POINT LOMA NAZARENE UNIVERSITY

Effects of Discourse on High School Students' Conceptual Understanding of Natural Selection

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by

Douglas M. Dolter

Committee in charge:

Dr. April Maskiewicz, Chair
Dr. Dianne Anderson
Dr. Walter Cho

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The thesis of Douglas M. Dolter is approved, and it is acceptable in quality and form for publication:

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Chair

Point Loma Nazarene University

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I dedicate this thesis to my wife and children, who have sacrificed far too much so that their husband and father can pursue a graduate level education. This thesis, and the research contained within, could not have been accomplished without their support, love and unwavering belief that I am a better man than I believe myself to be.

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Abstract

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by

Douglas M. Dolter

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Dr. April Maskiewicz, Chair

Evolution, and more specifically, natural selection, is the foundation of many biological topics. Thus, a scientific understanding of this concept is crucial for a comprehensive understanding of biology. However, studies have revealed that high school students have a limited understating of natural selection and often apply non-scientific reasoning when thinking about the way populations change over time. Therefore, there is a need for interventions that reveal students' reasoning and promote the construction of accurate scientific understanding.

This study examines the effects of an argumentative discourse intervention on high school students' conceptual understanding of natural selection. The participants included two sophomore biology classes (n=67) from an urban high school in Southern California. The control class was provided traditional lecture-based instruction while the experimental class participated in argumentative

discourse regarding three different phenomena of natural selection. Both the control and experimental class were administered a pre and post-test, and three students from each class were interviewed before and after the treatment to examine any change in conceptual understanding. This intervention was designed to allow students to confront any potential issues with their non-scientific reasoning while providing the opportunity to construct a scientific understanding of natural selection. While neither the control nor experimental class produced significant gains between pre- and post-tests, student interviews revealed a greater shift in scientific understanding of natural selection for the experimental group when compared to the control group, especially where it concerns an understanding of survival of the fittest.

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Point Loma Nazarene University

Introduction

Evolutionary theory is a unifying concept in biology that serves as a foundation on which all other biological concepts are built. Its ability to make connections between organizational levels in biology allows evolution to permeate into many biological topics. This is most evident in Dobzhansky's (1973) statement that "Nothing in biology makes sense except in light of evolution" (p.125). Therefore, research into students' conceptions of evolutionary theory has the potential for significantly impacting students' overall learning of biology.

High school instruction on evolution focuses predominantly on the process of natural selection (Catley, 2006), yet studies have revealed that students continue to struggle to construct a scientific understanding of this concept and its application to evolutionary theory (Anderson, Fisher & Norman, 2002; Hokayem & BouJaoude, 2008; Nehm & Schonfeld, 2008). Informal interviews conducted with my own students revealed myriad alternate conceptions regarding the process of natural selection providing a personal window through which to view this phenomenon. Throughout the interviews, students would frequently fail to provide scientific mechanisms, such as random mutations and

natural selection, to explain observed phenotypic change in a population. In their place, most student responses were flavored with ideas rooted in teleological or Lamarckian explanations. As research has demonstrated, these difficulties linger and re-emerge in college level biology courses, continuing the propagation of naive evolutionary conceptions (Anderson et. al, 2002; Dagher & BouJaode, 2005; Hokayem & BouJaode, 2008; Nehm & Schonfeld, 2008; Novick, Schreiber, & Catley, 2014). Thus, implementation of instructional practices that focus on providing students opportunities to construct a scientific understanding of natural selection in authentic learning situations is paramount for students' success in biology, and thus there is a need for further research in this area. The purpose of this research is to explore the use of discourse as an authentic learning practice to provide this opportunity, and to promote a more scientific understanding of evolution by high school students.

Literature Review

Theoretical Perspective

The external world of a learner is filled with knowledge-rich environments containing myriad experiences shaping the process of learning. According to Piaget (1964), when a learner is presented with experiences that cause disequilibrium, cognitive structures of the learner must be modified, and the construction of knowledge ensues. However, this process cannot be accomplished without the influence of the environment in which learning is taking place. As such, external factors such as the use of language and other semiotic tools should be acknowledged with regards to concept construction (Brown, Collins & Duguid, 1989). Rogoff (1994, p.209), in her examination of socio-cultural impacts on learning, states: "Learning is a process of transforming participation

in shared sociocultural endeavors." In other words, the construction of knowledge is fostered through the practice and participation in social experiences (Brown et al., 1989), and therefore it becomes vital to provide opportunities for students to engage in authentic social learning practices of the discipline being studied. Thus, it is a social-constructivist perspective that guides this research.

