the classroom. The conclusions from the study were that the student-teachers realized the versatility of using practical work in the classroom. Some of the objectives they stated for practical work were related to connecting theory and practice, learning experimental skills, increasing scientific thinking and motivation, and providing a means for assessing student thinking. One positive result from the study was that the student-teachers did not think verifying already-proven science concepts was an objective of practical work.

Ferreira and Morais (2014) considered the application of practical work by examining various degrees of conceptual demand on the student. The study was conducted with two biology classrooms in a high school setting during a unit on osmosis. The study concluded that many of the practical work activities included in these classrooms had low levels of conceptual demand, which resulted in students misunderstanding some of the science concepts.

When properly implemented, practical work has a place in the science classroom as a valuable instructional tool (Haslam & Hamilton, 2010; Hirvonen & Viiri, 2002). The benefits have been examined at various grade levels of science education (Abraham & Millar, 2008; Haslam & Hamilton, 2010; Toplis & Allen, 2012). Practical work should actively engage students in doing science as part of the learning process, which can engage them in learning science content while learning about the nature of science (Haslam & Hamilton, 2010).

Although practical work is a term used more frequently in international education settings, practical work in the United States can be compared to active learning. Active learning is a “model of instruction that encourages meaningful learning and knowledge construction through collaborative activities that support thinking and doing” (Mintzes & Walter, 2020, pg. xiii). The terms practical work and active learning are similar because they both describe instructional strategies that require students to be engaged in the content and use their own ideas to reflect on the information. The terms both cover a plethora of instructional strategies that could be used to teach science, including (group work, inquiry learning, experiments.). However, this definition of active learning does not include instructional strategies, such as teacher demonstrations, because active learning requires students to work in collaboration with each other. Strategies such as demonstrations, phenomena instruction, and virtual investigations are not considered active learning strategies but are considered practical work because they can require the students' minds being actively engaged in the thinking of science even if they are not physically manipulating materials. As a result, active learning strategies represent a subset of instructional strategies that can be categorized as practical work. Practical work was utilized in this study because it encompasses a broad range of classroom learning experiences that includes more than just students being engaged in the doing of science, but also the thinking of science. For example, students are passive while viewing a virtual simulation of photosynthesis; they are not manipulating items or collaborating with peers. However, they are involved in practical work as they build knowledge about the process of photosynthesis through observation of the phenomena. Figure 2.1 represents examples of aspects of instruction that could be considered practical work.

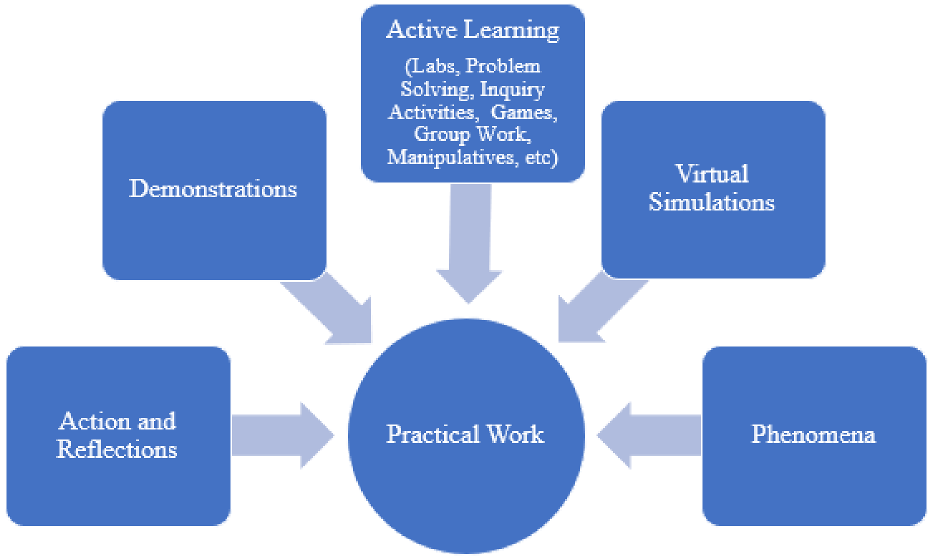

Figure 2.1. Instructional strategies that can be included in practical work.

Regardless of the term used to describe scientific instruction (e.g., practical work, active learning, inquiry-based, three-dimensional instruction), students must begin to engage in the content. Rather than continue to approach hands-on instruction in a prescriptive format, teachers must begin to facilitate meaningful learning (Brumby, 1984; Lucero & Petrosino, 2017). Addressing alternative ways of thinking and the knowledge students bring to the classroom will help guide instruction to focus on the content that needs to be addressed (Brumby, 1984).

Alternative Conceptions

One of the overarching themes of life science instruction is the biodiversity of life and how that biodiversity has occurred (Dobzhansky, 1973; Stern, 2004). Biodiversity can be defined as the variety of life in the world, and the one factor that influences biodiversity is evolution (Dobzhansky, 1973; Stern, 2004). Evolution can simply be defined as the process of an organism diversifying over time (Stern, 2004). Natural selection is a mechanism through which evolution can occur (Gregory, 2009). Natural selection is the change of inheritable traits over time (Gregory, 2009). This change leads to the diversification of organisms, which lends itself back to the overall theme of biodiversity (Gregory, 2009). In the middle school curriculum, the study of biodiversity is an all-inclusive unit that focuses on how life is diversified by the process of natural selection and human influence (NGSS Lead States, 2013). The use and misuse of terms associated with evolution, the simplicity in which the information is taught, and the alternative conceptions that students bring to the classroom are all factors in instructing on this topic (Robbins & Roy, 2007).

Alternative conceptions can be defined as beliefs that go against scientific thinking about a concept (Aldahmash & Alshaya, 2012; Karagoz & Cakir, 2011; Poehnl & Bogner, 2013; Wandersee et al., 1994). Alternative conceptions can come from students' misunderstanding of other subjects from previous experiences (Aldahmash & Alshaya, 2012; Wandersee et al., 1994). When holding alternative conceptions, the student has made a commitment to an explanation that differs from accepted scientific explanations (Aldahmash & Alshaya, 2012; Wandersee et al., 1994). Because alternative conceptions are persistent and embedded in a student's thinking, they can become a barrier to instruction in the classroom (Danaia & McKinnon, 2007; Sinatra et al., 2008; Taber, 2003). Even though students bring alternative conceptions to the classroom, there is not a lot of time invested in what students already know or do not know when entering the classroom (Tanner & Allen, 2005). To address this problem, teachers need to identify students' prior knowledge about a science topic and then begin to guide the students to more scientifically appropriate conceptions (Chin & Teou, 2010; Lucero & Petrosino, 2017; Pringle, 2006).

Alternative Conceptions and the Classroom

According to Piaget's (1983) work, students' alternative conceptions and the ideas they bring to the classroom are the beginning of instruction. These ideas need to be refined, revised, and connected by the teacher and the student (Piaget, 1983). Alternative conceptions should not be viewed as obstructions to instruction, but rather as assets (Lucero & Petrosino, 2017; Lucero, Petrosino, & Delgado, 2017). Alternative conceptions can be a pivotal place to begin instruction.

The National Research Council supports the notion of focusing on ideas that students bring to the science classroom. For example:

> Some of children's early intuitions about the world can be used as a foundation to build remarkable understanding, even in the earliest grades. Indeed, both building on and refining prior conceptions is important in teaching science at any grade level. (National Research Council, 2012, para. 2)

This statement illustrates the importance of teachers recognizing and identifying the alternative conceptions that students bring to the classroom. Teachers should use those ideas to strengthen instruction. Young learners already know a great deal about science through early experiences but knowing how to build upon those early ideas is important pedagogically.

One of the most important factors that influences students' learning of new concepts is the previous information they bring to the science classroom, whether formally or informally taught. In recent years, there has been an increasing number of studies focused on alternative conceptions held by students in the field of science (Aldamash & Alshaya, 2012; Baumgartner & Duncan, 2009; Danaia & McKinnon, 2007; Nehm & Reilly, 2007; Stern, 2004; Taber, 2003). One topic in life science about which students have alternative conceptions is biodiversity (AAAS Project 2061, 2016; Stern, 2004). Biodiversity is a conceptual foundation that scientifically explains the origin and diversity of life. In the NGSS standards at the middle school level (NGSS Lead States, 2013), students are expected to construct explanations based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in different environments. They also must describe the growth and survival of individual populations and the availability of resources to determine whether the relationships provide evidence of a causal link among these factors. For students to achieve these objectives, they must have acceptable conceptions of biodiversity.

As alternative conceptions may be deeply embedded, activating students' alternative conceptions is not enough to restructure students' ideas (Poehnl & Bogner, 2013). Only activating students' alternative conceptions without giving them time to process new information has been thought to hinder learning instead of aiding it (Poehnl & Bogner, 2013). When addressing alternative conceptions in the classroom, students need to recognize the difference between the alternative and the scientific concept to begin to restructure thoughts in their minds (Lucero et al., 2017). This restructuring process can influence conceptual change. The effects and influence that conceptual change has on students' thinking are still being researched.

The Study of Biodiversity

The evolution of living things is a unifying theory and an essential process in biology that is addressed in the Benchmarks for Science Literacy (AAAS Project 2061, 2016), the National Science Education Standards (National Research Council, 1996), and the Next Generation Science Standards (NGSS Lead States, 2013). Evolution by natural selection has clear relevance to everyday life. For example, the overuse or incorrect use of antibiotics leads to antibiotic-resistant bacteria, but many students miss the connection (Stern, 2004). Having knowledge about concepts related to biodiversity can help students become scientifically literate about evolution (Stern, 2004). The concept of genetic change over time among populations is one of the core principles in the study of biology (Baumgartner & Duncan, 2009). Not only is evolution a unifying theory in life science but understanding the process of evolution is based on understanding science. However, it can be difficult for students to understand and accept for personal reasons related to religious beliefs the origin of life, particularly human life (Stern, 2004). National polls show that more than 45% of Americans reject the theory of evolution by the process of natural selection (Baumgartner & Duncan, 2009).Some of the persistent alternative conceptions concerning natural selection and evolution include viewing individual organisms as representative of entire populations, tending to think that organisms can change their traits in response to their environments, and not fully understanding the definition of a theory (AAAS Project 2061, 2016; Baumgartner & Duncan, 2009).

One reason why the concept of biodiversity can be challenging for students to learn is that it can be difficult for them to relate it to their daily experiences (Andrews et al., 2011; Stern, 2004). For example, because evolution takes time to occur in most species, giraffes stay giraffes and worms stay worms. Students cannot physically see organisms changing (Stern, 2004). Comprehending natural selection is intertwined with two important processes in evolution: the random occurrence of new traits in a population and the non-random effect of these traits on survival (Stern, 2004).

Although the body of work dealing with biodiversity is large, the major concept addressed in this study focused on the core perspective of evolutionary causation and has direct relevance to middle school science standards on natural selection (NGSS Lead States, 2013). Natural selection is one of the most important mechanisms of evolution. Even though things such as genetic drift and mutations are also mechanisms of evolution, the middle school curriculum focuses strongly on the process of natural selection (Baumgartner & Duncan, 2009; NGSS Lead States, 2013).

Natural selection is based on two basic ideas: organisms in a population are different and some of those differences are advantageous in terms of survival (Stover & Mabry, 2007). The individuals in the populations with the advantageous genes have a higher chance of survival and of successful reproduction. After an extended period, the individuals with the favorable characteristics will make up a larger portion of the overall population. Alternative conceptions of natural selection have been abundant and persistent (Beggrow & Nehm, 2012). Different studies have focused on each level of student from elementary to medical students, and the alternative conceptions continue to prevail (Brumby, 1994; Emmons & Keleman, 2015; Geraedts & Boersman, 2006; Robbins & Roy, 2007).

Alternative Conceptions Concerning Natural Selection

The middle school curriculum does not explicitly call for exploration of the other mechanisms, but that does not mean that natural selection is the only mechanism for evolution (NGSS Lead States, 2013). Due to the nature of covering the mandated state standards, the other mechanisms are sometimes left out of instruction (Lucero et al., 2017). This could lead to or help facilitate some students' alternative conceptions dealing with natural selection (Andrews et al., 2011; Gregory, 2009; Lucero & Petrosino, 2017). Many alternative conceptions associated with natural selection are widespread among students of a variety of ages and levels of education (Andrews et al., 2011; Gregory, 2009; Lucero & Petrosino, 2017).

The premise around natural selection seems easy to grasp, but the mechanisms behind it have many alternative conceptions (Gregory, 2009). When dealing with natural selection, the most common alternative conceptions include: changes in traits are from the use or disuse of features, changes in traits are based on an organism's need for survival, and there are no clear roles for the differences in organisms within a population (Gregory, 2009; Stover & Mabry, 2007). The alternative conceptions regarding natural selection are due to a poor understanding of the basics of genetics (Stover & Mabry, 2007).

Robbins and Roy (2007) took a three-step approach to examining college student alternative conceptions concerning natural selection. They first identified students' alternative conceptions, then taught purposeful lessons to challenge the students' thought patterns. Finally, they used the content from the lessons for the students to develop a new idea about natural selection. At the beginning of the unit, only 6% of students correctly explained the theory of evolution. By the end of the unit, 92% of students correctly explained the process. One implication from this study was that when teachers directly confront students' thinking, changes can begin to occur.

Research of students at all levels paints a disappointing picture regarding the level of understanding of natural selection (Brumby, 1984; Gregory, 2009; Robbins & Roy, 2007). The understanding of natural selection is based on well-established and simple components, but a proper understanding of the mechanisms and implications are difficult for people who are not specialists in the field (Gregory, 2009). This problem has continued in education. It is clear from various studies that simply explaining the facts of natural selection rarely imparts an understanding of the process to students (Brumby, 1984; Gregory, 2009; Robbins & Roy, 2007). Natural selection, like many complex scientific theories, seems counterproductive to common experience and therefore competes with intuitive ideas in students' minds about inheritance, variation, function, intentionality, and probability (Gregory, 2009).

Common Alternative Conceptions Regarding Evolution

Many of the alternative ways of thinking about natural selection have been described with different names. Some of the most common alternative conceptions found in the evolution education research are addressed in this section: Lamarckian, Essentialism, and Teleological. In addition, this section addresses vernacular alternative conceptions.

Lamarckian. Lamarckian refers to French zoologist Jean-Baptiste Lamarck, who developed a single straight line of the evolutionary process (Stover & Mabry, 2007). This alternative conception is based in the use or disuse of specific traits: what organisms use, they will pass on to the next generation, and traits that are not used will eventually fade out (Stover & Mabry, 2007). Students think that traits change due to environmental factors or that organisms change based on their need to survive or the use/misuse of different body parts (Berti, Barbetta, & Toneatti, 2017). For an alternative conception to be defined as Lamarckian, students must think organisms adapt to abiotic and biotic factors during their lifetime and that these changes are passed down to their offspring (Geraedts & Boersma, 2006). One important thing to remember about the thought process of students who hold this alternative conception is that they are thinking on the individual level and not the population level (Geraedts & Boersma, 2006).

Essentialism. Essentialism can be described as the tendency to represent members of a category as all holding the same traits (Berti et al., 2017). The same traits are passed down from parent to offspring (Berti et al., 2017). This line of thinking includes that all animal species share common properties that determine their identity (Emmons & Keleman, 2015). Although some common properties cannot be seen, young students still make inferences using these properties. For example, students with this viewpoint believe things such as, even if a rabbit is raised by a different species, it will still love carrots and have large ears (Emmons & Keleman, 2015). These naïve views can persist and have a strong influence on how students think about the process of natural selection.

Teleological. The term "teleological" comes from the Greek word *telos*, which means end or goal (Stover & Mabry, 2007). The teleological alternative conception refers to the idea that any benefits of an organism are a reason for its existence; this negates the impact of variation (Stover & Mabry, 2007). This thinking in a student's mind is rooted in the fact that an organism needs to adapt to its environment. Students' thinking that falls under this category includes an outside factor that has a direct influence on organism changing, and that outside force could be nature or God. Students think nature selects what organisms need in terms of helpful changes (Stover & Mabry, 2007). The default mode of teleological thinking is normally suppressed in introductory science education instead of being changed (Gregory, 2009). It can reappear later in advanced life science courses.

Vernacular alternative conceptions. Another area of concern is confusing terminology. This can be referred to as vernacular alternative conceptions. This type of alternative conception arises from the use of words that mean one thing in everyday life and another in a scientific context, for example the word “adapt.” In everyday terms, adapt means to change for a new purpose. Scientifically, adapt is a dynamic evolutionary process that fits organisms to their environment. Another common statement that can lead to alternative conceptions is “survival of the fittest,” which according to Darwin means “the best suited to an environment” (Gregory, 2009). In common terms, fittest normally means most physically fit. This statement puts a heavy emphasis on survival. Survival is important because dead organisms cannot reproduce. However, when considering evolution, survival is only important when looking at the number of offspring reproduced (Gregory, 2009). This phrase also applies a cyclical nature (i.e., Who survives? The fittest. Who are the fittest? Those who survive) (Gregory, 2009). Using the common words in the common phrase survival of the fittest aids in students’ alternative conceptions because they feel like they have a grasp on those words, when in the reality of evolution education those words have deeper meanings. The tendency in classrooms, books, and outside the classroom to use inaccurate language to describe natural selection reinforces some of the common vernacular alternative conceptions (Gregory, 2009).

Scientific Vocabulary

There are multiple areas of concern when instructing on biodiversity, such as the terminology, the lack of genetics understanding, and the complex nature of the topics. Terminology is the area of concern in this literature review. Scientific vocabulary is imperative to understanding biodiversity (Brown & Concannon, 2016; Harper, 2018). Some of the scientific terms in biodiversity can be intertwined in the vernacular sense, such as adapt, evolve, and fittest; however, these terms can have different scientific meanings and often cannot be used interchangeably. Townsend, Brock, and Morrison (2018) investigated with a mixed method approach growth in science academic vocabulary as it related to the teacher's instructional practices. The qualitative results from this study showed that students began to engage with the scientific academic language, and the quantitative results showed increased ownership of academic vocabulary when a variety of vocabulary strategies were implemented in the classroom (Townsend et al., 2018). This research demonstrated that students could enhance their scientific vocabulary when vocabulary instruction is embedded in authentic, social, and multimodal disciplinary learning activities (Townsend et al., 2018).

The research on vocabulary instruction has shown that students need multiple exposures to and opportunities to practice and assimilate new words to acquire deep understandings of words and the concepts they represent (Brown & Concannon, 2016; Townsend et al., 2018). The science topic of biodiversity has many key vocabulary words and nuances that must be grasped for students to understand the content (Brown &

Concannon, 2016; Harper, 2018). Students bring all different types of ideas to the classroom before instruction begins (AAAS Project 2061, 2016; Andrews et al., 2011). Natural selection instruction in the middle school classroom can bring out many different ideas about the process (AAAS Project 2061, 2016; Baumgartner & Duncan, 2009). To address and restructure ideas, one area on which teachers can focus their instruction is conceptual change.

Conceptual Change

There have been explicit shifts in the goals of science education. These shifts have moved from a general knowledge base of scientific facts to a deeper understanding of scientific concepts across disciplines (Tanner & Allen, 2005). Studies in conceptual change research for the past 30 years have shown that students enter the classroom with a set of already-established untaught ideas about natural phenomena and with ideas that are drawn from their day-to-day experiences through the world (Tanner & Allen, 2005). Students deal with these ideas in a variety of ways: some ignore the new information and continue to use their old way of thinking, some maintain the new and the old way of thinking and allow the two methods to run simultaneously in their heads, and some may construct a new conceptual framework from the given information (Beggrow & Nehm, 2012). From a constructivist perspective, students interpret new information in the light of these existing ideas, which then can be changed or displaced with classroom instruction. One of the key findings concerning alternative conceptions is that information presented through classroom instruction can often clash with the pre-conceived ideas they bring to the classroom (Lucero et al., 2017; Nehm & Reilly, 2007). These alternative conceptions have been observed in the answers to and explanations of biodiversity questions formulated by students, adults, and even science teachers (Nehm & Schonfield, 2008; Tanner & Allen, 2005).