Students' Understanding of Natural Selection

Studies showing that students struggle to use scientific concepts to explain evolutionary phenomena, specifically in relation to natural selection, are prevalent in the world of educational research. In a study conducted by Nieswandt and Bellomo (2009), students struggled to connect descriptive concepts (those that can be observed and described), theoretical concepts (based on an understanding of theories) and hypothetical concepts (could be observed if time was not a constraint) to explain how phenotypic change may have occurred in several example populations. The failure to bridge these concepts not only reveals a novice understanding of natural selection, but may also impact students' acceptance of evolutionary theory (Dagher & Boujaoude, 2005; Hokayem & BouJaoude, 2008).

It seems then, in order to view natural selection through a scientific lens, students need to meld their compartmentalized understanding of the different aspects of this topic. This may be especially arduous when attempting to examine the evidence in support of natural selection, as the Theory of Evolution does not rely exclusively on direct evidential arguments for conceptual understanding, such as those employed in physical-based sciences. Instead, evolution, and similarly natural selection as a mechanism of evolution, relies on an accumulation of circumstantial, direct, and historical data that merge to

provide a comprehensive conceptual framework of this process (Dagher & BouJaode, 2004). As a study conducted by Dagher and BouJaode (2004) reveals, students' failure to merge these distinct forms of evidence can promote erroneous conclusions regarding the scientific nature of natural selection. For example, the majority of students interviewed in Dagher and BouJaode's (2004) study described natural selection as lacking "hard facts", as evidenced by one student's comments that natural selection is very hard to "prove" because it requires "thousands or even hundreds of million years to take place". Additionally, students expressed difficulty perceiving natural selection as "scientific" due to the inability to carry out predictable experimentation. Thus, the very nature of natural selection is misunderstood and provides the potential for the development of alternate conceptions about this topic.

The nature of students' alternative conceptions regarding natural selection have been meticulously examined by educational researchers, including Jensen and Finley (1996), who sorted phrases associated with common alternate conceptions into four categories consisting of Teleology, Lamarck, Natural Theology and "Other Alternate Conceptions" (Table 1). This scheme provides an alarming glimpse of the challenge many high school biology teachers face when teaching this topic. If allowed to develop unchallenged by teachers, these alternative conceptions may continue to accumulate, producing a weak cognitive foundation that promotes a non-scientific understanding of natural selection and diminishes the conceptual framework of evolution in the minds of students (Hokayem & BouJaoude, 2008).

Table 1

Four Alternative Conception Categories and Corresponding Key Ideas (Jensen & Finley, 1996)

Category	*Commonly Used Phrases*
Teleology	In order to; it had to evolve in order to; need; it needs it; have always needed; they had to (no Darwinian rationalization to justify the teleological remark; however, sometimes a teleological and a Darwinian idea can be found in the same answer); in order to survive; they needed; for the purpose of; have to have; so that they (same as "in order to"); as one gets faster, the others will get faster, to balance nature; they changed because it was the only other alternative rather than dying.
Lamarck	Use and disuse of organs; and/or; passing this trait to the next generation; they passed it (e.g., immunity) on to their offspring; passed the genes that were modified; a bit more each generation.
Natural Theology	Must mention supreme being (e.g., "God created," or "I believe in God').
Other Alternate Conceptions	Everything learns to adapt in a given situation; learning (very common in students' responses-"they learned how to," "speed was taught"-a training or learning component in the student's response); I chose because every organism is going to have to be able to "go with the flow" of life and environment; just like if we had to learn how to live life in hiding or underground; the environment initiated a change; their offspring will improve and adapt to the environment; different species breeding with each other; difficulties with genetic concepts; genes going from recessive to dominant; the original genes were more dominant (e.g., so they became blind again); becoming more dominant over time; because they were always that way; if it were due to chance, it could not have happened; move to the environment that fits your phenotype or genotype; as time goes by, humans and animals improve themselves.