To adequately address alternative conceptions and to begin to restructure them, a shift in thinking must occur for the learner (Alparslan, Tekkaya, & Geban, 2003). When examining this shift in an individual's conceptual framework at any level of education, conceptual change can be used as a broad term to denote this phenomenon (Alparslan et al., 2003). In this study, conceptual change was defined as an outcome of the learning process in which an existing conception held by a student is shifted and restructured often away from an alternative conception, hopefully in the direction of the conception held by experts (Tanner & Allen, 2005). Teachers must begin by examining students' prior knowledge in the classroom, which helps foster learning (Poehnl & Bogner, 2013). A teacher must be aware of the knowledge that students bring to the classroom about the subject matter. After this has been determined, the process of conceptual change can be implemented. Conceptual processes that gradually change existing knowledge structures as they are being enriched and restructured are more likely to be accepted (Poehnl & Bogner, 2013). Conceptual change can be described as not adding to existing knowledge, but helping people revise their way of thinking to create a totally different perspective (Sinatra et al., 2008). When teaching toward conceptual change, it can be counterproductive for teachers to continue to instruct new material without engaging students in a metacognitive analysis (Tanner & Allen, 2005).

There are several different aspects that hinder students from changing their thought processes on concepts. Some of the major challenges include: basic constraints that are present from a young age, experiences that reinforce alternative ways of thinking, and barriers (e.g., emotional, motivational, and social) that make students unwilling to entertain change (Sinatra et al., 2008). Some strategies for aiding in conceptual change include active engagement of students with evidence; consideration of the learner's needs, which includes alternative conceptions; and a curriculum that challenges the learners (Baumgartner & Duncan, 2009). Practical work, by definition, engages students in the content. By engaging students in the content, practical work attempts to focus the learner on the correct scientific thinking of science concepts.

Theoretical Framework

The work presented in this study was grounded in theoretical perspectives of learning and understanding of students' alternative conceptions. By taking their previous knowledge and assimilating it with the new knowledge presented, learners construct new knowledge and understanding. When learning is constructed by the learner, this follows the views of constructivism (Vygotsky, 1978). The knowledge that learners bring to the classroom should be identified and addressed (Kibuka-Sebitosi, 2007). According to the conceptual change model, for individuals to change their ideas they must first become dissatisfied with their ideas and be introduced to new ideas that will explain a concept (Tanner & Allen, 2005). The conceptual change model is constructivist in nature because learners must be directly connected to their alternative conception and then explore and analyze evidence that builds on their ideas (Tanner & Allen, 2005). Instruction that is aligned with constructivism and conceptual change should be varied and allow the learners to have multiple representations of concepts (Tanner & Allen, 2005). Practical work activities that vary in the science classroom can serve to represent the content in varied different forms. Throughout this varied representation, students' alternative conceptions are addressed and potentially restructured.

Chapter Summary

This chapter presented research on how practical work has been used in various classrooms. Practical work can be an avenue to help students overcome alternative conceptions. Several different types of alternative conceptions that students have concerning biodiversity instruction were presented in this chapter. The next chapter will discuss the methodology used to examine how alternative conceptions can be modified during a unit on biodiversity that includes practical work.

CHAPTER THREE: METHODOLOGY

Introduction

Alternative conceptions concerning natural selection are commonly found among students (AAAS Project 2061, 2016; Nehm & Reilly, 2007). Investigations into how to modify alternative conceptions, particularly at the middle-grades level, remain limited. The purpose of this qualitative study was to examine middle school students' alternative conceptions regarding biodiversity while engaged in a unit of study that included practical work activities. This chapter provides an overview of the methodology, the context in which the research occurred, the instruments and data sources, and the procedures. This section will also explain the limitations and delimitations of this study.

Reshaping the Research Question

As a result of the researcher's independent study on nature of science and how students' thinking can be influenced in the classroom, the researcher decided to conduct a qualitative study to examine students' alternative conceptions in the science classroom and the effect of practical work on these alternative conceptions. The initial research question posed was: What is the influence, if any, of engagement in practical work on middle school students' alternative conceptions regarding biodiversity? Prior to data collection, the researcher did not know what type of activities the teacher would classify as practical work and speculated that most instruction would fall under the umbrella of practical work.

Over the course of the study, however, it became clear that most of the classroom activities were not practical work. Although the researcher was not able to categorize the classroom activities as originally intended, they were still useful for exposing students' thinking concerning the different alternative conceptions. Creswell (2007) encouraged qualitative researchers to acknowledge the dynamic nature of inquiry and to be aware of design elements that may change and emerge as fieldwork is conducted. With the additional information gained through the data collection process, the reshaped research question emerged: How are students' alternative conceptions altered, if at all, during a unit of instruction on biodiversity that includes practical work?

Overview of Methodology

The methodological design of this study was best characterized as an exploratory case study (Yin, 2014). In general, the case study methodology allows the researcher to explore a phenomenon from several different lenses and data points (Yin, 2014). The case study design also allowed for an in-depth description.

The case study approach has its origins in the constructivist paradigm, which examines participants subjectively, allowing the researcher to gain insight into the participants' actions (Creswell, 2007; Yin, 2014). There were three major reasons the case study method was best suited for the study. First, the case study method requires data collection in natural settings (e.g., classrooms) involving a small group of participants. The case study methodology aligned with this study's goals: to describe students' alternative conceptions throughout a unit of instruction. Second, by looking at a multiple case study design to investigate students' alternative conceptions, the researcher provided insight into the different alternative conceptions. Third, the case study model gave an inside view of the relationship among varying factors such as students' thought processes, their alternative conceptions, and the way they engage in learning. Not only were multiple data sources collected, but several different cases were examined. One benefit of using a multiple case study was that it can be both robust and reliable (Baxter & Jack, 2008; Yin, 2014). The reliability and robustness of the findings are a result of being able to compare or replicate the findings across different cases (Baxter & Jack, 2008; Yin, 2014).

Research Context

The context in which a research study takes place is a pivotal piece of a study. There are many different factors that are important when looking at the educational research context. For this study, the factors in hierarchy were the state, district, school, and classroom. Each of these factors will be described in the following sections.

State

The study took place in a southeastern state. The science standards in place at the time of the study were adopted and approved by the state's board of education during the 2007-2008 school year and implemented during the 2009-2010 school year. This state held science education in high regard with science standards that began in kindergarten. Science standards for grades K-8 in this state were the framework for instruction, and the science content was assessed through end-of-the-year testing. The science graduation requirements at the high school level encompassed three years of laboratory science classes, including biology, chemistry, physics, and/or physical science.

District

The district had been consistently ranked in the top 10 school districts in the state based on rigorous analysis of key statistics, such as state test scores, college readiness, teacher quality, and graduation rates. It was an affluent suburban area approximately 10 miles south of one of the largest cities in the state. The district's free and reduced lunch percentage was approximately 11%. The district's average ACT score was a 23.8 with a 94% graduation rate. One of the main goals in this school district was to increase the rigor in education to ensure all students were prepared for college. At the time of the study, the percentage of students who attended college from this district was nearly 75%. The county was approximately 90% Caucasian, 4% African American, 3% Asian, and 3% of mixed descent.

School

The research took place in a large middle school with more than 1,000 students ranging from sixth to eighth grade. Students rotated teachers and classes throughout the day in 55-minute increments. Teachers were highly qualified as determined by the state in the subject area(s) taught.

Classroom and Teacher

The study took place in an eighth-grade middle school science classroom during a three-week unit of instruction on the topic of biodiversity that included a variety of practical work activities. The class was conducted during sixth period and met each day for 55 minutes. The time frame was from 12:45-1:40. The class had 32 students, none of whom had individualized education plans, and was considered on grade level. The classroom teacher, Mrs. Smith (a pseudonym), encouraged the students to share and voice their opinions and provided multiple knowledge checks throughout the unit to aid in instructional practices. With more than 10 years of experience, Mrs. Smith was a veteran educator. She frequently attended professional development sessions, was the lead science teacher for the school, and had led more than five different professional development sessions in her county. One of her classroom mottos was, “All children can learn, so if you are not learning, show me how to help you learn.”

Participants

The participants were three students in the selected eighth-grade science class. The participants were chosen based on their responses to a pre-assessment on biodiversity content and suggestions from the classroom teacher. The participants had different ideas about the four identified alternative conceptions and represented a mix of genders, classroom participation styles, and varying thinking. The selected participants were Lauren, James, and Bailey (pseudonyms). Details of the selection process can be found in the Procedures section. Information on the participants and their backgrounds is provided in Chapter Four.

Instruments and Data Sources

Multiple sources of data were utilized in this study to connect information (Creswell, 2007) thus allowing for triangulation. The multiple data sources gave a more complete explanation to inform the research question. The researcher observed instruction each day during the three-week unit. As participants engaged in practical work and normal classroom activities, the researcher documented each of the cases. Documentation was focused on participants’ understanding of concepts and how these concepts were reflected in their work. The following sections will discuss the different tools that were used to gather data in this study.

Unit of Instruction Pre-Assessment

Before the instructional unit on biodiversity, each student in the class took the pre-assessment survey (Appendix A), which consisted of three open-response and nine multiple-choice questions. The researcher designed the survey to capture alternative conceptions held by middle school students as determined by assessment items developed by Project 2061. Project 2061 is a long-term science education reform initiative of the AAAS. The project has explored different alternative conceptions in several areas of science and has a section concerning evolution and natural selection, which were encompassed in the biodiversity unit. The survey included open-ended questions on topics taught during the biodiversity unit. The open-ended questions captured students' thought processes and were a more authentic representation of student thinking than the traditional multiple-response questions.

Interviews

The researcher utilized semi-structured interviews to provide additional insight on students' views of alternative conceptions from the pre-assessment. Through semi-structured interviews, the researcher could add or delete questions as necessary to maintain fluidity during the interview (Cohen & Crabtree, 2006). Participants were interviewed at different times during the study to explore the restructuring of alternative conceptions. Appendix B includes sample interview protocols for the initial interview during the unit of study and at the end of the study.

Classroom Observations

To understand more about participants' understanding of biodiversity, classroom observations occurred during the unit of study. During classroom observations, the researcher used a classroom observation protocol (Appendix C) adapted to the biodiversity topics observed in the science classroom. The protocol included a list of key biodiversity concepts. As the researcher observed, a check mark was made if participants mentioned anything that suggested if they held or did not hold an alternative conception. While observing the classroom, the researcher also kept a detailed record tracking students' thoughts and interactions with peers that occurred in the classroom using the Student Observation Protocol (Appendix D). This protocol provided a space for recording interactions of participants in the classroom, movements, and conversations with their peers and teachers.

Lesson Artifacts

The researcher collected artifacts during classroom observations, which included: student handouts, student written work, student projects, and assessments. The teacher submitted a unit plan to the researcher. Lesson plans during the unit were used to clarify, identify, and describe the practical work and the context for instruction used in the classroom.

Researcher as Instrument

The study involved the researcher interpreting information from the pre-assessment, the interviews, and the biodiversity unit observations; therefore, the researcher was an instrument in the study (Creswell, 2007). The qualifications of the researcher included more than 10 years of experience teaching science in the middle school in which the study occurred. The researcher also had classroom and background knowledge about the implementation of practical work in the classroom. The researcher completed four years of coursework toward a doctoral degree in science education, which included coursework on qualitative research methods. The researcher maintained a research journal that was used to document the daily lessons observed in the classroom and reflect on the processes and decisions occurring in the classroom.

Procedures

After receiving Institutional Review Board approval from the school district and the university (see Appendix M), the researcher received recommendations from the district science coordinator for classrooms in which to conduct the study. The researcher contacted the six recommended teachers and interviewed each separately, with interviews lasting approximately 15 minutes. The interviews allowed the researcher to determine whether the teachers utilized practical work in their classrooms. The brief interview questions and the responses from the selected classroom can be found in Appendix E. Mrs. Smith's classroom was selected because she had a wide range of science background knowledge, implemented practical work, and was enthusiastic about teaching. In addition, she had several practical work activities planned for her biodiversity unit.

Mrs. Smith taught four different science classes during the school day. Sixth period was chosen because it did not include any students with individual education plans or major behavior problems. On an initial visit, her classroom was buzzing with activity as students asked questions, interacted with peers, and attended to the teacher's actions.

In Mrs. Smith's class, all 32 students completed the pre-assessment survey (Appendix A). After the pre-unit assessment survey, the teacher and researcher discussed the students' scores. From the pre-assessment survey data, the teacher and the researcher identified four main alternative conceptions. Those alternative conceptions were based upon common alternative conceptions in biodiversity such as generalizing organisms to large groups, assuming organisms can adapt quickly to their environments, and not looking at evolution as a theory.

The teacher and the researcher graded the pre-assessment survey to see which students held three or four of the alternative conceptions. From the group of 25 students who held three or more of the alternative conceptions, the teacher reduced the number of possible participants to five students by considering students who possessed strong opinions about the alternative conceptions, a willingness to participate, and overall classroom performance. The researcher reviewed these five students' answers to tailor the questions that were asked during the interviews. The researcher then conducted a 10-minute pre-observation interview with each of the five selected students. During the interview, the researcher asked questions about the students' pre-assessment survey responses for clarification (Appendix B). Three participants were selected from the five interviewed to participate in the study. The criteria for selection was different ideas concerning the alternative conceptions and dispositions during the initial interview. Two participants held all four at the beginning of the unit, and one participant held three alternative conceptions at the beginning of the unit. Dispositions were noted to assure that participants could be reasonably expected to engage in the practical work activities. The differences about the alternative conceptions and dispositions led to varied interactions and responses during data collection.

The researcher observed the participants during a three-week unit of instruction on biodiversity in the classroom. The details of the unit will be provided in Chapter Four. The researcher observed the participants as they engaged in the unit's activities and documented the participants' ideas related to each alternative conception. The researcher recorded the activity on the Observation Protocol (Appendix C) and the Student Observation Protocol (Appendix D). During the observations and immediately afterwards, the researcher recorded participants' ideas related to the alternative conceptions through a journal. The researcher also collected all lesson artifacts, such as handouts from the teacher, science journal entries, student data collected from the activities, and classroom formative assessments that accompanied the unit being observed. After the unit of instruction, participants were interviewed to see if their alternative conceptions had been restructured. Appendix B provides examples of the interview questions that were asked during the various interviews.

Data Analysis

Detailed case descriptions were written for each participant in which a chronological narrative described the participants' conceptions of biodiversity made throughout the unit of study (Yin, 2014). Each participant was considered an individual case. To begin the analysis, the researcher compared participants' pre-assessment surveys with common alternative conceptions taken from the literature.

The data were extracted and coded from data collected in the observations, interviews, and science journals to develop categories to describe the restructuring of participants' thinking. Data were analyzed after each class activity to identify instances where participants' ideas were related to the alternative conceptions. The data were coded as being aligned with scientific thinking, a partial explanation or developing conception, or an alternative conception. Participants' responses were coded as alternative conception when their ideas were not aligned with scientific thinking, partial or developing explanation when their ideas were mixed with scientific thinking and the alternative conceptions, and scientific thinking when their responses aligned with scientific point of view. Figure 3.1 demonstrates the relationship of the codes for the data. These codes and examples are detailed in Table 3.1

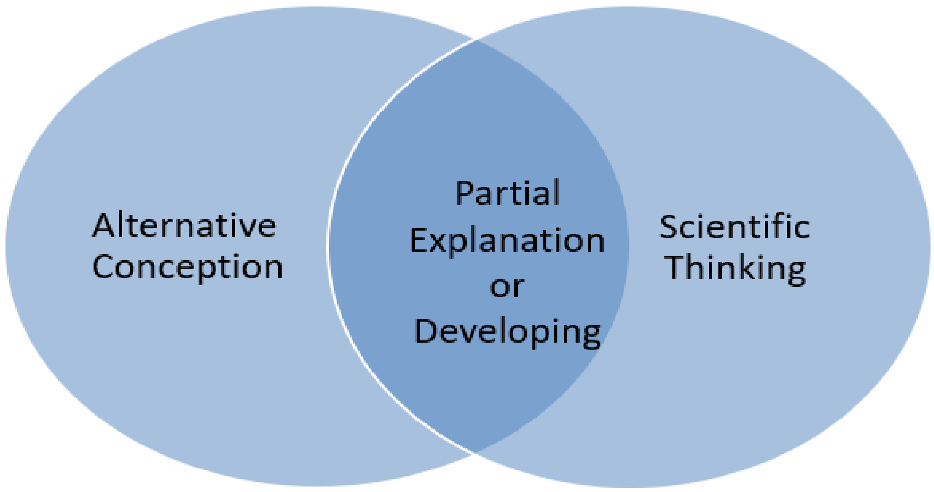

Figure 3.1. Codes for Data

Table 3.1

Codes for Participants' Thinking

Code	Example (Alternative Conception Number One)	Participant Example
Alternative Conception	Organisms can will themselves to adapt.	"Organisms have to adapt to the different environments. To adapt, sometimes they must change to have more opportunities to gather food and live" (Lauren's Pre-Interview, March 29th)
Partial Explanation or Developing	Organisms will change to survive.	"Natural selection is not a quick process; that it takes species time to change, especially when they have to change traits that are better suited for the environment" (Bailey's Interview #2, April 5th)
Scientific Thinking	Adaptations are a complicated process that naturally occur over time.	"Natural selection takes time and it occurs with nature. You cannot force it to happen" (Bailey's Interview #3, April 10th)

In developing the case descriptions, the researcher started with the first alternative conception and went through the data chronologically, identifying instances of where the ideas related to this conception were expressed. Each of these were coded as alternative conception, partial/developing thinking, or scientific thinking. Then the researcher developed a narrative describing the participant's thinking on this alternative conception prior to the unit, during the unit, and after the unit. This allowed the researcher to track the ideas and their development across the unit. This process was then repeated for the remaining three alternative conceptions, in effect creating four chronological narratives for the participant, one for each alternative conception. This process was repeated for the remaining two participants.

The cross-case analysis took place after the individual case analyses. For the first alternative conception, the three participants' thinking was tracked at each activity, to recognize any trends in the data. This was then repeated for each of the three remaining alternative conceptions. The researcher used tables to display the data and to assist in analyzing similarities and differences among the cases of Lauren, James, and Bailey.

Limitations

The limitations of a study are characteristics that impacted or influenced the interpretation of the data. This study had three major limitations. First, although the original research plan included classroom video, the school district where the research was conducted did not allow videoing of the classroom. Video could have added an extra dimension to the data collected and could have caught small nuances missed by the researcher. Second, the teacher had several lessons in the unit that were not practical work. The teacher and the researcher had different ideas regarding what made a class activity practical work. The inclusion of non-practical work in the unit made it difficult to answer the original research question, which resulted in the changed question. The third limitation was the researcher as a novice interviewer. With stronger interview skills, the researcher likely would have been able to draw out additional insights from the participants regarding the alternative conceptions.

Delimitations

Delimitations are factors that narrow the scope of the research and are under the control of the researcher. Decisions related to the exact class period, location of the school, grade level, and sample size were, therefore, considered delimitations. One delimitation involved conducting the study in a suburban school where many of the teachers and students had access to laboratory supplies (compared to other schools across the state). This was important when choosing the location due to the materials needed to include practical work during the unit.

In terms of the small sample size, the inclusion of three participants was ideal for answering the research question; however, this limited the generalizability of the results. With qualitative research, though, the intent is not to generalize but rather to support transferability. The researcher supported transferability by providing rich descriptions of the context and each particular case. Additionally, careful selection of the participants and the teacher classroom created an authentic environment in which to study participants' alternative conceptions concerning biodiversity.

Trustworthiness

An important term when describing validity in a qualitative study is trustworthiness (Gay, Mills, & Airasian, 2012). The four criteria for addressing trustworthiness are: credibility, dependability, transferability, and confirmability. Credibility is the degree to which qualitative data accurately gauge what the researcher is trying to measure (Gay et al., 2012). To establish credibility in this study, the researcher employed triangulation. Triangulation was accomplished by having different data collection strategies and several data sources to ensure a complete picture of what was being studied. Another way to establish credibility was through referential adequacy, which refers to a check of analyses to ensure that interpretations accurately reflect the data (Gay et al., 2012). Referential adequacy was completed by the researcher going over primary sources, documents, and detailed accounts of the study with two experienced educational researchers. Dependability refers to whether one can track the processes and procedures used to collect and interpret the data (Creswell, 2007). To achieve this, the researcher provided a detailed and transparent description about how the data were collected and analyzed. The fit or match between the research context and other contexts is known as transferability (Creswell, 2007; Gay et al., 2012). The researcher developed transferability by providing descriptions of the context, each particular case, and a natural environment for educational research to occur. Finally, confirmability is the neutrality and objectivity of the data (Gay et al., 2012). Triangulation supported the confirmability of the study by using the participants' thoughts during the interviews, their classroom handouts, and their class assessments. By having multiple sources of data, the researcher could examine the data objectively. The utilization of all these strategies collectively established the trustworthiness of the study.