Once established during high school, a cognitively stable, but scientifically feeble evolutionary foundation can persist through college (Anderson et al., 2002; Dagher & BouJaoude, 2005; Hokayem & BouJaoude, 2008; Nehm & Schonfeld, 2008). As students complete their educational journey and enter the mainstream populace, these alternative conceptions are carried forth and perpetuated in the culture, leading to proliferation of unscientific understanding and possible rejection of evolutionary theory (Hokayem & BouJaoude, 2008). This cyclic dissemination of flawed evolutionary theory may continue to diminish the potential explanatory power of not only this specific topic, but a comprehensive understanding of biology as well. It becomes essential therefore, to address alternative conceptions that may serve as building blocks to a weak evolutionary

foundation in a way that allows students to construct the bridges necessary to develop a comprehensive, and scientific, understanding of natural selection.

Competing Elements of a Scientific Understanding of Natural Selection

The implementation of practices that allow students to engage in authentic social learning that leads to a scientific understanding of natural selection can be complex and time consuming in the classroom. Therefore, it is distressing when studies reveal that the time spent teaching evolutionary theory is, in some cases, limited to as little as five instructional days (Shankar & Skoog, 1993). If this timeframe is perpetuated throughout American schools, it is not unreasonable to assume that this constraint may negatively impact students' ability to link biological concepts to evolution and construct a meaningful scientific understanding of evolutionary theory. In addition, many high school teachers teach the topic towards the end of the year, in isolation from the other topics, rather than as a unifying theory that ties the entire class together.

The impact of a limited time frame is exacerbated when one considers other possible elements at play during instruction of an evolutionary unit. For example, noncladogenic evolutionary diagrams found in many high school biology textbooks fail to convey a scientific understanding of natural selection (Cately et al., 2010). This is evident in a study by Cately et al. (2010), which found that college students' explanations of these diagrams included anagenic (describing a change from ancestor to descendent without the branching of a new taxon) and teleological conceptions of evolutionary change. Furthermore, these students failed to connect ideas of ancestors, descendants and common ancestry when describing evolutionary relationships, instead using terms such as "evolved into" and "became", demonstrating the need for interventions that build an

understanding of these relationships. Thus, it seems that even the very educational tools that are used within the classroom during instructional time may fail to promote the development of and bridging of scientific concepts to understand the various mechanisms by which natural selection occurs.

In considering the roles of classroom elements that hinder students' scientific understanding of natural selection, one must also consider the content presented during an instructional unit. For example, ecology is typically presented in isolation from evolutionary concepts, and as such, students fail to see the interactions of organisms with their environment as necessary conditions for natural selection (Catley et al., 2006). This content "silo-ing" of natural selection is prevalent even at the collegiate level, as demonstrated by college students' failure to connect concepts of macroevolution and microevolution to fully explain evolutionary change within a population (Novick et al., 2014). Thus, there is clearly a need for the implementation of a framework that allows for application of these dissociable constructs as we continue to expect students to demonstrate a comprehensive understanding of natural selection.

The effects of content silo-ing are even more dramatic as opportunities for peer collaboration diminish in the science classroom as a result of the aforementioned limited instructional time frame. This constraint restricts opportunities for students to exchange ideas and socially build connections between other biological topics and concepts of natural selection. Providing students the opportunity to engage in dialogic inquiry concerning evolutionary events may allow for these connections to be established and promote a more holistic view of evolution and natural selection, one that "captures the full grandeur of Darwin's theory" (Cately et al., 2006).

Instructional pedagogy can be equally significant in the formation of a scientific understanding of natural selection. Dissemination of evolutionary concepts from teacher to students is traditionally monologic in nature, with the teacher prescribing a set of incontrovertibly factual statements regarding the nature of change within a population (Ford & Wargo, 2012). As a result, students view evolution as a set of foregone conclusions instead of a comprehensive vision of the ongoing progression of a phenomenon in which theory building can be socially constructed. This idea is reinforced with the application of pre-designed labs, fated with outcomes that fall within a restricted spectrum of acceptable results (Sandoval, 2002). Thus, students are required to verify a given hypothesis instead of engaging in social construction of their own explanations (hypotheses) of evolutionary phenomenon that is then followed by the testing of these student-generated hypotheses. This restriction of student inquiry and discovery may affect students' epistemological views of evolutionary theory, and consequently natural selection (Sandoval, 2002), and contribute to a vacuous understanding of the very nature of science (Dagher & Boujaoude, 2005).

The Use of Classroom Discourse to Promote Learning of Scientific Concepts

The role of student discourse in the construction of scientific ideas is well documented. Research, such as Mercera, Dawes, Wegerif and Sams, (2004) speaks to the effectiveness of student-student interactions during scientific investigation to promote students' understanding of scientific concepts. Student investigation conducted under this social umbrella allows for a more symmetrical flow of ideas between teachers and students, and among classmates, and provides different opportunities to describe observed events and develop reasoned arguments concerning these events (Mercera et al.,

2004). This idea is further supported by Chin and Osborne (2010) when they state that "as students reason about the advantages and disadvantages, pros and cons, as well as causes and consequences of alternative perspectives, they are exposed to a greater variety of ideas—an activity which can stimulate more extended cognitive engagement" (p.5). Hence the dynamic social nature of this cognitive web provides the context in which a more scientific understanding of natural selection may develop.

As a result of students' failure to apply scientific principles to natural selection, numerous studies have presented suggestions for possible intervention strategies. In his research titled, "Thinking about theories or thinking with theories: A classroom study with natural selection", Jimenez (1992) allowed secondary students to compare the Darwinian model of natural selection to their own, less scientific Lamarckian ideas. The opportunity for discourse provided by this strategy proved to be more efficacious than content presentation alone as it allowed for a multi-directional construction of knowledge rather than a more traditional, lecture-based monologue, where the flow of knowledge is solely from teacher to student (Ford & Wargo, 2012).

While the value of group collaboration is evident, there is a need for students to participate in social engagements that accurately reflect the practices of scientists. Argumentative discourse provides the context for these practices, as students explain ideas to one another while also having the opportunity to support or rebut each other's claims. The construction of scientific explanations that result from this practice is an essential part of scientific inquiry (Berland & Reiser, 2009), and has been found to foster conceptual change in students with alternative conceptions concerning natural selection, as evidenced in research conducted by Asterhan and Schwartz (2009). During their

study, paired undergraduate student dyads were split into two groups, and asked to engage in either dialogic argumentation (experimental group), or peer collaboration (control group), to construct explanations for different evolutionary phenomena, such as the evolution of webbed feet in ducks. Groups that participated in dialogic argumentation, where students questioned each other's ideas as shown in Table 2, demonstrated greater conceptual changes than groups engaged in one-sided arguments or collaboration, where questioning is replaced with compliance or agreement, as shown in Table 3, in order to construct their explanations.

Table 2
Protocol excerpt from a dialectic dialogue (Asterhan & Schwartz, 200

Speaker	Contribution
A	*I do not understand how he understood that—suddenly he says that they developed webbed feet*
B	*So how do you think it happened, that it happened overnight?*
A	*That one by chance had something similar to webs. He survived, and…the webs just developed [evolved], become more sophisticated.*
B	*And what if—*
A	*—Not something out of nothing!*
B	*And what if no one had it?*
A	*Then they would not have survived.*
	How could they have survived?
B	*Maybe they just developed it somehow?*
A	*The question is, development of the type "something out of nothing"…. or something that was already there.*

Table 3
Protocol excerpt from a one sided dialogue (Asterhan & Schwartz, 2009)

Speaker	Contribution
M	*-they don't swim all day long, they just practice.*
N	*No, but they practice, yeah, right.*
M	*It is not really their natural environment.*
N	*Right.* *And it's the natural environment and they need to continue to adapt to living, not a human that was supposed to adapt to…* *Like when I immigrated to Israel and I needed to adapt to the heat. So the first years were hard and I had a headache and so on, but after that I did not notice the…heat anymore.*
M	*Right*
N	*On the opposite, I am cold….outside. I don't remember what is winter*
M	*And also the thing that, like here, with the Olympic swimmer. An Olympic swimmer, when he comes out of the water he dries his feet, the water is gone. The duck is wet all the time.*

Thus, an intervention that follows a framework of dialogic discourse may be effective in nurturing a more scientific understanding of evolutionary theory, helping reduce alternative conceptions of natural selection that plague many classrooms.

The last twenty years have witnessed a plethora of research devoted to the use of argumentative discourse in the science classroom. It is not surprising then, that within the scope of this research, questions of instructional methodology have been investigated, and from these investigations two broad philosophies have developed. Frameworks for argumentative discourse rooted in formal structure, such as Toulmin's Argument Pattern (TAP), have been embraced by researchers such as Erduron, Simon and Osborne (2006), who provide evidence of a correlation between students' abilities to develop a formal argument and their conceptual comprehension of scientific ideas. In this model, students are asked to form structured arguments that are assessed on the basis of their formal components including claims, data that supports the claims, warrants that provide a link between data and the claims, backings that strengthen the warrants by answering questions related to warrants, and rebuttals. While this type of research holds potential for improving student comprehension of scientific concepts, its guiding formal structure may limit the use of dialectical structures/patterns that students use naturally during peer-to-peer conversation (Duschl, Ellenbogen, & Erduran, 1999). Therefore, a less restricting, dialogic approach that guides the development of argumentation, as seen in small group investigations (Jiménez-Aleixandre, 1992), allows students to build the analytical structures/patterns that scientists employ by using more informal patterns of discourse that students intrinsically possess.