Chapter Summary

To explore how practical work can aid in helping students overcome alternative conceptions, a multiple case-study design was adopted. This chapter contained the study's context, data collection sources, instruments, and procedures. The chapter also discussed limitations, delimitations, and trustworthiness of the study. Finally, the results of this analysis are in the following chapter.

CHAPTER FOUR: RESULTS

Introduction

Evolution is the unifying theory in biological science that explains the diversity of life on Earth (Dobzhansky, 1973). Natural selection and adaptation are some of the processes involved in evolution, which explains biodiversity, and are the most common concepts taught in K-12 settings (AAAS Project 2061, 2016). Teaching students about evolution through the lens of natural selection can come with challenges, but it is imperative to life science (Dobzhansky, 1973; Stern, 2004). Understanding students' alternative conceptions is one of the challenges teachers face when teaching about the biodiversity of life through natural selection. Alternative conceptions are when students' ideas are not aligned with the scientific view (Stein et al., 2008). This led to the purpose of this study: to examine middle school students' alternative conceptions regarding biodiversity while engaged in a unit of study that included practical work activities. To this end, the following research question was posed: How are students' alternative conceptions altered, if at all, during a unit of instruction on biodiversity that includes practical work?

This chapter will include selected eighth-grade state science standards on biodiversity, the students' alternative conceptions, a detailed description of the biodiversity instructional unit, a narrative of each of the case participants, and themes that emerged from the data. In the description of the unit, the standards are included to illustrate the concepts the teacher was responsible for teaching and to directly connect them to the students' alternative conceptions. The intent of each of the lessons was to demonstrate what the teacher thought the students should gain from the lesson. Each case participant has a narrative that provides details of the participant's thought patterns and their engagement in the classroom. Lastly, the themes that emerged through a cross-case analysis will be presented.

State Biodiversity Standards and Alternative Conceptions Held

The state science standards are included in this section to identify the instructional focus of the unit for the eighth-grade science class that was the context for this study. The standards are also included so that the connection to alternative conceptions around these topics about biodiversity could be explained in relation to the standards. The standards that were specifically addressed in the biodiversity unit were the following:

> Standard 1. Analyze structural, behavioral, and physiological adaptations to predict which populations are likely to survive in an environment.
>
> Standard 2. Analyze data on levels of variation within a population to make predictions about survival under environmental conditions.

An analysis of the entire class's pre-assessment survey revealed four alternative conceptions related to the biodiversity standards. The researcher conducted an analysis of the pre-assessment survey and case study interviews to identify the alternative conceptions held by the participants prior to the study. The pre-assessment and student responses can be found in Table 4.1. The researcher then followed the case study participants' alternative conceptions throughout the unit of instruction to document the influence, if any, of the unit that included practical work on the participants' alternative conceptions.

Table 4.1

Pre-assessment Questions and Participants' Responses

Pre-Assessment Survey	Lauren	James	Bailey
What are the first three words that come to mind when you think of the term, "natural selection?"	Adaptations, animals, environment	Death, strong, rabbit	Number of animals
Natural selection applies to	Individuals, populations, all organisms	Individuals, populations, all organisms	Population, all organisms
The measure of success in nature is	Enemies killed, mating opportunities, surviving offspring, food gathered	Age reached, mating opportunities, surviving offspring, food gathered	Surviving offspring
Concerning biodiversity, changes result from	Genetic material being passed on	Genetic material being passed on	Genetic material being passed on
Which of the following is TRUE about the species that are living on earth today?	All species living today have existed since the time life began.	Most species living today did not exist at the time life began.	There is no way of finding out whether all, most, or only a few species living today existed since the time life began.
Individual members of a species could have differences in inherited characteristics that affect which of the following?	Both their ability to find food and their ability to avoid predators.	Both their ability to find food and their ability to avoid predators.	Neither their ability to find food nor their ability to avoid predators.

(continued)

Pre-Assessment Survey	Lauren	James	Bailey
Which of the following is TRUE about individuals of the same species?	Individuals of the same species have the same inherited traits but different acquired traits, such as what they have learned and skills they have developed. Only these different acquired traits can cause differences in an individual's chances of survival and reproduction.	Individuals of the same species may have different inherited traits. These different inherited traits may cause differences in an individual's chances of survival and reproduction.	Individuals of the same species have the same inherited traits but different acquired traits, such as what they have learned and skills they have developed. Only these different acquired traits can cause differences in each individual's chances of survival and reproduction.
According to the theory of natural selection, what would happen to a species of lizards when a new predator is introduced into the environment where the lizards live?	All the lizards would try to develop new physical traits to avoid the new predator.	The lizards that already have the physical traits needed to avoid the new predator would be more likely to survive and reproduce, and the ones that do not would be less likely to survive and reproduce.	Because all lizards of the same species have the same physical traits, one lizard would not have an advantage over another lizard. They would either all survive or all die.

(continued)

Pre-Assessment Survey	Lauren	James	Bailey
Which of the following is REQUIRED for the process of natural selection to occur?	Traits must be inherited from one generation to the next.	Traits must be inherited from one generation to the next.	There must be a sudden environmental change.
Are humans evolving?	Yes! Every day and every few seconds, new humans are born. Humans can reproduce and create multiple offspring.	Yes, we are getting better.	No, when people are born another person dies.
Theory of Evolution vs. Law of Evolution	A law is different from a theory. Someone may think something, and that can become a theory. If it is established and is correct, it could possibly become a law. I don’t know much about theory, but if the details are correct, then possibly.	Theory= guess Law= Proven Maybe, I can’t see the future.	Scientific laws are proven to be correct; theories aren’t necessarily true or proven correct. I don’t think the theory of evolution will ever become the law of evolution because if you look at the Big Bang Theory, it has been a theory for quite some time and still has not been proven correct.

The first alternative conception involved students thinking that individuals can make themselves adapt to an environment. This is fundamentally incorrect because natural selection acts on the genetic variation in a population, and genetic variation is generated by random mutation. It is only through sexual reproduction that these variations manifest themselves in a population. After examining the pre-assessment survey, it appeared that students understood that organisms could not intentionally adapt, but during the pre-interview their responses demonstrated that they did not fully understand this concept.

The second alternative conception involved participants' tendency to base the measure of evolutionary success of a population on more factors beyond survival of offspring. Success in evolutionary terms has a different meaning than in common usage. For example, when thinking of success there are several factors that influence success, such as available resources, predators, and living conditions, but they are not the ultimate measure. Success is only measured by an organism's ability to pass genes to the next generation. Students selected additional items such as enemies killed, mating opportunities, and food gathered. Although these were all factors that contributed to an organism's success, they did not represent the ultimate measure. Mating opportunities did closely relate to reproductive success.

A third alternative conception that students held was that parents could select which traits they would give to the next generation. This is a false idea because parents cannot influence which genes are passed down. During sexual reproduction, the unique genetic make-up of each parent is randomly sorted. There is not a mechanism for parents to influence this biological process beyond selecting each other as mates. This alternative conception was not directly addressed on the pre-assessment survey but was expressed in each participant’s initial interview.

The fourth alternative conception that the students held involved the students’ definitions of evolutionary terms. Students tended to think that evolving was related to reproduction, meaning that when an organism reproduced the species automatically evolved. Students also had a naïve conception of how evolving occurred in nature, which led to an incorrect definition of the word “evolve.” Evolving for an organism or biological feature means to develop over successive generations, especially because of natural selection. “Adapt” was a term that students used on the pre-assessment in various ways. Students used adapt as change and as a way for organisms to make themselves better. Table 4.2 summarizes the alternative conceptions held prior to the unit of study.

Table 4.2

Alternative Conceptions Held Prior to the Unit of Study

Alternative Conception	Description
1	Individuals can intentionally adapt to their environment.
2	The measure of success of an organism is related to several different factors.
3	Parents select what genes they pass on to the next generation.
4	Evolve means to reproduce or replace the death of an organism via the birth of a new organism. Adapt means to change quickly.

These are the alternative conceptions that were recognized during the pre-assessment survey and the pre-interview that aligned with the science standards and activities used in the instructional unit. The researcher examined these four alternative conceptions throughout the instructional unit. Table 4.3 provides an overview of each participant's alternative conceptions prior to the unit of study.

Table 4.3

Participants' Prior Alternative Conceptions

Alternative Conception	Lauren	James	Bailey
1- Species Make Themselves Adapt	Yes	Yes	Yes
2- Multiple Factors	Yes	Yes	No
3- Parents Select Genes	Inconclusive	Yes	Yes
4- Evolve Meaning	Yes	Inconclusive	Yes

The following section will summarize each activity that was completed during the unit plan. Each lesson completed will be described with an objective, what classified or did not classify it as a practical work activity, and a brief synopsis of the lesson. The dates of the lessons and interviews are documented as well.

Unit Plan Narrative

A chronological narrative of the observed lessons is provided to give background information on the practical work activities included during the unit of instruction. A synopsis of each practical work activity and the lesson objective is provided to clarify what was taught and why. Assorted practical work activities ranged from laboratory to virtual investigations. Each practical work activity addressed a different topic and targeted an aspect of natural selection. Table 4.4 provides a chronological outline for the unit.

Table 4.4

Activities Completed, Standards Addressed, and Lesson Objective

Event	Date	Standard	Objective of Lesson
Pre-Assessment Survey	3/28/17	All	
Pre-Interview	3/29/17	Standard 1 & 2	
Shall We Hunt	3/29/17	Standard 1	The students will be able to understand the different selective pressures on populations.
Shall We Hunt Interview	3/30/17	Standard 1	
Galapagos Island Virtual Field Trip	3/30/17	Standard 2	The students will be able to understand different adaptations and Darwin's contribution to research.
Near Pod Notes (Population Change)	3/31/17	Standard 1 & 2	The students will be able to explain the vocabulary that goes with population change, the process of speciation, and environmental factors that affect biodiversity.
Notes and Video Interview #1	4/3/17	Standard 1 & 2	
Peppered Moth Web Quest	4/3/17	Standard 1 & 2	The students will be able to examine how different mutations effect the survival of organisms.
Workday Complete Assignments/ Review Information	4/5/17	Standard 1 & 2	The students will be able to review all information from the unit so far.

(continued)

Event	Date	Standard	Objective of Lesson
Population Change Assessment and Short Answer Question	4/6/17	Standard 1 & 2	The students will be able to show the information they learned by completing a small multiple-choice test and short answer question.
Biodiversity Notes	4/7/17	Standard 1 & 2	The students will be able to understand how to protect and conserve different habitats from destruction.
Assessment and Note Interview #3	4/10/17	Standard 1 & 2	
Mandatory Achieve Article (School-wide reading and writing initiative)	4/10/17	Standard 1 & 2	The students will be able to read, write, and answer questions about a subject-specific topic.
Biodiversity Web Quest	4/11/17	Standard 1	The students will be able to explore different diverse environments in nature. By doing so, they will examine the different species that live in different areas.
Review Game	4/12/17	Standard 1 & 2	The students will be able to review information for the upcoming assessment.
Biodiversity Assessment and Short Response Question	4/14/17	Standard 1 & 2	The students will be able to show the information they learned by completing a small multiple-choice test and short answer question.
Final Interview	4/17/17	Standard 1 & 2	

Note. This includes all activities for the entire unit: practical work and non-practical work activities.

Baumgartner and Duncan (2009) stated that, “Strategies for conceptual change include active engagement with evidence, consideration of student learning needs, representation of the nature of science within the concepts under study, and a challenging curriculum” (p. 218). The activities that occurred during this study addressed several of these strategies, such as engagement with evidence, considering learner needs, and a challenging curriculum. The section that follows contains an outline of the activities that occurred during the unit of instruction. The researcher determined whether an activity was or was not practical work. For an activity in this study to be considered practical work, it had to include students and/or teachers manipulating and observing real objects and materials (Abrahams & Millar, 2008; Beatty & Woolnough, 1982).

Practical Work Activity #1- *Shall We Hunt Lab*

The *Shall We Hunt Lab* was a simulation that took place outside. The researcher categorized this lab as practical work because students participated in an investigation to discover what it was like to be in a predator-prey scenario. This assignment aligned with the criteria of practical work because the students were manipulating the walking sticks and attempting to mimic the process of natural selection. Students modeled a predator-prey situation by acting as predators looking for different walking sticks represented by colored toothpicks in the grass. The toothpicks represented the prey. The students completed several rounds of the predator-prey relationship and collected data about how many walking sticks were consumed. In each round, the teacher made the scenario different, for example some students had to hop on one leg while looking, others could only use one arm, and other students could only grab one color. The teacher used these different scenarios to demonstrate how different predators have advantageous adaptations to capture prey. The objective of this lesson was for students to begin to understand the role of competition in nature through selected adaptations of some of the predators. This practical work highlighted that some adaptations made different species more likely to survive in different environments. The handout for this lesson can be found in Appendix F.

Activity #2- *Galapagos Island Virtual Field Trip*

The *Galapagos Island Virtual Field Trip* consisted of the students watching a movie called “Voyage to the Galapagos” (Scientific American Frontiers, 1999). The teacher classified this as practical work because she deemed the video a virtual investigation. According to the definition used in this study, however, this activity was not a practical work activity since neither the students nor the teacher manipulated or observed real life materials. The video was engaging and informative for the students but did not require them to physically manipulate any of the science materials. The video was selected because of its format. The format made it look like the students were visiting the Galapagos Islands. In the video, the lead character traveled to the Galapagos Islands to meet the animals and birds that inspired the theory of evolution. During this journey, he was joined by scientists who witnessed the daily struggle for survival that had shaped the island’s wildlife. The narrator read from Darwin's journal as a primary source and then displayed some of the island's native species. Graphics were displayed to show change over time and how the area was a laboratory for evolution. The narrator in the video also discussed eco-tourism and how it helps and hurts the islands. The objective of this lesson was for students to understand the wide variety of biodiversity in the world and the origin of Darwin’s work on evolution. The students received a short handout to guide them while they watched the video. The researcher included this video in the narrative of activities, because even though students did not engage with the materials, the video and the questioning afterwards gave insight into the participants' thinking behind some of the alternative conceptions found in the pre-assessment survey. The handout is found in Appendix G.

Activity #3 – *Near Pod Interactive Notes (Population Change)*

Near Pod is an interactive educational technology tool to bring direct instruction alive. The students completed notes in their science journal throughout this activity. The *Near Pod Interactive Notes (Population Change)* platform allowed the students to have the notes directly in their hands, including learning checkpoints, discussion boards, and formative assessments. The interactive notes focused on the basics of Darwin's research, natural selection, population change, and speciation. This program was an innovative way of taking notes. Each student had the slides on their electronic devices; some slides had notes on them and the others contained action items for the students to complete. Students could ask questions, interact with peers, and click on different links for further investigation. The teacher embedded a simulation, group discussion posts, and a short video clip in the presentation on population change. Even though students were engaged in the lesson, this was not classified as practical work since students did not manipulate any materials.

Practical Work Activity #4 – *Peppered Moth Web Quest*

The *Peppered Moth Web Quest* was an online journey through the lifecycle of a peppered moth. The objective of this lesson highlighted the impact of mutations that occur in different species. It showed the process of natural selection that occurred in a moth population around the time of the industrial revolution. The web quest also allowed the students to become birds and see how easy or difficult it was to capture a moth depending on their adaptive coloration. This activity was classified as practical work because at the end of the web quest students were required to complete a simulation with the different peppered moths. This simulation walked the students through the steps of how different adaptations affect species' prey, their food source, and their predators. The participants had to actively engage in the process of natural selection by pretending to kill the moths during the simulation. Participants then tracked the number of moths for each color, round after round. At the end of the simulation, students were asked questions verbally and in writing about the processes that were behind the simulation. The questions that the students answered throughout the interactive web quest are found in Appendix H.

Practical Work Activity #5- *Human Interference Simulation*

This was an interactive simulation where students modeled the changing population of a wolf pack. This was classified as practical work because as students interacted with the process of human interference on a population of wolves, they collected and analyzed data. Students were given the following scenario:

> You and your colleagues have just discovered a pack of wolves. Develop a model that would ensure that this pack's population continues to survive.

Each pair of students began the simulation with eight wolves. The students began to make their wolf population plan by rolling dice. Each number on the dice represented a situation that could happen to the pack. Some of the situations were disease, food shortage, attacks, and overpopulation. The students kept a recording of the population after several years of the activity. Each year was categorized by a roll of the dice. The objective of this lesson was for students to understand how humans play a major role in changing populations of different species. The different scenarios that occurred and the directions for this activity are found in Appendix I.

Activity #6 – *Biodiversity Notes*

The *Biodiversity Notes* were completed on the *Near Pod Interface*. The *Near Pod Interactive Notes (Biodiversity)* platform allowed the students to have electronic notes directly in their hands. The students completed fill-in-the-blank notes, watched a short video clip, participated in class discussion, and completed a short interactive activity. The interactive notes focused on the basics of biodiversity, the different types of biodiversity, and different causes of biodiversity. The teacher embedded these different features into the presentation. The researcher did not categorize this activity as practical work because students did not get the opportunity to manipulate any of the items during the lesson. The students were actively engaged in the science learning process by completing the discussion posts on the interface. During this lesson, students had an opportunity to summarize, answer discussion questions, explore different web pages, and complete an interactive formative assessment. The objective of this lesson was to cover the basic content of biodiversity. The interface added another dimension to the simple task of taking notes.

Activity #7 – *Biodiversity Web Quest*

The *Biodiversity Web Quest* was an activity that required students to think critically about biodiversity and how it affects different species. The researcher did not classify this activity as a practical work activity because even though the students were engaged with the content on the web interface and even though the teacher-created handout asked questions that caused the participants to think critically about the content, the students did not have to manually manipulate any materials. The participants clicked through information on biodiversity and answered questions ranging from basic recall to higher-level thinking. The participants also used information from previous lessons in the unit to build on and engage in some of the questions that required higher-level thinking. The biodiversity web quest handout can be found in Appendix K.

Summary

This section included the activities the participants engaged in during the three-week biodiversity unit. The unit of study included web quests, simulations, labs, videos, and interactive notes. Students were required to complete assignments even if they missed the class period. Each participant turned in all documentation to the teacher for each activity, whether present or not. The next section includes narratives of the case study participants. Each participant's thoughts are examined according to the alternative conceptions identified.

Narrative of the Case Study Participants

The following sections provide an in-depth review of each of the participants' alternative conceptions regarding biodiversity during the unit of instruction. The participants included two females, Lauren and Bailey, and one male, James. The teacher characterized each participant as above average regarding his or her science content knowledge, even though they possessed alternative conceptions on the pre-assessment survey. Each case is presented according to the different alternative conceptions of the biodiversity unit to ensure the tracking of participants' thought processes throughout the unit.

Case of Lauren

Lauren was a straight-A middle school student. The teacher described Lauren as a student who loved to answer questions in class, was an active participant in groups, and gave 100% effort on assignments. When the researcher examined Lauren's ideas on the pre-assessment survey, it was evident that she held three of the four identified alternative conceptions regarding biodiversity and the evidence was inconclusive on one of them.

During the unit of instruction, Lauren was an active participant in the classroom. She answered questions, worked with her groups, and turned all class assignments in on time. She missed one class period during the three-week unit when the class was being observed. The class period missed was during the first practical work assignment, *Shall We Hunt.* Lauren was given an alternative assignment to make up the work missed.

The following sections have been organized according to the four prominent alternative conceptions found during the pre-assessment and pre-interview. Each of these sections will address Lauren's thoughts before, during, and after the unit of instruction.

Alternative Conception #1 – Organisms Can Intentionally Adapt

The first alternative conception was characterized by the thought pattern that organisms can intentionally or deliberately adapt to an environment, situation, or need. This section is organized by Lauren's thoughts prior to, during, and after the unit of instruction. Lauren's thoughts are traced through each of the different classroom activities completed.

Prior to the unit of study. In her pre-assessment survey, when asked for three words to describe natural selection, the first three words Lauren used were adaptations, animals, and environment. These words indicated that Lauren had some idea of the meaning of natural selection because they were directly related to the phenomena. These words are used in most descriptions of the process of natural selection. During the pre-interview, the researcher asked Lauren to describe adaptations. Lauren responded, “Organisms have to adapt to the different environments. To adapt, sometimes they must change to have more opportunities to gather food and live” (Pre-Interview, March 20, 2017). This demonstrated alternative conception number one, because Lauren believed organisms change in response to their environments. Even though populations change in response to their environments, by saying “more opportunities to gather food and live,” it seemed that Lauren believed that adaptations on the individual level could occur intentionally. The process of evolving does not happen on an individual level. Throughout an organism’s lifetime, it maintains the same set of genes. As traits become more beneficial to survival, these traits begin to become more prominent in future members of the species, making the populations change over time. Lauren’s statement that “organisms have to adapt” did not demonstrate that she understood this process happens in populations rather than in individual organisms. If she did understand this process, it was unclear in her answers.

In addition, on the pre-assessment survey, Lauren answered the following question incorrectly:

> Question: According to the theory of natural selection, what would happen to a species of lizards when a new predator is introduced into the environment where the lizards live?
>
> Lauren's answer: All the lizards would try to develop new physical traits to avoid the new predator.

This response aligned with the alternative conception that organisms can develop new traits because they need them for survival (AAAS Project 2061, 2016). Alternative conception number one was demonstrated here because Lauren's answer referred to thinking that organisms intentionally change in response to a situation for survival purposes.

During the unit of study. During the unit of study, the scientific concept behind alternative conception number one was related to most of the lessons, because it is essential to the understanding of the evolutionary process. Understanding that organisms cannot intentionally change to suit their environment is the basis for understanding natural selection. One practical work assignment, *Peppered Moth Web Quest,* required students to describe natural selection in their own words. Lauren defined natural selection as "a concept proposed by Charles Darwin and was meant to explain how new species evolve. All types of living things have small differences between the individuals in the species" (PMQ, April 10th, 2017?). This definition indicated that Lauren believed that species could have variations since she used the nomenclature of "small difference between the individuals." Even though Lauren used the word evolve, it was uncertain whether she fully understood that these "small differences" contribute to the variations in species. These variations within species are the beginning of how new populations can come about in the environment.

Another situation confronting Lauren's thinking was during the *Biodiversity Web Quest*. The content and the questions directed Lauren's attention to examine various aspects of biodiversity. The first question on the handout asked students to explain biodiversity and the different types. Lauren responded, "Biodiversity is the rich variety of life on Earth. There are 3 kinds: (variety of genes, variety of species, and variety of ecosystems)" (BWQ, April 11, 2017). Even though this was deemed an individual assignment in the classroom, Lauren discussed different answers with her table partner.

> Lauren: It is so many different types of biodiversity.
>
> Table Partner: Yeah, who cares. Can you help me with question #1?
>
> Lauren: Sure. Biodiversity is just the mix of species on the Earth. The types are genes, species, and ecosystems. Biodiversity comes when
> individuals must change due to their environment, or predators, or if they have to adapt because they don't have enough food. (BWQ, April 11, 2017).

Lauren's response on her written assignment was correct. She defined biodiversity correctly and named the different types. While the researcher was listening to her and her table partner's discussion, though, it was clear that Lauren had more opinions about the subject than she wrote on her paper. Based on the additional information she shared about how individuals change, it was evident that Lauren was thinking more on an individual level than on a population level. She seemed to be under the assumption that each individual organism would change in response to an environmental need.

After the unit of study. One of the multiple-choice questions on the post assessment was associated with the alternative conception that organisms can intentionally adapt to their environments. Lauren answered the question correctly. The question and Lauren’s response are demonstrated in Figure 4.1.

In which scenario below would natural selection most likely occur?

_X_ A. centuries of gradual climate change

___ B. catastrophic destruction of habitat

___ C. rapid and profound climate change

___ D. immediate loss of primary food source

Figure 4.1. Question from teacher-made post assessment on population change (April 6, 2017).

By answering this question correctly, Lauren demonstrated an understanding of natural selection as a gradual process that happened over long periods of time. It was still unclear if she understood that this happened at the population level, not the individual level. In the post-interview, Lauren was asked to describe natural selection in her own words.

> Lauren: A process where some animals have better adaptations. The animals with better adaptations are more likely to survive, especially for that area.
>
> Researcher: What do you mean by the term, “better adaptations?”
>
> Lauren: These animals have the traits that are more suited for survival. If you can survive more, then you have the better genes. (Final Interview, April 17, 2017).

Lauren equated adaptations with better genes to enhance survival chances based on her second response when asked to clarify her thinking. She thought survival was based on individuals adapting. From Lauren's response, she based the adaptation feature of these genes solely on the individual need to survive, not any scientific reasoning.

From her answers at the beginning to her answers at the end, Lauren still held the belief that organisms would change to survive. This was not scientifically incorrect, but it reflects a naïve view of the process of natural selection (Ferrari & Chi, 1998). Lauren's thought patterns were missing that natural selection is a gradual process that happens over time for populations, not a specific single organism.

Alternative Conception #2 – Multiple Factors Determine Evolutionary Success

Alternative conception number two referred to the way that evolutionary success is classified in nature versus the factors that influence success. The measure of success in nature is determined by the number of surviving offspring in the population, not a multitude of factors. The factors are vital to a population's success but are not the main measure of success. This section is organized based on Lauren's thoughts prior to, during, and after the unit of study.

Prior to the unit of study. When describing the measurements of success in nature, Lauren included enemies killed, mating opportunities, and food gathered (Pre-assessment survey, March 28, 2017). These are all important factors, but these are not the ultimate measurements of success. This response showed that Lauren held a partial belief in alternative conception number two. She understood what it took for an organism to be successful, even if she did not state the ultimate measure.

During the unit of study. During the unit of instruction, Lauren engaged with content that concerned alternative conception number two several times. The first noted incident was during the *Galapagos Island Virtual Field Trip*. The video went into detail about several different species, their adaptations, and Darwin's contribution to research. When asked in the first interview about the video, Lauren stated, "Populations only decrease when there are predators harming the animals" (April 3, 2017). By using the phrase, "populations only decrease," Lauren was only looking at one factor of an organism being successful. Predation was one of the factors that Lauren listed on her pre-assessment that influenced an organism's survival.

Another noted event was during the *Nearpod Population Change Notes*. This activity was not classified as practical work, but students were engaged in the content through teacher questioning and the computer interface. When asked to respond to the discussion post on the computer (i.e., summarize insecticide resistance), Lauren responded, "Insects that are more resistant will have more offspring than insects that are not resistant." When interviewed about her response, Lauren stated, "Organisms must reproduce to be successful. If they don't, then they kinda wasted being resistant to the spray" (Interview #1, April 3, 2017). Even though Lauren continued to use the insect example, she started to think about the reproduction of organisms as being a way to measure their success. This was different from her initial response where she listed factors that influence success. Lauren still did not distinguish between the factors of success and the ultimate measure but did point out the significance of reproduction in organisms.

The *Human Interference Simulation* also activated Lauren's thinking on success in nature. While the researcher was observing the participants during the activity, Lauren stated, "My wolf pack is doing so great. We have a lot of food and a lot of babies" (HIS, Apri1 4, 2017). Lauren still mixed factors that influence success with the ultimate measure of success. One of the conclusion questions on the handout asked, "Do you feel this game accurately modeled the changing population of a wolf pack? Explain your answer." Lauren wrote, "Yes, I think it did. I think that the population could increase or decrease from these reasons. Wolves could die from other packs, food shortages, humans, and other causes. Wolves can also reproduce a lot according to this reasoning" (HIS, April 4, 2017). This response again demonstrated that Lauren intermingled the factors and the ultimate measure. In the interview afterwards, Lauren was asked what was the big takeaway from this simulation.

> I am amazed at how small things that humans do could really affect the populations of other species. Populations are constantly changing, populations can increase or decrease due to various factors such as predators, food shortages, and humans. Reproduction rates also depend on the same thing. (Interview #2, April5, 2017)

This statement indicated that Lauren understood reproduction was an important factor of an organism being successful in nature and that reproduction can be influenced by many different factors. She distinguished the factors from reproduction but lumped them all into what affects different populations' success. It could not be determined if her thinking differed from her pre-test since Lauren selected all responses to determine success in nature (i.e., age reached, enemies killed, mating opportunities, surviving offspring, and food gathered).

After the unit of study. After the unit, students completed an assessment that was created by the teacher. There were two questions that directly addressed alternative conception number two, and Lauren missed one question and got the other one correct on the assessment. The first question and Lauren's response are documented in Figure 4.2. The scientifically correct thinking pattern should have been that variation influences whether organisms are more likely to survive to reproduce. Random variations that result from new genetic combinations through reproduction can influence reproductive success. Organisms that inherit and share genetic combinations that permit survival and subsequent reproduction are considered successful. When asked about this question in the post-interview, Lauren still seemed confused and ignored the word "inherited" in the question stem. Lauren restated, "Variation influences who you breed with" (Final Interview, April 17, 2017). This statement had no direct connection with the measurement of success in nature or with inherited variation.

Variation happens as a result of the exchange of genetic information as it is passed from parent to offspring. Which of the following is true about inherited variation?

___ A. Variation can influence separation.

_X_ B. Variation can influence selective breeding.

___ C. Variation can influence the resources that are available to an organism.

___ D. Variation can influence whether organisms are more likely to survive to reproduce.

Figure 4.2. Question from teacher-made post assessment on population change (April 6, 2017).

The second question on the teacher assessment concerning this alternative conception was answered correctly. The question and response are shown in Figure 4. 3. Lauren correctly identified the response that a species' ability to survive is based on its ability to reproduce. When asked about this question in an interview, Lauren responded, "They all are important to survival, but if you cannot reproduce then your species basically cannot continue" (Final Interview, April 17, 2017).

A group of birds become separated from its original population. Over a period of time, the new population of birds adapted to its new environment. If this new population returned to the environment it originated from, which of the following would most likely determine its ability to survive as a species?

___ A. its beak size
___ B. its ability to fly
___ C. its common ancestry
_X_ D. its ability to reproduce

Figure 4.3. Question from teacher-made post assessment on population change (April 6, 2017).

Lauren articulated that in the beginning of the unit, not all her thinking was correct, nor did it align with the science concepts. When asked how her thinking changed about biodiversity, she stated:

> Lauren: I used to think that it was just different kinds of animals in an environment, but now I know that it is diversity between species that go through competition, overproduction, etc. to survive and reproduce. It is really [a] more complicated process than people think.
>
> Researcher: Can you elaborate?

Lauren: Biodiversity is just the differences of species. (Final Interview, April 17, 2017).

Lauren's explanation on biodiversity was limited or narrow in scope. It was unclear at the end of the unit whether Lauren had deviated from her initial thoughts on success in nature. She continued to list factors that influence organisms' survival along with reproduction.

Alternative Conception #3 – Parents Select the Genes They Pass to their Offspring

The understanding of the scientifically correct thinking associated with alternative conception number three is essential to the understanding of natural selection and biodiversity. Parents cannot select which genes they pass to their offspring. The passing down of traits is a random process that happens by chance. However, Lauren's thinking aligned with the thought pattern that parents could select what genes to pass down to their offspring. This section is organized into Lauren's initial thinking on genes being passed down prior to, during the unit, and after the unit.

Prior to the unit of study. During the initial interview, Lauren was asked to share her thoughts on how different adaptations were passed from generation to generation. Lauren stated, "Parents pass on these adaptions to their offspring. Why would a parent pass on bad genes? All parents want to help their kids" (Pre-Interview, March 29, 2017). From Lauren's response, it can be assumed that she thought parents had the greater good in mind for their offspring. She explicitly stated that it is the parents' desire to pass on favorable genes; however, she did not state that parents have control over what they pass down to their offspring. There was no clear evidence that Lauren held this alternative conception. Her thinking was inconclusive from her statements on how genes are passed down from parents to offspring.

During the unit of study. During the unit of study, there were several opportunities for Lauren to confront that parents cannot select which genes are passed to their offspring. One activity that revealed Lauren held the alternative conception was the *Nearpod Notes on Population Change*. When asked to summarize insecticide resistance, Lauren responded with the following statement.

> Lauren: Some organisms are resistant to insecticide and some are not. Meaning that if insecticide was sprayed on a leaf, a certain species may be resistant to it, and won't be killed/harmed. On the other hand, some species are not resistant and are harmed/killed by it. The organisms that are resistant will have more offspring than those who aren't resistant.
>
> Researcher: Please elaborate this response.
>
> Lauren: Each time insecticide is sprayed many insects would die, then the ones that do not die will be able to pass on the resistance to their offspring. (Interview #1, April 3, 2017)

Lauren realized that adaptations of animals could be passed on from generation to generation because she explained that insects that are resistant will reproduce in the form of more insecticide-resistant insects. It is unclear from her explanation whether she thought that they are passed down because of the principles of genetics or because parents want to pass down favorable genes.

In the *Peppered Moth Web Quest*, alternative conception number three was confronted in one of the analysis questions.

> Question: What would happen if there were no predators in the forest? Would the colors of the moths change over time? Defend your answer.
>
> Lauren's written response: No, the color is determined through genetics. If the moths were continuing to reproduce, the color would not change. (PMWQ, April 3, 2017)

It is a point of interest that Lauren mentioned the word "genetics" when she answered the question. In the second interview, Lauren was asked to elaborate on this answer.

> Researcher: What did you mean by the statement, "Color is determined through genetics?"
>
> Lauren: Hmmm, parents don't have a say-so in what color is passed down to their offspring. It is all in the genetics, if they are a light moth they pass on those genes, if they are a dark moth they pass on those genes. That is the way stuff works. Predators don't affect what genes are passed down from parent to offspring. (Interview #2, April 4, 2017)

The written response to Lauren's question left the impression that Lauren was basing her answer solely on genetics. Her answer was also correct regarding the question asked in the handout. However, when she elaborated in the interview, it was clear that her thinking behind the correct answer was flawed. Her answer was based on parents passing genes on to their offspring according to the genes they possess, which was an accurate response. She then expounded by saying that predators do not affect which genes are passed down. Although all these statements were true, if there are predators after a certain prey species, over time this may repeatedly impact the prey population. When responding about the passing of traits, Lauren used the terminology of passing on which genes they possess instead of favorable genes. This statement showed that Lauren used the principles of genetics to determine which genes are passed down from parent to offspring.

After the unit of study. In the short answer question after the unit, Lauren described variation “as the process where the parents give the offspring specific genes, but those genes are different from other genes, so they don’t look the same, or have the same innate behaviors. This creates diversity” (Biodiversity Assessment, April 14, 2017). By the end of the unit, Lauren no longer used the terminology, “parents pass on favorable genes,” but attempted to explain answers using the principles of genetics. Even though the references to favorable genes had been eliminated, there was no conclusive evidence Lauren’s thinking was changed regarding alternative conception number three.

Alternative Conception #4 – Evolving Means to Reproduce or Die

Many of the words in the biodiversity unit were words that students used in a variety of different ways. The words “adapt” and “evolve” were both used incorrectly throughout the unit. This section provides evidence of how Lauren used those terms prior, during, and after the unit of study.

Prior to the unit of study. During the pre-interview, Lauren was asked several questions to determine her thoughts about the words “adaptation” and “evolving.” An excerpt from Lauren’s pre-interview follows.

> Researcher: Can you describe why the word adaptations came to mind when thinking about natural selection?
>
> Lauren: Like, if a human is cold, they can adjust the heat or get a coat. They are adapting to the cold environment.

Researcher: Please describe your thoughts about humans evolving. Are humans evolving?

Lauren: Yes! Every day and every few seconds, new humans are born. Humans can reproduce and create multiple offspring. (Pre-Interview, March 29, 2017).

These quotes and Lauren's confident demeanor during the pre-interview demonstrated that Lauren had a strong view about her definitions of adaptation and evolving, even if the definitions did not align with scientific definitions of those key terms. Lauren's initial views were naïve when discussing the term adaptations. By using the coat example, Lauren trivialized adaptations into something that could easily change. Lauren was using the word "evolve" like the word "reproduce." She equated evolving with babies being born. The pre-interview question and her explanation demonstrated that Lauren had incorrect ideas about the definition of evolving.

Another portion of the pre-assessment survey where Lauren demonstrated alternative conception number four was on a question from the pre-assessment survey. The question and Lauren's response are indicated in Figure 4.4.

Which of the following is TRUE about the species that are living on earth today?

__X___ A. All species living today have existed since the time life began.

_____ B. Most species living today have existed since the time life began, but a few have appeared more recently.

_____ C. Most species living today did not exist at the time life began.

_____ D. There is no way of finding out whether all, most, or only a few species living today existed since the time life began.

Figure 4.4. Question from pre-assessment survey (March 31, 2017).

By answering the question as such, Lauren did not think about how the process of evolving has been changing species since the beginning of time. This showed that Lauren believed all species began at the same time and still exist today. Her response did not demonstrate how species have evolved over time.

During the unit of study. During the unit of study, the teacher and the students used the different terms evolve, evolving, and adaptations. Lauren used both words, evolve and adaptations, in several of her practical work activities. On the handout that accompanied the *Galapagos Islands Virtual Fieldtrip*, a question asked her to describe the differences between the mockingbirds on the islands. Lauren answered, “The different birds of the same species evolved into different types of mockingbirds due to the fact that each island had different resources to help the birds survive” (GIVFT, March 30, 2017). During the first interview, when asked about this Lauren explained how the mockingbirds evolved again. Lauren responded, “Well, they just did. They had to change in order to survive on the different islands. Each island even though close together had different resources” (Interview #1, April 3, 2017). This comment along with the answer on her handout made it seem that Lauren used the words evolve and change synonymously. “Change” and “evolve” can be used interchangeably in vernacular vocabulary, but the term “evolve,” when used in the scientific context of natural selection, has a deeper meaning than just change. However, the usage of evolve synonymously with change was a shift from her thinking at the beginning of the unit where Lauren used evolve and reproduce interchangeably.

The following question was also asked in the video: “Discuss how the land iguana may have evolved into the marine iguana. Think about factors such as vegetation, selective pressures, and isolation as you prepare your answer." Lauren raised her hand and responded, "Land iguanas evolved into marine iguanas because there were more options for food in the water. Over time, they began to continue to get closer to the edge to get these resources. As they kept going in the water, they began to change so they could live there easily." The teacher then posed the question, "How did they change? Did it involve variation, selective pressure, and/or isolation?" Lauren stated, "Not sure, I think variation, but really unsure how it happens" (GIVFT, March 30, 2017). This response showed that Lauren understood that different things such as finding food could cause organisms to change. She still did not scientifically describe the process of how the change occurred. This dialogue related to the word evolve because the teacher wanted Lauren to expound and use the terminology evolve in her explanation. From Lauren's first response she seemed knowledgeable on the subject, but when asked to explain she did not expound on her thinking.

In the *Peppered Moth Web Quest*, Lauren used the word evolve to describe how species change during natural selection: "It means how new species evolve." Even though the term was used in the correct context, when asked to describe the process of how the population of moths evolved, it was unclear if she fully understood the scientific definition. Lauren responded, "They just change. It is hard to describe, but when their traits no longer suit their living environment they have to change" (Interview #2, April 4, 2017). She shifted her thoughts in the sense that she recognized that evolve is not only used in everyday language, but also it is described in the scientific process of natural selection. She still used the term evolve interchangeably with change.

After the unit of study. In the final short answer question, Lauren described the word adaptation and how it related to natural selection.

> If different species were relocated to new places, they would have to adapt to their new environment, using adaptations. If some animals were more well-adapted to their environment and had a much better chance of survival than others that is called natural selection. (Final Interview, April 17, 2017)

Lauren's thoughts seemed to have aligned with the scientific definition of adaptation. The scientific definition states that adaptation is a change or the process of change by which an organism or species becomes better suited to its environment. It appeared to be a clear shift from her original thoughts regarding adaptation.

During the final interview, the researcher asked Lauren about the word evolve.

> Researcher: What does the word evolve mean regarding natural selection?
>
> Lauren: Well, I do know now that evolve is not a quick term. Organisms have to gradually take their time and evolve or change as the need arises. (Final Interview, April 17, 2017)

This represented a change in thinking from the beginning of the unit when Lauren used evolve synonymously with reproduction. She now correlated evolving with a change gradually over time.