In a study conducted by Ford and Wargo (2012), high school students participated in two separate activities that supported scientific thinking about natural selection by offering a scaffolding framework to encourage classroom discourse. The first task required students to compare three different evolutionary schemes (Paley, Lamarck and Darwin) to explain examples of natural phenomena, while the second task required students to select particular statements about natural phenomena that corresponded to these different theories. In each of these activities, students not only constructed a basic understanding of these theories, but also applied each to dissimilar examples of natural phenomena, thereby making a connection between conceptual and epistemic aspects of natural selection. Although Ford and Wargo attest to the role of discourse to promote scientific understanding of natural selection, they express the need for further research to support this hypothesis. Thereby, this thesis study endeavors to maintain the aforementioned premise posed by Ford and Wargo, and to determine if utilizing a dialectic strategy of student-to-student discourse contributes to an increased scientific understanding of natural selection.

Methods

Research Goals

Although many instructional strategies that teachers implement into their curriculum may provide opportunities for student-to-student interactions, few focus on the use of argumentative discourse as a tool for the construction of scientific knowledge. As the literature demonstrates, this tool, if wielded effectively, can be a powerful ally in a science classroom, especially when tackling a leviathan of biology content such as the

Theory of Evolution. Therefore, the research question that guided this study is the following:

> *Does limited participation of students in student-to-student argumentative discourse promote a greater scientific understanding of natural selection among high school biology students when compared to a more traditional lectured-based instructional model?*

Research Design

This research was conducted using a quasi-experimental mixed methods design in order to determine the effectiveness of an intervention based on student discourse. Quantitative data, in the form of pre and post-test scores, as well as qualitative pre and post-interview data, were analyzed (Figure 1) and deemed equally essential in forming conclusions regarding any cognitive effect that an argumentative discourse intervention, had on students' scientific understanding of natural selection.