Summary

In summary, Lauren demonstrated three alternative conceptions at the beginning of the unit through evidence of her thinking in the pre-assessment survey and the pre-interview. By the end of the unit, it appeared that Lauren had restructured her thoughts somewhat on alternative conception number one. When discussing in written and oral language, Lauren no longer used the terminology “will” or “adapt” to describe how organisms respond to the environment. Regarding alternative conception two, the measure of success to Lauren still depended on several factors at the end of the unit. She did realize, however, that it was a complicated process and reproduction was important, although not the sole means for determining success. Even though Lauren held alternative conception number two at the end of the unit, she was conscious that reproduction plays a major part in an organism’s success. Alternative conception number three did not have conclusive evidence regarding whether Lauren had changed her thinking. However, she had begun thinking about the random process of genetics, instead of parents passing down only favorable genes. Concerning alternative conception number four, Lauren gave the impression that she could and would use the common terms evolve and adapt with the scientific meaning in mind. This indicated a positive shift towards using scientific language correctly when discussing biodiversity and natural selection. Table 4.5 provides a comparison of Lauren’s alternative conceptions at the beginning and end of the unit.

Table 4.5

Summary of Lauren's Thinking Regarding the Four Identified Alternative Conceptions

Alternative Conception	Beginning of Unit	End of Unit
1- Organisms can intentionally adapt.	Organisms must change.	Survival is based on having better suited genes.
2- Multiple Factors	Multiple factors measure success in an organism.	Multiple factors play a role in organism success. Reproduction is one of those factors.
3- Parents Select Genes	Parents want to help their kids, why not pass on the best genes.	Begin to use genetic principles to describe how traits are passed from parent to offspring.
4- Evolve Meaning	Evolve means to reproduce.	Evolve means to change over time.

Case of James

Given his facial expressions, James appeared to be indifferent and detached during most of the activities in class. The teacher described James as a bright student who was nonchalant about school. When called on directly or when working with a partner, James shared his responses. James was present for all class activities and did not miss any instruction during the unit of study.

On the pre-test and pre-interview, James provided evidence of holding three of the identified alternative conceptions regarding biodiversity and the evidence was inconclusive on alternative conception number four. The following sections have been organized by each of these alternative conceptions. Each section will address James's thoughts before, during, and after the unit of instruction. The sections will give a narrative from written work and assessments completed during class activities, his comments with classmates, and responses during interviews.

Alternative Conception #1- Organisms Can Intentionally Adapt

Alternative conception number one was concerned with James's thinking that organisms can intentionally develop adaptations in response to different selective pressures. The scientific conception that organisms cannot intentionally change but that it is a random evolutionary process was addressed in many of the lessons in the unit. This section is organized by the thoughts that James had prior to, during, and after the biodiversity unit.

Prior to the unit of study. On the pre-test, the three words that came to James's mind when thinking of natural selection were death, strong, and rabbit. The researcher asked James to further explain his use of the different words to determine his thoughts about their relationship with natural selection.

> The word death reminds me of natural selection because some things die. Not every organism lives to pass on genes to the next generation. You have to be willing to change, so that you can survive. I used the word strong because the process of natural selection is strong. Even though one thing could change the course, it is hard to change the path of organisms. Rabbits would be a good animal to test natural selection on, since they are supposed to reproduce frequently. (Pre-Interview, March 29, 2017)

James had a clear explanation for choosing each of those words. Concerning the word death, James described it as the process of natural selection in that some organisms will die, and others will live on to pass down their traits. His line of thinking was accurate when describing the basics of how natural selection works. However, by stating, "You have to be willing to change so that you can survive," it seemed that he made organisms in charge of their ability to survive. James used the word "death" to explain the result of not adapting to the environment. If the organisms could not change for survival, then they would die. This is a true statement, but organisms do not have a choice regarding whether they can adapt.

James's second word used to describe natural selection was "strong." When asked for clarification regarding the word strong, James offered the following:

> The word strong describes the process of natural selection. It takes a strong force to change the course of the natural selection process without something interrupting it. (Pre-Interview, March 29, 2017)

When describing natural selection, strong is often used in the vernacular sense (e.g., only the strong survive) to describe the process of natural selection. James used the word strong to describe the force behind the process, which demonstrated a naïve way of thinking. This is not entirely incorrect thinking because natural selection acts upon populations over time, and that slowly begins to change entire populations. When James described the process of natural selection by terms that organisms "have to be willing to change," the terminology used showed evidence of the alternative conception. Because James thought, if necessary, organisms could intentionally change themselves for survival purposes, he associated this process with a common misconception about how natural selection proceeds. This common misconception is related to teleological thinking (AAAS Project 2061, 2016; Bishop & Anderson, 1990; Passmore & Stewart, 2002; Stern & Roseman, 2004).

In his response, James also mentioned the word “rabbits.” By mentioning rabbits’ reproduction frequency, he alluded to a tenet of natural selection, which is that organisms produce more offspring than survive. When James mentioned rabbits, he had a smirk on his face; it was unclear if James was being funny or sarcastic by using rabbits as a way for scientists to examine the process of natural selection.

One pre-interview question also asked James to describe natural selection using the word “adaptation.” James described adaptation as being “connected to natural selection because that is the only way an organism can survive” (Pre-Interview, March 29, 2017). James associated natural selection with organisms’ ability to survive and believed “they must adapt and change to different situations, so they can live” (Pre-Interview, March 29, 2017). Natural selection is concerned with organisms’ survival in the sense that they need to survive to reproduce. James’s statement, however, was about the idea that organisms could change or adapt as necessary, missing the important fact that it is a gradual process that happens in populations over time and has nothing to do with the organism’s will to change.

During the unit of study. James was presented during the unit of study that organisms cannot will themselves to change; however, based on his responses this thought pattern persisted throughout the unit. In the practical work activity, *Shall We Hunt*, James was not as actively engaged in the activity as the other students. James walked around slowly and calmly while outside compared to other students who were running wildly or became excited about succeeding in the activity. The *Shall We Hunt* activity was used to demonstrate the concept of predator/prey. The others picked up as many walking sticks as possible, while James only gathered a few. In the interview afterwards, the following dialogue occurred:

> James: I was not interested in chasing fake animals to model science concepts.
>
> Researcher: What science concepts were being modeled?
>
> James: Predator-prey stuff. Things dying off because they are easy to find.
>
> Researcher: Can you explain?
>
> James: Not really, the whole activity was dumb. (Interview #1, April 3, 2017)

James had few remarks about the lesson. During the interview, James gave simple and curt responses about the science concepts modeled in the lesson.

Another question asked during the interview was about survival. The researcher wanted to know how the different groups of walking sticks or the adaptations of the different groups of walking sticks affected survival.

> Researcher: Describe what can increase or decrease an organism's chance of survival.
>
> James: Camouflage and being dangerous to predators did increase organisms' chances of survival. Organisms must be able to adapt when predators are after them. They must change themselves so that they have a higher chance of survival. (Interview #1, April 3, 2017)

Regarding alternative conception number one, when James stated, "Organisms have to adapt when predators are after them," he made it seem as if organisms had a choice in their adaptations. It also implied that organisms could intentionally adapt. James also mentioned, "They have to change themselves so that they can survive." By saying organisms "have to change," James gave the capability to the organism. James felt the organism could modify itself based on different conditions. This thinking was aligned with holding alternative conception number one. Even though James appeared to be disengaged by his reserved demeanor and unwillingness to fully participate during the activity, he expressed the key concept of the lesson, which was that selective pressure on different populations affected the survival of the organisms within that population. However, from his response concerning organisms changing to minimize predation, it was clear he still held the alternative conception that organisms could intentionally change in a pressing situation.

In the *Peppered Moth Web Quest*, the concept of natural selection was also addressed. During the Web Quest in class, James interacted with the simulation. He recorded how his population declined and increased due to the different colors of the moths' wings. On his handout, James wrote, "If they can blend in, they can survive" (PMWQ, April 3, 2017). It was unclear from this statement if James was being factual about his thoughts: that moths that can blend will survive or that moths intentionally blend for survival purposes. Also, on his Web Quest handout, James wrote, "If they can blend in then their chances of survival are much higher, so basically they have to blend in or they die out" (PMWQ, April 3, 2017). From the combination of written statements, James was connecting the ability to blend to survival rates. He also used the terminology, "have to blend," which demonstrated that he was giving the capability to the organisms in this situation. By giving power to the organisms, his thinking was aligned with alternative conception number one (that organisms could will themselves to adapt if they had to survive).

After the unit of study. James missed the question on the post-test that was closely aligned with alternative conception number one. The question and James's response are demonstrated in the following Figure 4.5.

In which scenario below would natural selection most likely occur?

___ A. centuries of gradual climate change

___ B. catastrophic destruction of habitat

___ C. rapid and profound climate change

_X_ D. immediate loss of primary food source

Figure 4.5. Question from teacher-made post assessment on population change (April 6, 2017).

The correct response to the question was answer choice A. James's response of D indicated that James thought organisms could change quickly depending on a situation in which they are deprived of food. In Interview #3, James was prompted to explain why the other answers were incorrect and his was correct.

> A- That would take a long time to show a difference in organisms. Natural selection can occur quickly if an organism needs to adapt. B – same as A, if organism's habitats are destroyed, they die off or immediately find somewhere new to live. C – if the climate was to change quickly, I don't know what would happen to different organisms. D – this answer choice has to be correct. If organisms don't have food, they have to participate in something that will help them to survive. This survival process is natural selection. (Interview #3, April 3, 2017)

James's thinking was aligned with the idea that organisms can control the process of natural selection. He believed when things happen in nature to organisms' habitats or food, they can intentionally change or adapt. At the end of the unit, James still held alternative conception number one.

Alternative Conception #2 – Multiple Factors Determine Evolutionary Success

Alternative conception number two was concerned with the determination of evolutionary success in nature. There is a difference between what influences actual success versus the measurement of success in nature. The ultimate measure of success in nature is the number of surviving offspring. Many factors influence success, such as food gathered, finding a mate, suitable habitat, and number of predators. James could clearly describe the factors that influence success, but not the ultimate measure of evolutionary success, which is to survive and produce fertile offspring. This section is organized by charting James's thoughts prior to the beginning, during, and after the unit was completed.

Prior to the unit of study. On the pre-assessment survey, each student could check as many possible answers to the statement, "The measure of success in nature is _____." James selected the following answer choices: age reached, mating opportunities, surviving offspring, and food gathered. James elaborated in the pre-interview by stating, "Success is hard to measure. There are a lot of different factors that go into it" (Pre-Interview, March 29, 2017). James's response showed that he did not think the question had one right answer but rather several correct answer choices. Mating opportunities and surviving offspring would constitute a part of reproductive success. By considering the various factors, James demonstrated that he held a partial belief in alternative conception number two. The other factors play a part in survival but do not ultimately represent the measure of a population's success in nature.

During the unit of study. James's responses during the unit of study gave insight into his thinking concerning alternative conception number two. The first response was recorded during the first interview and demonstrated partial understanding (April 3, 2017). The researcher wanted to know how the different types of walking sticks or adaptations to the different walking sticks affected survival. James responded, "Camouflage and being dangerous to predators did increase organisms' chances of survival. Organisms have to be able to adapt when predators are after them. They have to change themselves so that they have a higher chance of survival" (First Interview, April 3, 2017). James's response indicated a factor that influences success: predators. His responses continued to point to factors that are not the ultimate measure. James's answer also pointed to survival rates. Survival is another viable measurement when looking at factors that influence success.

Another occurrence when alternative conception number two was discussed by James was during the *Peppered Moth Web Quest*. One of the questions on the handout said, "Explain the concept of natural selection using your moths as an example." James correctly responded, "Better adapted moths survive, reproduce, and pass on genes" (PMWQ, April 3, 2017). This response suggested that James understood that organisms must reproduce to be successful. James was asked questions during Interview #2 to determine some of the thinking behind this response.

> Researcher: How did the *Peppered Moth Web Quest* help you understand the science concept of biodiversity? What aspect from the lesson helped your thinking, if any?
>
> James: When moths live, they have a better chance of reproduction. If they reproduce, then, of course, there are better chances of genes being shown in their offspring. (Interview #2, April 5, 2017).

James's answer demonstrated that he understood the value of reproduction in an organism. He understood that if organisms did not survive then they could not pass on genes to their offspring. He also did not stop with the organisms but continued to describe the value of the organisms passing traits on to their offspring.

Another example during the unit when James interacted with alternative conception number two was during the practical work activity, *Human Interference Simulation*. After the lesson, the researcher interviewed James.

> Researcher: Consider what you learned in the simulation. How does humans' interference affect different animals? What made the organisms successful or not during the simulation?
>
> James: There are multiple factors that affect living and reproduction for different organisms, but humans are the main reason affecting if some species would live or die. Organisms have to find food, have to find a mate, and reproduce to be successful. (Interview #2, April 5, 2017)

James was still measuring success based on the factors that influence them instead of the ultimate measure He gave a list affecting living and reproduction, such as food and finding a mate. He continued to have a partial understanding of success in nature, because he continually mentioned the role of reproduction in the organisms' success along with factors that influence it. There was no clear distinction in responses from the factors that influence it and the ultimate measure.

After the unit of study. On the population change assessment, one multiple-choice question and response stood out when examining alternative conception number two. The question and James's response are shown in the following figure.

A group of birds become separated from its original population. Over a period of time, the new population of birds adapted to its new environment. If this new population returned to the environment it originated from, which of the following would most likely determine its ability to survive as a species?

___ A. its beak size

_X_ B. its ability to fly

___ C. its common ancestry

___ D. its ability to reproduce

Figure 4.6. Question from teacher-made post-assessment on population change (April 6, 2017).

The correct response to this question was D and James selected B. In the final interview, James was asked to explain his reasoning behind the choice.

> I really thought there were several right answers to the question. I think birds need to be able to fly to get food, to get away from predators, and to find a mate. I also thought that being able to reproduce would be a great answer as well. I could only pick one, so I went with fly. Birds need to fly. (Final Interview, April 17, 2017)

This response showed that James was still thinking about the factors that influence success. Without James's explanation, it would have seemed that reproduction was not important; however, he seemed to understand reproduction's value when it comes to an organism being successful in nature. James also understood at the beginning and the end of the unit the factors that play a pivotal role in making an organism successful. He indicated in the pre-test factors such as mating opportunities and surviving offspring, and he indicated these in the post-test as well.

Alternative Conception #3 – Parents Select the Genes They Pass to their Offspring

Alternative conception number three concerned parents' genes being passed down from generation to generation. The alternative conception was that parents can select which genes should be passed down. This section is organized by James's thoughts on how genes were passed down prior to, at the beginning, middle, and at the end of the unit.

Prior to the unit of study. During the pre-interview, James demonstrated that he held alternative conception number three via the following response:

> Researcher: What do you think the connection is between the passing of traits and natural selection?
>
> James: Parents pass on genes that help their offspring live. They want them to have the best genes. The connection is parents naturally pass on the better genes during natural selection. (Pre-Interview, March 29, 2017)

James used the phrases "best genes" and "pass on better genes" to describe what type of genes parents pass to their offspring. By using those phrases, it appeared that James thought parents would naturally pass on the better genes from generation to generation. James did not discuss the mechanics of this statement, so it is unclear if he believed that parents had control over the process. James could have been thinking correctly but using the wrong language. Evolution research uses words such as "fitness" and "fitter" when discussing natural selection. These words could be compared to when James used the word "best." It is unclear whether James held the alternative conception due to the different vernaculars used concerning natural selection.

During the unit of study. While completing the activity *Near Pod Interactive Notes (Population Change)*, James was encouraged by the teacher to take notes and ask questions if confused. In addition, during this activity, students had to write a response about insecticide resistance in their science notebook. James's response was short, "When insects build up an immunity to insecticide, they are the ones that live, thus making them able to pass on that immunity to their offspring" (PCN, March 31, 2017). When questioned about this concept during Interview #2, James elaborated on his response.

> I understood that parents passed traits down to their offspring. Sometimes it is up to the parent and other times it is not. If all the insects that did not have the immunity die, there is no way they can pass on their genes. So therefore, only insects that are resistant will mate and pass on genes. (Interview #2, April 5, 2017)

This response indicated a difference in James's thinking compared to his thinking at the beginning of the unit. In the interview response, he did not use the terminology "best or better genes" to be passed down. In this response, James articulated that sometimes it is up to the parents and other times it is not. It is unclear from this statement if he was discussing parents having control over the genetic process or if it was bundled with his thinking that organisms that do not survive have no way of passing down traits.

The next activity where James engaged with this alternative conception was an interactive web quest that included simulations and a learning game. In the *Peppered Moth Web Quest*, one of the questions on the handout asked students to describe natural selection. James's definition of natural selection was "where the better-adapted individuals survive, reproduce, and pass on their genes to their offspring" (PMWQ, April 3, 2017). This definition showed that James understood that it is not just beneficial to have the better-suited genes, but also showed the importance of being able to survive to pass these genes on to their offspring. In the interview, James was asked to elaborate on his definition.

> Sure, here is an example with the peppered moths. When I completed the simulation, it was harder to catch the moths that had adapted to the background, making the ones that were better suited for the environment to be able to live. When the moths live, they have a better chance of reproduction, if they reproduce more, then, of course, the genes are going to be seen more in their offspring. (Interview #2, April 5, 2017)

James continued to use the terms "better-suited" and "better-adapted" to explain which genes were passed down from parent to offspring. Even though James used those terms, he seemed to be using them to describe the parents and not necessarily the offspring. Since James used those terms to describe the parents, he was on the path of scientific thinking. If organisms that were not suited for the environment died, there was no way they could pass on their genes, hence not having any offspring. He had the idea that the better genes lived on because the parent organism that survived would produce offspring. This thinking contrasted with his initial thinking reflected in the pre-interview where he did not mention how the best genes were passed down, but rather that the parents wanted their offspring to have the best genes.

After the unit of study. The final short response question was the following: "Geologists have evidence that the continents were once a single giant continent. This giant landform eventually split apart, and the individual continents moved to their current positions. What role might this drifting of continents have played in the formation of new species?" James offered the following response.

> The way that the two groups of animals would adapt would be by natural selection. Since the animals that were separated were so used to their old environment, only the animals with the combinations of genes that were right for this new environment would survive and reproduce. After they reproduced, their offspring would have these genes that were adapted to this new environment and the cycle would repeat until it would be narrowed down to the best set of genes for the environment. (Final Interview, April 17, 2017)

James's response described the process of natural selection. Genes are passed down to their offspring in a random combination through sexual reproduction. Over time, due to reproductive success, the genes that are more suitable for survival in that environment are selected through natural selection.

In the final interview, James articulated his opinions about natural selection and biodiversity.

> Researcher: Describe the process of natural selection.
>
> James: Animals/organisms that are not better adapted to an environment die off more than animals that are adapted to their environment. The animals that do

> survive are also more likely to pass on better genes to their offspring. (Final Interview, April 17, 2017)

James articulated that the passing of traits from parent to offspring was important to survival, and that organisms that do not survive cannot pass on unfavorable genes. James still used phrases such as "better adapted" and "better genes" to describe natural selection; however, he seemed to use them in a more scientifically accurate manner. By the end of the unit, it was still unclear whether James thought parents had the capability to select which genes are passed down to their offspring. He responded differently to the two different prompts that were given.

Alternative Conception #4 – Evolving Means to Reproduce or Die

Alternative conception number four refers to scientifically defining the word "evolve." The word evolve is used in common terminology, which can easily cause students to get the scientific and common use of the terms jumbled. This section traces the use of the word evolve by James prior to, during, and after the unit of study.

Prior to the unit of study. On the pre-assessment survey, James was asked if humans were evolving. James responded, "Yes, we are getting better" (Pre-Assessment Survey, March 31, 2017). With this statement, James described the term evolve as improvement. Sometimes when organisms evolve, it does appear that they are improving, but that is not always the situation because some advantageous traits for individuals can be detrimental for populations over time (University of California Museum of Paleontology, 2018). For example, if an environment suddenly changes, populations that once thrived could no longer be suited to survive. Also, if an advantageous trait is overproduced in a population the population could expand beyond carrying capacity.

When using the terminology “getting better,” James seemed to leave out the random events that are a critical part of the evolutionary process. From his statement, James’s thinking on the definition of the word evolve did not show he was completely aligned with the scientific meaning of the word. On the pre-assessment survey, one question showed that James understood the term evolution. The question and James’s responses are shown below in Figure 4.7. James answered the question correctly. By answering the question correctly, he understood the basic concept that species have evolved over time into new species. James’s answers on the pre-assessment survey and during the interview were inconsistent. It was unclear whether he had a correct definition of the term.

Which of the following is TRUE about the species that are living on earth today?

_____ A. All species living today have existed since the time life began.

_____ B. Most species living today have existed since the time life began, but a few have appeared more recently.

___X_ C. Most species living today did not exist at the time life began.

_____ D. There is no way of finding out whether all, most, or only a few species living today existed since the time life began.

Figure 4.7 – Question from pre-assessment survey (March 31, 2017)

During the unit of study. In the second activity, *Galapagos Island Virtual Field Trip*, James took notes in his science notebook during the video. His notes stated, “When species spread out to different places, they begin to slowly adapt to their new environment thus causing different species” (GIVFT, March 30, 2017). The researcher then asked James questions about the writings in his science notebook.

Researcher: You used the word “slowly” when referring to how species adapt to their new environment. Explain what you meant when you used the term slowly.

James: Organisms do not just change traits overnight; it takes time for the species to adapt to the new environment. It is not a quick process. There is no timeframe on the word slowly. When it is time for animals to evolve, they just will. (Interview #1, April 3, 2017)

Further down in his notes from the video, James wrote, “When new species are introduced to an area, current species could die out or evolve depending on their interactions” (GIVFT, March 30, 2017). James used the word evolve in a scientifically correct manner in his writing.

During interview #1, James was asked to elaborate on his statement from the video notes written above. “New species disrupt environments, sometimes good and sometimes bad. Existing organisms have to make a change or evolve to stay alive” (Interview #1, April 3, 2017). This response showed that regarding the introduced species, James was beginning to shift his thinking about the term evolve. His thinking shifted from evolve being a process that organisms use to get better to a process that naturally occurred for organisms to make changes necessary for survival.

After the unit of study. In the final interview, James was asked what three words come to mind now when thinking of natural selection. James’s new words were Darwin, evolution, and death (Final Interview, April 17, 2017).

Researcher: How are the three words Darwin, evolution, and death related to natural selection?

> James: Darwin – one of the main men that researched and studied how natural selection worked. Evolution – the gradual process of species changing. Species are constantly evolving due to different factors in nature. Death – some species naturally die out. Some species are just not fit to survive. I truly believe in survival of the fittest. (Final Interview, April 17, 2017)

James's final three words that came to mind when thinking about natural selection were somewhat different than his initial words of death, rabbit, and strong. James was reluctant to give up the word death, he felt like going extinct was death, and that was closely tied to the process of natural selection. Death and extinction can be closely tied to natural selection, even though they are not synonymous. Death is a natural part of living, where extinction is when populations are not able to reproduce for a variety of different reasons. It is unclear from the final response whether James was referring to a population but using the common mistake of calling it a species, or if he was thinking on more of an individual level.

In the final interview, James was also asked to explain the scientific definition of evolving. James explained natural selection as the following, "Natural selection is the gradual process of a species changing. Species are constantly evolving due to different factors in nature. This evolving could help or hurt a species in nature" (Final Interview, April 17, 2017). James used the word evolve in a scientifically correct manner in his sentence at the end of the unit. The correct use of the word in the sentence did not necessarily mean his thinking had been converted to the scientific meaning of the word, but it did display a change in his thinking that evolve means to improve.

Summary

In conclusion, on a self-reflection question after the unit was completed, James stated that his thinking had changed from the beginning of the unit until the end of the unit. James felt he had a broader understanding of scientific terms such as biodiversity, natural selection, and evolution, and how they are related. There was still evidence that James held alternative conception number one at the end of the unit. At the beginning, he thought that an organism had to intentionally adapt to survive, and the thought process persisted throughout the unit. Concerning alternative conception number 2, James continued to focus on all the factors that help organisms reproduce successfully. On alternative conception number 3, it was unclear at the beginning and the end of the unit whether James clearly understood that parents did not have the capability to pass on the better genes. At the beginning of the unit, James did not provide explicit thinking around his definitions of key evolutionary terms, and by the end of the unit James had coherent definitions of natural selection and evolve. Table 4.6 depicts James's thoughts from the beginning to the end of the unit.

Table 4.6

Summary of James's Thinking Regarding the Four Identified Alternative Conceptions

Alternative Conception	Beginning of Unit	End of Unit
1- Organisms can intentionally adapt.	Adaptations are necessary for organisms to survive.	Organisms must respond quickly to things that change in nature, their habitat, or their food.
2- Multiple factors	Gave a list of factors that help with living and reproduction rather than the measure of success.	Reproduction is important to success, but there are still other factors.
3- Parents select genes	Parents naturally pass on the better genes.	Unclear if parents had the capability of selecting which genes are passed down.
4- Evolve meaning	Evolve means to improve/get better.	Evolve means a gradual change that could help or hurt a species in nature.

Case of Bailey

Bailey was described by her teacher as a happy student who went the extra mile in the classroom by always raising her hand, asking questions, helping other classmates, and volunteering to assist the teacher. She was also not afraid to ask for help from the teacher or a classmate. Bailey was enthusiastic about science. Her enthusiasm showed in her demeanor and her need for positive reinforcement from the teacher. From appearances, Bailey enjoyed when the teacher called on her, recognized her work effort, and gave her attention. She did not miss any school during the unit on biodiversity.

On the pre-assessment survey and pre-interview, Bailey provided evidence of holding alternative conception numbers one, three, and four. Bailey did not provide evidence in holding alternative conception number two at the beginning of the unit. Throughout the unit, she did not provide evidence of holding alternative conception number two, therefore it will not be referenced in this case. The following sections are organized by Bailey's thoughts, responses during interviews, and written answers on handouts. Each section gives a narrative from her thoughts prior to, during, and after the unit of study.

Alternative Conception #1 – Organisms Can Intentionally Adapt

The scientifically incorrect thinking of adaptation refers to the fact that organisms can willingly adapt themselves to their environment or situation. Bailey held this alternative conception at the beginning of the unit. This section details her thinking prior to, during, and after the unit.

Prior to the unit of study. During the pre-interview, Bailey was asked to explain adaptations. She stated, "Organisms change themselves so they can be better suited for the environment. Organisms have to adapt if their environment requires it" (Pre-Interview, March 29, 2017). Bailey's response, "change themselves," gave the capability to the organisms to change themselves. This portion of her response was scientifically inaccurate because organisms cannot change themselves. Also, the phrase, "adapt if their environment requires it," made it seem that if the organisms needed to adapt, then they would. This portion of her response was scientifically accurate because organisms do naturally adapt to their environments. Bailey's thinking was deemed incorrect because of what the first portion of her response implied about adaptations. Her response implied that organisms had the power to change when necessary.

During the unit of study. There were several times that alternative conception number one was confronted during the unit on biodiversity. Bailey listened intently and took a few notes during the *Galapagos Islands Virtual Field Trip*. On her handout, when responding to the question, “Today there are 13 species of finches, explain how the change from one species to 13 species might have happened,” Bailey wrote, “The finches had to separate into different species, so that each one could have what they needed to live” (GIVFT, March 30, 2017). The researcher asked Bailey to elaborate on her response. Bailey responded, “I am unsure why changes occurred, I just know they have to happen for organisms to survive” (Interview #1, April 3, 2017). Bailey was vague about her thinking and did not elaborate. She did not provide any justification to support her answer. She continued to use language such as “had to,” which showed that she thought organisms would change if it was necessary.

In the practical work activity, *Peppered Moth Web Quest*, Bailey was asked to define natural selection. She defined it as “the change in individuals in a species over time through genes when passed to offspring it passes on and changes the species” (PMWQ, April 3, 2017). This statement reflected that Bailey understood that individuals of the same species can have differences. Bailey was asked about these differences in an interview.

> Researcher: Can you elaborate on your definition of natural selection?
>
> Bailey: Well, species are constantly changing. These changes are sometimes what makes them survive over other individuals.

> Researcher: In your definition, you state these things happen over time. Can you explain your thinking?
>
> Bailey: Natural selection is not a quick process; that it takes species time to change, especially when they have to change traits that are better suited for the environment. (Interview #2, April 5, 2017)

Bailey's thinking concerning species changing to make them survive over other organisms did not demonstrate clearly whether she was thinking on more of an individual level or about entire populations. For her statement to be scientifically aligned, she would have had to distinguish that over time, the entire population of an organism would change, not just the particular organism that needed the adaptation at the moment.

Another question on the web quest handout elicited Bailey's thinking about this alternative conception as well.

> Question: Explain the concept of natural selection using your moths from the simulation as an example.
>
> Response: Their wings helped them blend in with their environment. Dark moths evolved to better survive in their environment. The dark moths had to change so that they would be hidden from predators. (PMWQ, April 3, 2017)

"Had to change" were the words Bailey used to describe the adaptations of the moth during the simulation. This phrase indicated that she thought the moths could intentionally change for survival purposes.

After the unit of study. Bailey had conflicting thoughts on the teacher-made post-assessment. On the short answer question, she wrote, "After the population has been separated, the species of the population had to adapt to its new environment, so that the population can produce offspring" (PC Assessment, April 6, 2017). Bailey was still using the terminology, "had to adapt." By using this terminology, her thinking still aligned with organisms that were forced to adapt for survival.

There was also another question on the multiple-choice section of the post-test that closely aligned with alternative conception number one. The question and Bailey's correct response are shown in the following figure.

In which scenario below would natural selection most likely occur?

_X_ A. centuries of gradual climate change

___ B. catastrophic destruction of habitat

___ C. rapid and profound climate change

___ D. immediate loss of primary food source

Figure 4.8. Question from teacher-made post assessment on population change (April 6, 2017).

The researcher asked Bailey to elaborate on her correct answer about natural selection.

Researcher: Explain how you knew that was the correct answer.

Bailey: Lucky guess, I guess. But really, natural selection takes time and it occurs with nature. You cannot force it to happen. (Interview #3, April 10, 2017)

Bailey responded more than once that she guessed on a lot of her answers. When asked during interviews, she explained her thinking behind her guesses. On this question, she started by stating, "You cannot force it to happen." Bailey removed the terminology that organisms could intentionally change. It is not certain from this one response that her entire thinking on alternative conception number one had changed, but it did demonstrate a change in thought patterns.

Alternative Conception #3 – Parents Select the Genes They Pass to Offspring

Alternative conception number three was concerned with the parent organism. This alternative conception referred to the concept that parents can select which genes are passed down to their offspring. This section has been organized by Bailey's thoughts before, during, and after the unit.

Prior to the unit of study. In the pre-interview, Bailey was questioned about how adaptations are passed to future generations. Bailey answered confidently and with a smile, "Parents select the genes that are better for survival to pass to their offspring" (Pre-Interview, March 29, 2017). Terminology such as "select" showed a belief in alternative conception number three that parents can choose which traits to pass to the next generation.

During the unit of study. With the third practical work activity, *Interactive Near Pod Notes (Population Change)*, Bailey appeared to be actively engaged by taking notes and periodically nodding her head during the instruction. On the discussion question, "Summarize the process of how insects become pesticide resistant," Bailey's written response demonstrated her thinking on the topic. Bailey's response was, "Over time, favorable genes can be passed down, causing most insects to become insecticide resistant" (PCN, March 31, 2017). Bailey used the term "favorable" in her response. Favorable, when used in this context, meant that organisms will pass down genes that give the best opportunity for offspring to survive. By using this terminology, Bailey possessed a naïve view of how genes are passed from parent to offspring. The environment creates a need for the trait (being resistant to insecticide); parents pass that trait to their offspring.

During the *Peppered Moth Web Quest*, Bailey demonstrated her belief in alternative conception number three. The objective of the *Peppered Moth Web Quest* activity was for students to review natural selection and the impact the environment has on species survival. The web quest had a set of questions for students to answer as they completed the assignment. Below is a portion of Bailey's answers from the handout.

> Question: What is natural selection?
>
> Response: It is the change in individuals in a species over time through genes; when passed to offspring, it passes on and changes the species.
>
> Question: Explain the concept of "natural selection" using your moths from the simulation as an example.
>
> Response: Their wings helped them blend in with their environment. Dark moths evolved to better survive in their environment. The dark moths had to change so that they would be hidden from predators. (PMWQ, April 3, 2017)

When asked about these responses in an interview, Bailey responded, "Parents have to give their children what they need to survive. Dark wings are what helps the moth survive, so that is what the parents passed down" (Interview #2, April 5, 2017). In this instance, Bailey still used the terminology, "have to give their children," which could indicate that parents want to give the most suitable genes to their offspring. This response was a clear indicator that Bailey thought parents had the ability to choose that they would pass down the best genes to help their offspring survive. Even though organisms cannot intentionally pass down the better-suited genes to their offspring, in a population over time the better-suited genes will prevail.

After the unit of study. On the post-assessment, Bailey answered most of the questions correctly. One question discussed variation. Bailey answered the following question shown in Figure 4.9 correctly.

Variation happens as a result of the exchange of genetic information as it is passed from parent to offspring. Which of the following is true about inherited variation?

___ A. Variation can influence separation.

___ B. Variation can influence selective breeding.

___ C. Variation can influence the resources that are available to an organism.

_X_ D. Variation can influence whether organisms are more likely to survive to reproduce.

Figure 4.9. Question from teacher-made post assessment on population change (April 6, 2017).

The researcher and Bailey went over several questions on the post-assessment. Even though Bailey got the correct response, the researcher wanted to know her reasoning behind the response.

> Researcher: Can you explain why you chose D?
>
> Bailey: Well, it seemed like the best answer. I just kept thinking variations are like changes, so variations in different offspring will determine how likely they are to survive and reproduce. Parents want to give their offspring the best variations to help them survive. The other answer choices other than resources available just did not make sense to me. (Population Change Assessment, April 6, 2017)

Bailey arrived at the right answer for the question even though her thinking only partially aligned with scientific thinking. Bailey was correct in knowing that inherited variation is what offspring get from their parents. Bailey stated that parents want to give their offspring the best variations, but she did not mention if it was within their power. This was a slight shift from the beginning of the unit where she stated parents could select which genes are passed down. It is unclear whether she still held alternative conception number three. From her post-test questions and interview responses, though, it seemed that her thinking had begun to shift.

Alternative Conception #4 – Evolving Means to Reproduce or Die

Vocabulary is important in conveying scientific concepts. The terms evolve and adapt were misused by Bailey during the unit. By using the words incorrectly, Bailey revealed that she held alternative misconception number four. This section is organized by Bailey's usage of the terms before, during, and after the unit of study.

Prior to the unit of study. A question on the pre-assessment survey asked about the process of human evolution. The question on the pre-assessment survey asked, "Are humans evolving?" Bailey responded, "When one human dies another is born" (Pre-survey assessment, March 28, 2017). During the first interview, the researcher reminded Bailey of her answer and asked her to explain her thinking.

> Bailey: Of course, when one human dies another is born.
>
> Researcher: Please elaborate on your response to this question.
>
> Bailey: It all is a cycle, when one human dies another is immediately born and that is the same thing as evolving. (Pre-Interview, March 29, 2017)

Bailey seemed to have an alternative conception built in her mind that evolving means that there is a cycle, which is partially true, but her explanation was not fully accurate. Cycles, when concerned with evolution, look at the process through the lens of populations of organisms. The populations continue to live, adapt, and reproduce. The cycles are not on an individual level. Evolving could be described as a cycle if an adequate explanation was given.

During the unit of study. The words evolve, evolving, and evolution were used several times during the unit. One incident wherein Bailey explained the word evolve occurred on her *Galapagos Islands Virtual Field Trip Handout*. The questions asked Bailey to discuss how the land iguana may have evolved into the marine iguana.

> The land iguana adapted to be able to live and eat in the water. These adaptations could have been caused by many different things such as not enough food, too many predators after them, etc., so over time, they just began to evolve so that they could live. (GIVFT, March 30, 2017)

Bailey used the term evolve correctly in this response. She used it as a change over time in dealing with the population of iguanas.

She also used the word evolve in a scientifically correct manner with a written response during the *Human Interference Simulation*.

> Question: How could the disappearance of wolves from their ecosystem affect the populations of other species?
>
> Answer: Some populations would increase because they wouldn't have any predators after them. Other species would have to adapt/evolve due to the wolves being gone so that they could survive. (Interview #3, April 10, 2017)

In the interview, the researcher asked, "Explain why you used adapt/evolve in your answer. Do you think that they are the same?" Bailey responded, "Well, to me they are. Especially in that situation. If one species is removed, then other species have to adapt or evolve to make up the difference, so things even out." In this situation, by using the words adapt and evolve interchangeably, Bailey was using a less sophisticated way of thinking of the words because she was referring to them more as a change.

After the unit of study. The researcher asked Bailey to describe the process of natural selection. Bailey responded, "When species evolve over time" (Final Interview, April 17, 2017). The researcher asked Bailey to elaborate. Bailey answered, "You know, organisms slowly change over time" (Final Interview, April 17, 2017). Bailey's responses showed that she used the terms evolve and change interchangeably.

Summary

At the beginning of the unit, Bailey was asked to describe three words that came to mind when describing the process of natural selection. Bailey used the words "number of animals." By the end of the unit, Bailey used the words adaptations, evolve, and slow (Final Interview, April 17, 2017). This change in words showed a different mindset from the beginning of the unit to the end. Bailey chose more appropriate words that reflected understanding by the end of the unit.

At the beginning of the unit, Bailey held three of the four selected alternative conceptions. Concerning alternative conception number one, it appeared that Bailey shifted from the idea that organisms must adapt to the idea that they cannot be forced to change. This shift was a change in direction towards the scientifically aligned thinking that organisms cannot force themselves to adapt. Alternative conception number three addressed parents being able to pass on favorable genes. Bailey did not shift her thinking from the fact that parents would pass on the better genes to their offspring to survive in the given environment. Alternative conception number four concerning the misuse of the word evolve was held by Bailey at the beginning of the study. At the beginning, Bailey was using the word to describe a cycle. By the end, she was using the word evolve synonymously with change and adapt. Although this change did not fully align with the scientific meaning of the word, it aligned more closely to the definition of evolve. Table 4. 7 summarizes Bailey's thoughts at the beginning and end of the unit on each of the alternative conceptions.

Table 4.7

Summary of Bailey's Thinking Regarding the Four Identified Alternative Conceptions

Alternative Conception	Beginning of Unit	End of Unit
1- Organisms can intentionally adapt.	Organisms must adapt if the environment requires it.	Cannot be forced
2- Multiple Factors	Surviving offspring is the measure of success in an organism.	Continuing to state that reproduction is vital to an organism's success.
3- Parents' Select Genes	Parents select genes that are better for survival to pass on to their offspring.	Parents want to help their offspring survive.
4- Evolve Meaning	When one human dies another is born.	Used the terms evolve and change interchangeably

Cross-Case Analysis

The following sections will show a holistic approach to the patterns in thinking demonstrated by the participants for each alternative conception. For interpretive purposes, figures are used to visually represent participants' shifts throughout the biodiversity unit. In each figure, an X indicates what the participant thought for a specific activity and an absence of an X indicates participants' thinking was not revealed or known for that activity. Activities that did not directly address a specific alternative conception were noted with an asterisk. Boxes identified the three practical work activities in the biodiversity unit: *Shall We Hunt, Peppered Moth WebQuest,* and *Human Interference Simulation.*

Biodiversity Vocabulary

Alternative conception number four referred to participants' understanding of scientific vocabulary associated with biodiversity. Each participant began the unit holding the alternative conception concerning biodiversity terminology such as what it means to evolve and adapt. Although some fluctuations occurred during the unit, at the conclusion of the unit all had reached scientific thinking (Figure 4.10). The participants had an opportunity to interact with vocabulary during each activity; at the conclusion of the unit, during the post-assessment and post-interview, they were able to demonstrate scientific thinking.

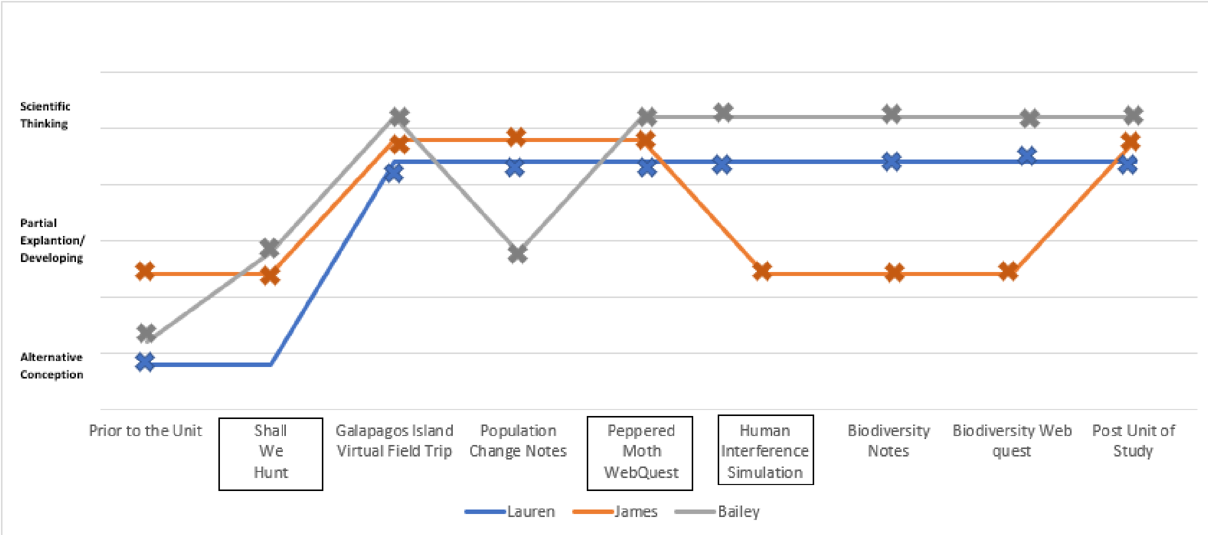

Figure 4.10. Participants' thinking about alternative conception number four, biodiversity vocabulary.

Multiple Factors Determine Evolutionary Success

Alternative conception number two was concerned with participants identifying the ultimate measure of success in nature. Lauren and James continued to incorporate factors that influence success with the ultimate measure. This scientific concept was addressed in the first five classroom activities but was missing from instruction in the last two activities. Bailey exhibited scientific thinking and did not hold alternative conception number two, for that reason she is omitted from Figure 4.11. Lauren and James maintained partial scientific understanding throughout the unit, with an uptick for James for the Peppered Moth activity (Figure 4.11). The five lessons that did address alternative conception number two did not distinguish between the ultimate measure of success and the factors that attributed to success in nature. Participants retained their partial scientific understanding and alternative conception about what ultimately is the measure of success in evolution.

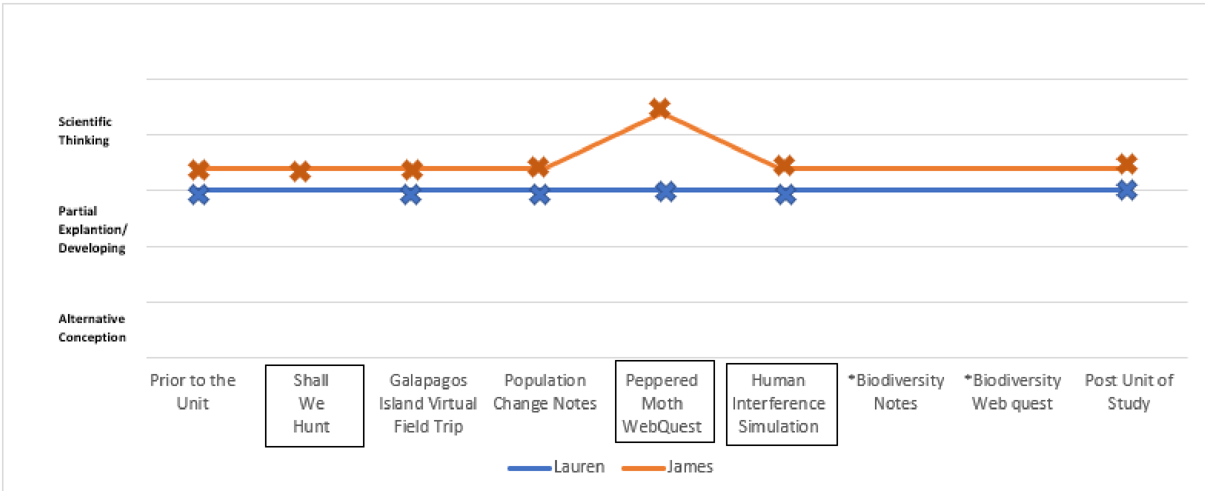

Figure 4.11. Alternative Conception Number Two, participants' thinking about the ultimate measure of evolutionary success.

Organisms Can Intentionally Adapt

Alternative conception number one was concerned with the faulty conception that organisms can intentionally adapt to the environment. Figure 4.12 depicts the four lessons that covered this topic and how participants' thinking fluctuated during the unit. Lauren demonstrated partial understanding throughout the study and ended with a partial understanding. Bailey began the unit with holding the alternative conception and by the end of the unit her thinking showed a partial understanding. Throughout the study participants continued to use words such as "could" or "would adapt" to different circumstances rather than acknowledge that species evolve due to random events in the environment. The difficulty associated with positively shifting this misconception during the unit was evident through missed questions or participants' inability to elaborate on correct responses concerning this alternative conception after the unit.

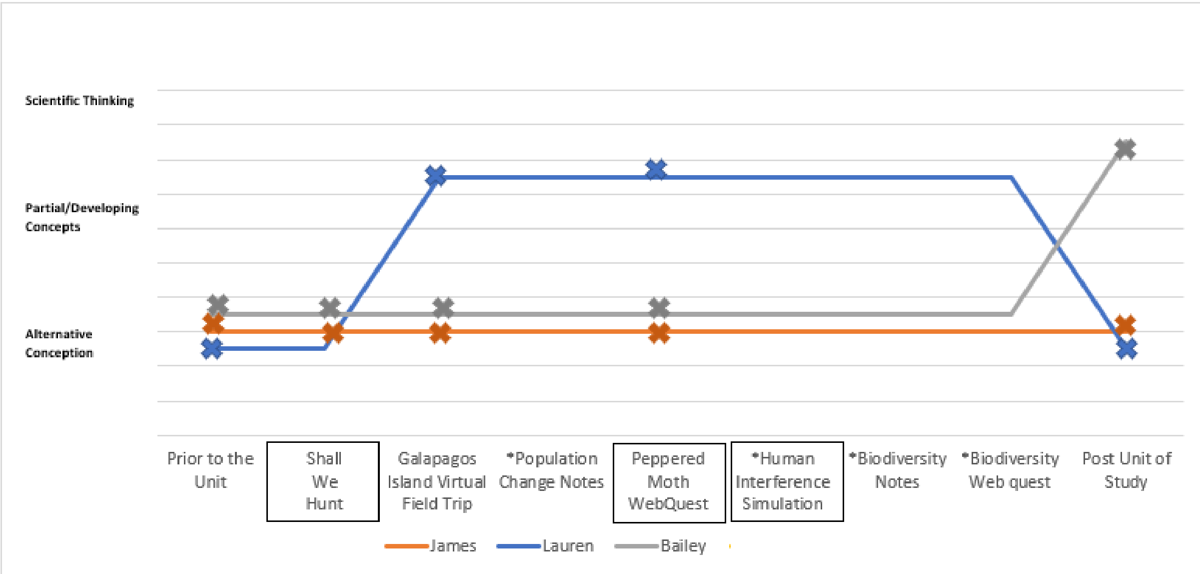

Figure 4.12. Alternative Conception Number One, participants' thinking about if organisms can intentionally adapt

Parents Select Genes that They Will Pass to Offspring

At the beginning of the unit, James and Bailey were unclear of the process of how genes are passed from parents to offspring. Lauren had a partial understanding of this process. Figure 4.13 depicts participants' thinking about this process throughout the unit. Only three lessons in the study addressed this alternative conception and were located at the end of the unit. Only one practical work activity, *Human Interference Simulation*, directly addressed the concept of how genes are passed from parent to offspring in this study. Lauren started the unit with partial understanding of the scientific content and had a peak in knowledge after the peppered moth activity, but by the end of the unit she still only demonstrated a partial understanding. James and Bailey both started off with their thinking aligning with the alternative conception and ended with a partial understanding. Each participant ended with a partial understanding; the class activities did not directly focus on the mechanism behind this process of how genes are passed down from generation to generation.

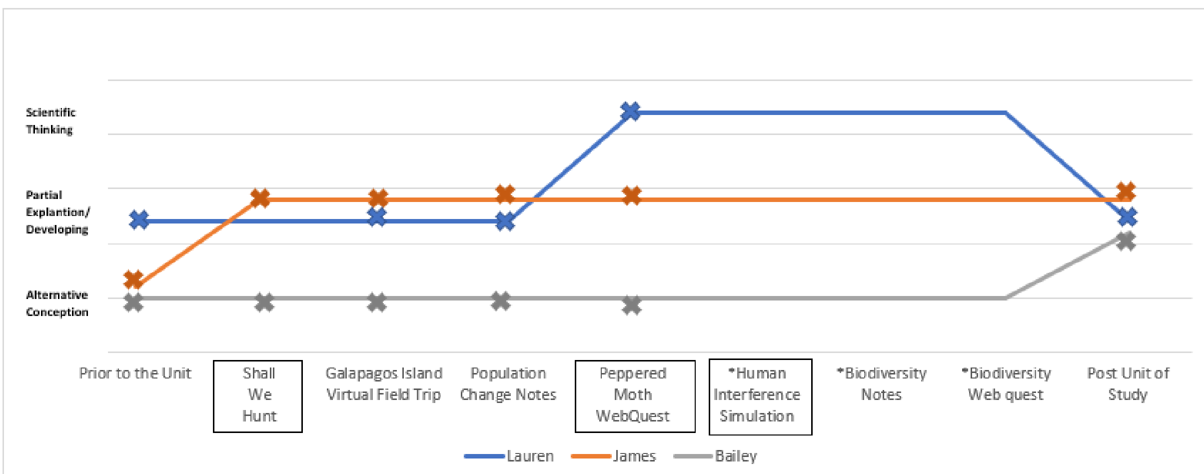

Figure 4.13. Alternative Conception Number Three, participants' thinking about parents being able to select what genes are passed down to their offspring.

Summary

Alternative conceptions, even with proper instruction, can continue to persist in participants' minds. Alternative conception number four showed the most improvement among participants with all students reaching scientific thinking. Participants had the most trouble with demonstrating scientific understanding with alternative conception number one. The biodiversity unit showed no real impact on the participants' long-term understanding of alternative conception numbers one, two, or three, even if they showed peaks of understanding throughout unit.

Chapter Summary

The purpose of this study was to examine middle school students' alternative conceptions regarding biodiversity while engaged in practical work in the classroom. To examine this, an exploratory case study design was adopted, in which each participant served as a case within the study. This chapter described the unit and its activities used in the classroom. This chapter also provided a rich chronological narrative of the participants concerning each of the four alternative conceptions. Lastly, this chapter revealed patterns within the embedded cases through a cross-case analysis. A discussion of the results of this study and implications for science education are discussed in the next chapter.

CHAPTER 5: SUMMARY AND DISCUSSION

Introduction

One major goal of science education is to produce scientifically literate students (NGSS Lead States, 2013; National Research Council, 2017; NCLB, 2002). Alternative conceptions can hold students back from becoming scientifically literate citizens. Biodiversity has proven to be an area in science where students hold many alternative conceptions (Lucero et al., 2017; Nehm & Reilly, 2007; Robbins & Roy, 2007). Effectively aiding in restructuring these alternative conceptions is aligned with the goal of improving science literacy (Lucero et al., 2017; Nehm & Reilly, 2007; Robbins & Roy, 2007). This goal can be attained by examining students' alternative conceptions and how they are altered, if at all, during a unit of instruction on biodiversity.

The purpose of this qualitative study was to examine middle school students' alternative conceptions regarding biodiversity while engaged in a unit of study that included practical work activities. Throughout the unit, alternative conceptions were examined across each activity. In this chapter, a review of the methodology that was utilized by the researcher will be discussed, and then a summary of the results of the study will follow. Finally, the results will be discussed which will include implications of the study and recommendations for future research.

Review of Methodology

The methodological design of this study was best characterized as an exploratory case study (Yin, 2014). The case study methodology allowed the researcher to explore a phenomenon from several different data points (Yin, 2014). A multiple case study design was utilized because it allowed for an in-depth description of how each of the participant's alternative conceptions changed, if at all, throughout the study. In-depth classroom observations were conducted to qualitatively explore the process of restructuring alternative conceptions of biodiversity concepts during classroom instruction. The research question, "How are students' alternative conceptions altered, if at all, during a unit of instruction on biodiversity that includes practical work?" was explored through pre- and post-assessments, interviews with the participating students, and classroom observations.

The data were analyzed by examining each of the three participants' thoughts throughout the unit. Detailed case descriptions were written for each participant in which a chronological narrative described the participants' conceptions of biodiversity made through class observations, class handouts, interviews, and assessments. A cross-case analysis was conducted (Yin, 2014) to compare and contrast the cases according to each alternative conception.

Summary of Results

The researcher sought to examine students' alternative conceptions during a middle school biodiversity unit that included practical work. To this end, data representing the students' thinking prior to the unit, during the unit, and at the end of the unit were analyzed. A summary of the results of this analysis follows.

Alternative Conception #1- Organisms Can Intentionally Adapt

Throughout the unit, participants' views regarding organisms' ability to intentionally adapt varied. Although all three participants began the unit holding the alternative conception, only one participant (i.e., Bailey) concluded the unit with a demonstration of scientific thinking. When discussing if organisms could intentionally adapt, participants continued to use words such as "have to" when discussing adaptations.

Alternative Conception #2- Multiple Factors Determine Evolutionary Success

Throughout the unit, participants' views regarding the ultimate measure of success in nature were mixed. One participant demonstrated scientific thinking and held it throughout the study, while the other two participants demonstrated partial understanding and held it throughout. The partial understanding was that participants listed factors that attributed to success, such as finding a mate and food resources, but never clearly stated reproduction success. The participants knew that reproduction was important to success, but not the ultimate measure in nature.

Alternative Conception #3- Parents Select the Genes They Pass to their Offspring

During the unit, participants' views regarding parents being able to select the genes that they pass to their offspring were difficult for them to articulate. The participants used terminology to suggest that parents could select the genes or had the power to pass down the best genes to their offspring. The participants started with varying conceptions at the beginning of the unit. Even though their initial thinking varied, by the end of the unit all participants had a partial understanding of the concept.

Alternative Conception #4- Evolving Means to Reproduce or Die

Participants' views regarding biodiversity vocabulary (i.e., evolve and adaptation) shifted from holding the alternative conception/partial understanding to scientific thinking by the end of the unit. At the beginning of the unit, participants' definition of evolve was closely related to the cycle of life, not the broader picture of how evolving deals with biodiversity. Participants defined words such as adaptation and natural selection at the beginning of the unit with simplistic ideas about the subject, but by the end their explanations of the terms aligned to the scientific way of thinking,

Discussion of Results

This section discusses the results of how this study influenced the different alternative conceptions that were identified in this study. The data described and discussed in the results section of this study led the researcher to two important conclusions regarding the aim of the study. The most pertinent results in answering the research question are related to how scientific vocabulary was influenced and the effects of not directly confronting alternative conceptions during classroom instruction.

Vocabulary Instruction

As a result of participants engaging in the unit on biodiversity, which included practical work, each participant's alternative conception concerning the vocabulary terminology (evolution and adaption) shifted toward scientific thinking. There are two possible explanations described in this section: the multiple exposures to vocabulary and the variety of strategies used for vocabulary instruction.

Multiple exposures. Recent research on vocabulary instruction has shown that students need multiple exposures and opportunities to practice and assimilate new words to acquire deep understandings of words and the concepts they represent (Brown & Concannon, 2016; Townsend et al., 2018). Much research has investigated scientific vocabulary as it related to the teacher's instructional practices (Brown & Concannon, 2016; Townsend et al., 2018). One theme from several studies concerning science vocabulary instruction was the repetitive nature of science vocabulary included throughout the unit of instruction (Brown & Concannon, 2016; Harper, 2018; Townsend et al., 2018). The literature indicated that many teachers have moved away from introducing vocabulary at the beginning of the unit and instead have embedded it within the lessons (Brown & Concannon, 2016; Harper, 2018; Townsend et al., 2018). When analyzing the data in the current study, participants interacted with the vocabulary terms across each lesson in the unit, as demonstrated by the multiple instances of vocabulary used in the data analysis (see Figure 4.9). The multiple exposures to the different vocabulary terms could be a possible explanation of why participants seemed to grasp the scientific terminology by the end of the unit. These instances combined with the literature suggest that the ongoing opportunities to utilize the vocabulary during this unit that included practical work supported the shift in participants' thinking to scientific thinking.

Variety of strategies. Another key theme from the body of science literacy instruction focused on the use of meaningful and multimodal activities with key terms (Brown & Concannon, 2016; Harper, 2018). Different literacy strategies have been used to promote students' thinking about developing mastery in scientific concepts (Brown & Concannon, 2016). Harper's (2018) study indicated that not any one vocabulary strategy was better than the other one, but that varied and repeated vocabulary instruction is what improved students' understandings of science terminology. The unit in the current study consisted of practical and non-practical work activities, which likely resulted in the inclusion of multimodal activities. The variety of activities could be a possible explanation of why the participants' thinking shifted toward scientific thinking with terms associated with biodiversity.

Inconsistent Influence

As a result of participants engaging in the biodiversity unit that included practical work, there was no consistent evidence that instruction had a positive influence on the participants' thinking with regard to three of the alternative conceptions: organisms can intentionally adapt, evolutionary success versus the factors that influence it, and parents have control over genes they pass down. There are two possible explanations discussed in this section: opportunities for students to reconcile information brought to the classroom with science instruction and teachers planning the unit of instruction with alternative conceptions in mind.

Opportunities to reconcile. The science education research has shown that students often use newly acquired conceptions in an incorrect manner, which often leads to them experiencing dissatisfaction with their old conceptions, unaware of how the new information fits into their conceptual framework (Lucero et al., 2017; Nehm & Reilly, 2007). The students' old conception, therefore, is mostly retained and only modified to include newly learned information (Lucero et al., 2017). The research shows that when new scientific ideas are mixed with students' alternative conceptions that students merge the ideas in their minds and do not fully take on the scientific way of thinking (Lucero et al., 2017; Nehm & Reilly, 2007; Pringle, 2006).

The current study gave students opportunities to integrate their new knowledge. This was demonstrated in Figures 4.10, 4.11, and 4.12. In these figures, each X represented an instance where the alternative conceptions surfaced. Since opportunities to engage in the content to challenge their prior knowledge was sporadic throughout the unit, participants likely could not effectively allow the scientific content to convince them to change their prior ideas. It appeared from the data that participants allowed the information to merge with their own ideas, leaving them with a partial scientific understanding for these topics and retaining a Lamarckian view of evolution.

Alternative conceptions should influence the design of the unit. Another idea from the research demonstrated that teachers are consistently eliciting students' thoughts in the classroom, but the tracking of students' thinking can occur in different forms (Lucero et al., 2017; Nehm & Reilly, 2007). One way that this is done in the classroom is teachers eliciting students' initial understandings, but not consciously using this information about their students to shape their subsequent instruction or understandings throughout the unit of instruction (Lucero et al., 2017; Pringle, 2006). During the current study, the teacher elicited students' understandings prior to the unit of study but did not elicit thinking on a consistent basis during the unit of instruction on the alternative conceptions concerning organisms: intentional adaptation, evolutionary success, and parental control over inherited genes. The unit was planned before the alternative conceptions were identified and only small adjustments in instruction occurred. This could be a possible explanation for the inconsistencies shown in the current study with participants' thinking about some of the alternative conceptions. It was clear from the data analysis that some alternative conceptions did not surface over three lessons thus suggesting that participants' conceptions were not necessarily used to plan further instruction.

Implications and Future Research

The results of this study have two practical implications for science education. First, inclusion of practical work during the unit supported vocabulary development regarding biodiversity terms. Therefore, one implication from the current study is practical work should be included in a unit on biodiversity. Even though practical work was sporadically placed throughout the unit, by the end of instruction each participant had a stronger scientific knowledge when using the vocabulary terms. One limitation of the study, though, was its small sample size of three participants. The study should be replicated with a larger sample size. This study also focused on the topic of biodiversity; future research should implement practical work with different content areas of science.

Second, the inclusion of practical work was inconsistent on impacting other alternative conceptions in this study. Therefore, an implication from this study is that educators wishing to help students overcome alternative conceptions cannot rely solely on practical work during a unit. Teachers should make explicit connections to the alternative conceptions, so that they can disrupt students' thinking (Pringle, 2006). One area of future research should examine implementation of practical work and under what conditions it can be effective in the classroom. Attention must be given to how practical work elicits confrontation of students' alternative conceptions with the scientific concepts presented during instruction.

Conclusion

Students enter science classrooms with robust beliefs with which they attempt to explain their worlds (Poehnl & Bogner, 2013; Pringle, 2006). These beliefs are frequently not in line with the views currently accepted by the scientific community and are commonly referred to as alternative conceptions (Pringle, 2006). Many teachers assume that students will acquire the currently accepted scientific conceptions after they have had instruction concerning a topic. Research has demonstrated, though, that this simplistic assumption, especially in science education, is not the case (Danaia & McKinnon, 2007; Taber, 2003). Often, students end up with a mixed model of thinking encompassing their prior beliefs and those which have been presented by the teacher (Danaia & McKinnon, 2007; Pringle, 2006; Taber, 2003). The results in this study confirmed this, showing that despite the inclusion of practical work participants continued to mix their thinking with scientific thinking presented in class on most of the alternative conceptions.

Identification of alternative conceptions and explicitly teaching to counteract this faulty thinking is essential for the development of a scientifically literate society (Lucero & Petrosino, 2017). Science educators are responsible for promoting a scientifically literate citizenry, even while having students with alternative conceptions that persist in the classroom thus hindering the process. The results of this study serve to inform the role of practical work in achieving one of the goals of science education: science literacy for all.

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Appendix A

Biodiversity Pre-Assessment Questions

1. What are the first three words that come to mind when you think of the term natural selection? For questions 2 through 4, circle ALL answers you think are accurate about each statement

2. Natural selection applies to

A. Individuals
B. Populations
C. Everything but humans
D. All Organisms
E. Nothing
F. I don't know

3. The measure of success in nature is

A. Age reached
B. Enemies killed
C. Mating opportunities
D. Surviving offspring
E. Food gathered
F. I don't know

4. Concerning biodiversity, changes result from

A. Organisms learn to modify their bodies
B. Random mutation
C. Genetic material is passed on
D. Loss of body parts
E. Supernatural intervention
F. I don't know

Please mark only ONE correct answer for questions 5- 10

5. Which of the following is TRUE about the species that are living on earth today?

A. All species living today have existed since the time life began.

B. Most species living today have existed since the time life began, but a few have appeared more recently.

C. Most species living today did not exist at the time life began.

D. There is no way of finding out whether all, most, or only a few species living today existed since the time life began

6. Individual members of a species could have differences in inherited characteristics that affect which of the following?

A. Both their ability to find food and their ability to avoid predators

B. Their ability to find food but not their ability to avoid predators

C. Their ability to avoid predators but not their ability to find food

D. Neither their ability to find food nor their ability to avoid predators

7. Which of the following is TRUE about individuals of the same species?

A. Individuals of the same species may have different inherited traits. These different inherited traits may cause differences in each individual's chances of survival and reproduction.

B. Individuals of the same species have the same inherited traits, therefore each individual has an equal chance of surviving and reproducing as any other individual of the same age and gender.

C. Individuals of the same species have the same inherited traits but different acquired traits, such as what they have learned and skills they have developed. Only these different acquired traits can cause differences in each individual's chances of survival and reproduction.

D. Individuals of the same species may have different inherited traits, but these different traits do not cause differences in each individual's chances of survival and reproduction.

8. According to the theory of natural selection, what would happen to a species of lizards when a new predator is introduced into the environment where the lizards live?

A. The lizards that already have the physical traits needed to avoid the new predator would be more likely to survive and reproduce, and the ones that do not would be less likely to survive and reproduce.

B. All of the lizards would try to develop new physical traits to avoid the new predator.

C. Some of the lizards would try to develop new physical traits to avoid the new predator, and the other lizards would die.

D. Because all lizards of the same species have the same physical traits, one lizard would not have an advantage over another lizard. They would either all survive or all die.

9. Which of the following is REQUIRED for the process of natural selection to occur?

A. Members of the same species must compete with one another.

B. Members of different species must compete with one another.

C. There must be a sudden environmental change.

D. Traits must be inherited from one generation to the next.

10. Which of the following statements is TRUE about the evolution of plants and animals?

A. All plants and all animals share a common ancestor with each other.

B. All plants share a common ancestor, but all animals do not share a common ancestor.

C. All animals share a common ancestor, but all plants do not share a common ancestor.

D. No plants share a common ancestor with each other, no animals share a common ancestor with each other, and no plants share a common ancestor with any animals.

Please answer questions 11 and 12 in complete sentences.

11. Is the population of humans evolving? Please explain.

12. Students frequently learn about scientific laws, such as Newton's Laws of Motion, the Law of Inertia, or the Law of Gravity and they often learn about scientific theories, such as the Cell Theory, the Theory of Natural Selection, the Theory of Evolution, and the Big Bang Theory. The Theory of Evolution was first introduced by Charles Darwin in 1859. Scientists have a great deal of evidence to support it such as fossil evidence, DNA evidence, structural similarities in the anatomy of organisms, and similar amino acid sequences in proteins.

A. Explain your view of the difference between a scientific law and a scientific theory. How are they similar and how are they different?

B. Do you think the Theory of Evolution will ever become the Law of Evolution? Explain your answer.

Appendix B

Interview Questions

Pre-Interview Questions

- Describe why you choose the three words that came to mind when describing natural selection?
- Describe the process of natural selection.
- Can you describe the word evolve?
- In your own words, explain the process of natural selection using adaption.

Interview #1 (Notes and Video Interview)

- How did the Near Pod Notes help you understand the science concept of biodiversity? What aspect from the lesson helped your thinking, if any?
- Explain your thinking on insecticide resistance?
- How did the video help you understand the science concept of biodiversity? What aspect from the lesson helped your thinking, if any?

Interview #2 (Web Quest and Simulation Interview)

- How did the Web Quest help you understand the science concept of biodiversity? What aspect from the lesson helped your thinking, if any?
- How did the Web quest relate to natural selection?
- How did the Human Interference Simulation help you understand the science concept of biodiversity? What aspect from the lesson helped your thinking, if any?

Interview #3 (Assessment and Note Interview)

- How did the Biodiversity notes help you understand the science concept of biodiversity? What aspect from the lesson helped your thinking, if any?
- Explain your thinking, from _____________ question on your assessment.

Final Interview

1. Describe the process of natural selection
2. In your own words, define biodiversity.
3. What three words come to your mind when you think of biodiversity?
4. From the beginning of the unit, did you change your thinking on your definition of biodiversity? If so elaborate.

Appendix C
Observation Protocol

Anticipated Alternative Conceptions	**Holding (Evidence)**	**Not Holding (Evidence)**
1. Evolution results in progress; organisms are always getting better through evolution.		
2. Organisms evolve so that they are perfectly suited to their environment		
3. The fittest organisms in a population are those that are strongest, healthiest, fastest, and/or largest.		
4. Species that have no apparent, obvious, or superficial similarities have no similarities at all		
5. Except for a few major changes due to large volcanoes that have erupted or meteorites that have struck the earth, environmental conditions have stayed the same throughout the history of the earth		
6. Changes in a population occur through a gradual change in all members of a population, not from the survival of a few individuals that preferentially reproduce		
7. Species that are similar can share a common ancestor, but species that have no apparent, obvious, or superficial similarities cannot share a common ancestor		

Appendix D

Student Observation Protocol

Student A	Student B	Student C

Appendix E

Classroom Culture Selection Criteria

Directions: Please answer each question thoughtfully and honestly. – These are the questions that will occur in a face-to-face interview.

1. What is the school policy regarding the use of active learning in science class? Must laboratories be included? Do other teachers use all/some of the same laboratory exercises as you do?

> *The school does not have an exact policy on laboratories being included in the science classroom. They do want to see them actively engaged in the content. I love doing labs in my classroom. The other science teachers and I plan together each week and attempt to do the same activities*

2. Describe a typical sequence for a laboratory activity.

> *In my classroom, I usually give a general overview of the information and then dive right into hands on activities, whether it be a video clip, a demonstration, group work activity, or a lab.*

3. How much freedom do you give students to investigate problems of their own choosing?

> *It is hard to give a lot of freedom with so much to cover during the school year. I do believe in choice in my classroom, so some assignments they have different options to complete.*

4. Describe a typical day in your classroom.

> *Fun! Of course. There is normally a bell ringer activity, a quick whole class activity (which could include but are not limited to go over HW, introducing a new topic, a quick discussion, formative assessment, etc.), an activity to get them involved in the content, and then a wrap up to the class period.*

5. Describe an atypical day in your classroom.

> *Students sitting quietly waiting on me to give them all the information.*

Appendix F

Practical Activity #1- *Shall We Hunt*

When you examine an ecosystem, you find ***producers, consumers,*** and ***decomposers*** forming a variety of ***food chains*** and ***food webs***. You may also find evidence of ***competition*** for food, space, and shelter: ***predator-prey relationships***; and ***predator-prey adaptations***. In this investigation, you are going to examine an outdoor ecosystem to see what the effects ***protective coloration*** has on an organism.

Directions: Pretend that you are the ***predator*** and the toothpicks are the ***prey.*** Your goal is to see how many toothpicks you can capture in a given amount of time.

Record the amount of colored toothpicks that you collected in the data table below.

DATA TABLE- GROUP RESULTS

Color of toothpick	Trial 1	Trial 2	Total
BLUE			
YELLOW			
GREEN			
RED			
ORANGE			
Total prey captured			

Lab Analysis:

1. What color prey was captured the least often? How would you explain this?
2. What are some adaptations of the prey?
3. What are some of the adaptations of the predator?
4. Why was there less prey in round 2 than in round 1?
5. Did any of the packs die out? Why?
6. Predict the outcome of the sitting stick population if we continued our hunt for another round or two.
7. Imagine how you would improve the adaptations, features, or traits of the sitting sticks to increase their survival rates in this environment?

Appendix G

Galapagos Island Virtual Field Trip Handout

1. One species of finch came to the Galapagos Islands many years ago. Today there are 13 species of finches. Explain how the change from species to 13 species might have happened.

2. On one island the marine iguanas are large and on a second island they are small. Discuss how the small size is an adaptation that help the population survive on the second island.

3. Discuss how the land iguana may have evolved into the marine iguana. Think about factors such as variation, selective pressure, and isolation as you prepare your answer.

4. Masked boobies have behaviors that appear to be bad for survival of the population. Identify two of these behaviors and discuss how they are in fact adaptations that improve the chances that population will survive.

5. What can happen to an island ecosystem when a new kind of plant or animal is introduced? What effects did the arrival of humans have on the Galapagos Island ecosystem?

Appendix H

Practical Work-Activity #4- *Peppered Moth Web Quest*

Directions: Read the background information and answer the questions as you go.

Life Cycle of the Peppered Moth

1. Why are these moths called "peppered moths?"

2. What animals eat the peppered moth?

3. What is a lichen?

4. What do the larvae of the moth eat?

5. How do peppered moths spend the winter?

6. Moths that have more dark spots than the average moth are called what?

Impact of Pollution

7. Where was the first black form of the moth found?

8. What was the Industrial Revolution?

9. What was causing the different colors in the moths?

10. What is natural selection?

11. Who suggested that peppered moths were an example of natural selection?

12. What is industrial melanism?

Kettlewell's Experiments

13. What is an entomologist?

14. How do scientists test theories?

15. Write down ONE of Kettlewell's predictions.

16. Dark moths were found in what parts of the country?

17. How did Kettlewell directly study the moths?

18. Why did dark moths have a survival advantage?

19. When Kettlewell recaptured the marked moths, what did he find?

20. Where did Kettlewell publish his findings?

Birdseye View

21. Open the simulation and play the role of the bird in both the dark and the light forest. Try to behave as a bird would behave, choosing the moths that are the most obvious. At the end of each simulation, record the percent of moths captured in the table below.

	Percent Dark Moths	**Percent Light Moths**
Light Forest		
Dark Forest		

Final Analysis

22. Explain how the color of the moths increases or decreases their chances of survival.

23. Explain the concept of "natural selection" using your moths as an example.

24. What would happen if there were no predators in the forest? Would the colors of the moths change over time? Defend your answer?

Appendix I

Practical Work Activity #5- *Human Interference Simulation*

Analyze the Results

1. Did any team's pack die in either of the games? How?
2. Considering what you learned in the game, could wolves overpopulate without human interference? Explain.
3. How could the disappearance of wolves from their ecosystem affect the populations of other species?
    - Overproduction
    - Inherited variation
    - Struggle to survive
    - Successful reproduction
4. Do you feel this game accurately modeled the changing population of a wolf pack? Explain your answer.
5. What could be done to improve the potential survival of your pack?

Appendix J

Practical Work Activity #7- *Biodiversity Web Quest*

American Museum of Natural History

"Everything Counts"

Directions:

- Go to the web page titled "Biodiversity Everything Counts"
- http://www.amnh.org/explore/ology
- Scroll down and click on biodiversity
- Follow the instructions below

Find section: *What Is the Big Idea?* **(Don't forget to use the "next" button in this section)**

1. What is biodiversity and how many types are there?
2. Why is biodiversity so important anyway? List seven reasons why biodiversity is so important.
3. What can you do to help preserve biodiversity?

Go back to main biodiversity page, find section: *Saving Species, Click on Bahamas, then Madagascar, and finally Australia.*

4. Scientist are not finding a diverse population of organism on the coral reefs in the Bahamas, why?
5. What is so unique about Madagascar's ecosystem?
6. What is happening to the forest of Madagascar and what is the outcome?
7. Why is saving the biodiversity on Madagascar so important?
8. Why does Australia have such an unusual variety of spiders?

Go back to the biodiversity main page and find section: *Going Gone.*

9. What are five reasons species are becoming extinct? Explain how
10. What does it mean for a species to be extinct? Give an example
11. How do invasive species travel or spread to a different ecosystem? Give an example.

Appendix K

Adapting to the Environment Brain Buster Question

Geologist have evidence that the continents were once a single giant continent. This giant landform eventually split apart and the individual continents moved to their current positions. What role might this drifting of continents have played in the formation of new species?

Make sure to include the following in your response:

- The steps of speciation
  - Title of step being discussed
  - Description of how the step relates to the question
- The process of natural selection
  - Title of step being discussed
  - Description of how the step relates to the question
- Ways populations are limited

Appendix L

Pre-Assessment Survey Questions and Responses

Question	Responses
1. What are the first three words that come to mind when you think of the term natural selection?	Lauren- Adaptations, animals, environment James- Death, strong, rabbit Bailey- Number of animals
2. The measure of success in nature is A. Age reached B. Enemies killed C. Mating opportunities D. Surviving offspring E. Food gathered F. I don't know	Lauren- B, C, D, E James-A, C, D, E Bailey- D
3. Natural selection applies to A. Individuals B. Populations C. Everything but humans D. All Organisms E. Nothing F. I don't know	Lauren- A, B, D James- A, B, D Bailey- B, D
4. Which of the following is REQUIRED for the process of natural selection to occur? A. Members of the same species must compete with one another. B. Members of different species must compete with one another. C. There must be a sudden environmental change. D. Traits must be inherited from one generation to the next.	Lauren- D James - D Bailey – C
5. Concerning biodiversity, changes result from A. Organisms learn to modify their bodies B. Random mutation C. Genetic material is passed on D. Loss of body parts E. Supernatural intervention F. I don't know	Lauren- C James - C Bailey – C

6. Which of the following statements is TRUE about the evolution of plants and animals? A. All plants and all animals share a common ancestor with each other. B. All plants share a common ancestor, but all animals do not share a common ancestor. C. All animals share a common ancestor, but all plants do not share a common ancestor. D. No plants share a common ancestor with each other, no animals share a common ancestor with each other, and no plants share a common ancestor with any animals.	Lauren- A James - C Bailey – C
7. Which of the following is TRUE about the species that are living on earth today? A. All species living today have existed since the time life began. B. Most species living today have existed since the time life began, but a few have appeared more recently. C. Most species living today did not exist at the time life began. D. There is no way of finding out whether all, most, or only a few species living today existed since the time life began.	Lauren-B James- C Bailey- D
8. Individual members of a species could have differences in inherited characteristics that affect which of the following? A. Both their ability to find food and their ability to avoid predators B. Their ability to find food but not their ability to avoid predators C. Their ability to avoid predators but not their ability to find food D. Neither their ability to find food nor their ability to avoid predators	Lauren-A James- A Bailey-D

9. Which of the following is TRUE about individuals of the same species? A. Individuals of the same species may have different inherited traits. These different inherited traits may cause differences in each individual’s chances of survival and reproduction. B. Individuals of the same species have the same inherited traits, therefore each individual has an equal chance of surviving and reproducing as any other individual of the same age and gender. C. Individuals of the same species have the same inherited traits but different acquired traits, such as what they have learned and skills they have developed. Only these different acquired traits can cause differences in each individual’s chances of survival and reproduction. D. Individuals of the same species may have different inherited traits, but these different traits do not cause differences in each individual’s chances of survival and reproduction.	Lauren-C James- A Bailey-C
10. According to the theory of natural selection, what would happen to a species of lizards when a new predator is introduced into the environment where the lizards live? A. The lizards that already have the physical traits needed to avoid the new predator would be more likely to survive and reproduce, and the ones that do not would be less likely to survive and reproduce. B. All of the lizards would try to develop new physical traits to avoid the new predator. C. Some of the lizards would try to develop new physical traits to avoid the new predator, and the other lizards would die. D. Because all lizards of the same species have the same physical traits, one lizard would not have an advantage over another lizard. They would either all survive or all die.	Lauren-A James- A Bailey-D

11. Is the population of humans evolving? Please explain	Lauren-Yes! Every day and every few seconds, new humans are born. Humans can reproduce and create multiple offspring. James- Yes, we are getting better. Bailey- No, when people are born another person dies.
12. A. Explain your view of the difference between a scientific law and a scientific theory. How are they similar and how are they different? B. Do you think the Theory of Evolution will ever become the Law of Evolution? Explain your answer.	Lauren- A law is different from a theory. Someone may think something, and that can become a theory. If it is established and is correct, it could possibly become a law. I don't know much about theory, but if the details are correct, then possibly. James- Theory= guess Law= Proven Maybe, I can't see the future Bailey-Scientific laws are proven to be correct; theories aren't necessarily true or proven correct. I don't think the theory of evolution will ever become the law of evolution because if you look at the Big Bang Theory, it has been a theory for quite some time and still has not been proven correct.

Appendix M

IRB Approval

IRB

INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Tuesday, March 07, 2017

Investigator(s): Jessica J. Brown (Student PI), Angela Barlow (FA) & Kim Sadler (FA)
Investigator(s') Email(s): jjb4m@mtmail.mtsu.edu; angela.barlow@mtsu..edu; kim.sadler@mtsu.edu
Department: Mathematics and Science Education

Study Title: THE INFLUENCE of ENGAGEMENT IN PRACTICAL WORK ON MIDDLE SCHOOLSTUDENTS' ALTERNATIVE CONCEPTIONS REGARDING BIODIVERSITY
Protocol ID: **17-2157**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(7) Research on individual or group characteristics or behavior* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	APPROVED for one year from the date of this notification	
Date of expiration	3/31/2018	
Participant Size	35 (THIRTY-FIVE)	
Participant Pool	Eighth grade students from Williamson Country schools.	
Exceptions	Video recordings of the class lessons and audio recordings of interviews are permitted.	
Restrictions	**Students and parents are clearly informed and students can stop participation at any time.**	
Comments	NONE	
Amendments	**Date**	**Post-approval Amendments**
	N/A	NONE

This protocol can be continued for up to THREE years (3/31/2020) by obtaining a continuation approval prior to 3/31/2018. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Continuing Review Schedule:

Reporting Period	Requisition Deadline	IRB Comments
First year report	2/28/2018	INCOMPLETE
Second year report	2/28/2019	INCOMPLETE
Final report	2/28/2019	INCOMPLETE

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

Click here for a detailed list of the post-approval responsibilities.
More information on expedited procedures can be found here.