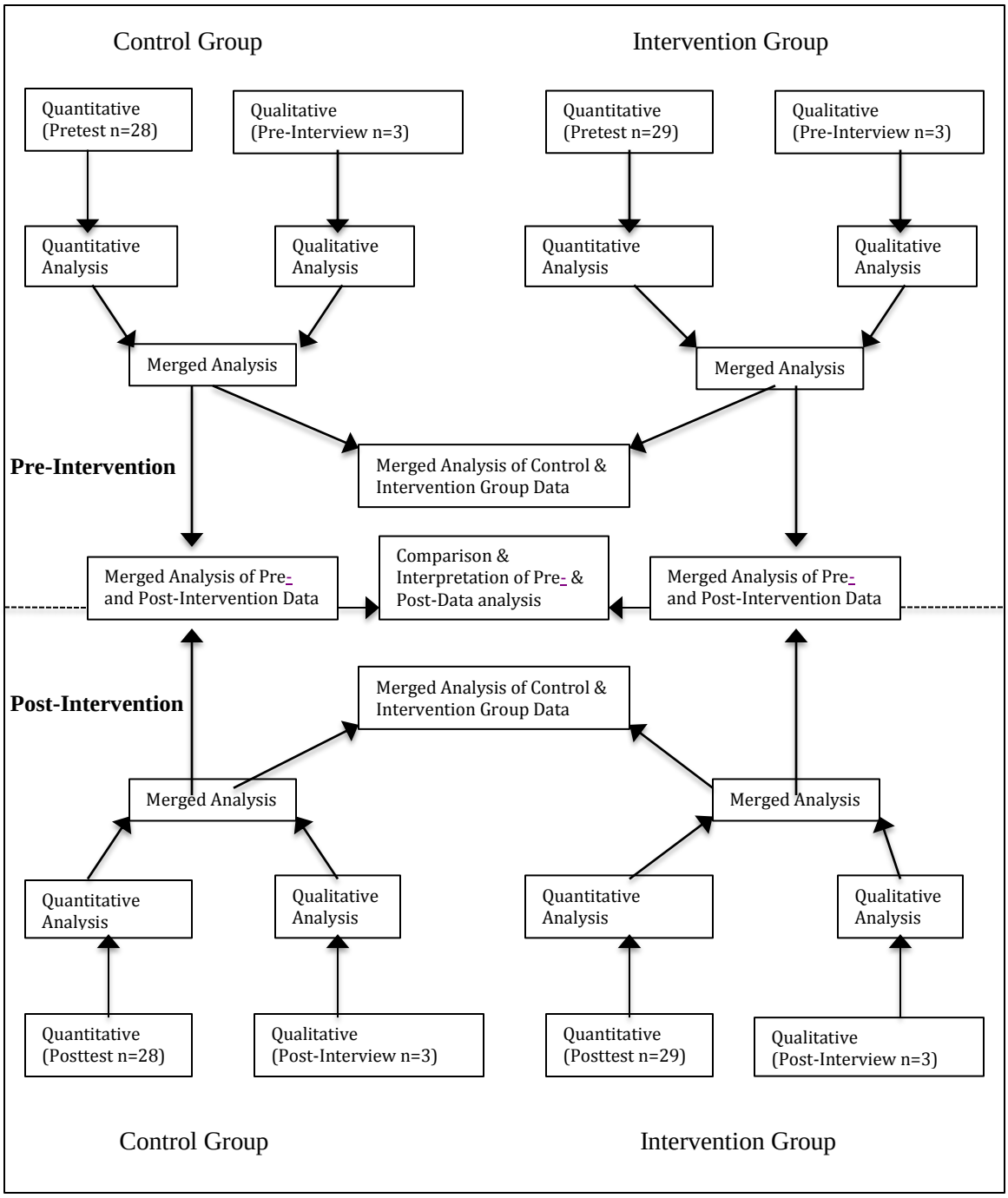

Figure 1: *Convergent Mixed Methods Research Design (Showing the Merging of Pre- and Post-Intervention Data).*

Study Site and Participants

This research took place at a comprehensive public high school in Southern California with a population of approximately 1300 students. The school is situated in the northwest corner of a small city of approximately 48,000 residents, in an urban area of Los Angeles County. The student population is composed of roughly 93% Hispanic, 3% Caucasian, 3% Asian and 1% African American students. Incoming freshman are placed into either Earth Science or Biology, with the latter dependent on performance in their middle school science courses and science teacher recommendations. The remaining biology students are sophomores who were enrolled in Earth Science their freshman year.

The participants for this research included second semester biology students from two separate biology classes under the responsibilities of a teacher with 32 years of teaching experience. Each class was an eclectic mix of grade level and academic performance. The teacher (Mr. H) has recently completed staff development, termed Cavi Training (name of author, not an acronym), where the focus was the integration of language development (speaking, writing, reading) in the science classroom. Thus, Mr. H understood the critical role that verbal language plays in the construction of scientific knowledge, and fully supported the implementation of an intervention based on argumentative discourse. While Mr. H is the normal instructor for these classes, I provided the instruction for both the control and experimental classes during the duration of this research in order to maintain the true focus of this study.

For this study, the control class was composed of 28 students with a comparable 29 students in the experimental class, from which pre and post-test scores were submitted. Participants for student interviews were chosen following Point Loma Nazarene

University Institutional Review Board (IRB) guidelines. Participants volunteered for the opportunity, with teacher recommendation based on grade level performance and participation in classroom discussion, playing a role in final participant selection. These students were compensated for their time with $10 Starbucks gift card after the second interview was completed.

It should be noted that neither the Control Class or Experimental Class received any previous instruction regarding natural selection nor the theory of evolution before this research took place.

Instructional Design - Control Group

The Conceptual Inventory of Natural Selection (CINS) (Anderson, 2002) was used as the pre- and post-test (see below for more information). Students in the control class participated in the following events: (a) pretest (CINS #1-10) to establish a quantitative value for students' prior understanding of natural selection; (b) viewing of an instructional movie excerpt; (c) follow-up lecture and discussion of natural selection; (d) immediate posttest (CINS #11-20) to assess any changes in an understanding of natural selection; (Table 4). In addition to the above sequence, three students were interviewed before and after instruction in order to provide the qualitative data that was combined with the quantitative data in order to develop a comprehensive conclusion regarding any change in students' understanding of natural selection.

Table 4
Timeframe for Control Group Instruction Design

Event	*Time Frame*
Pre-test	Given 1 week before intervention
Instructional Movie	Day 1 (≈16 minutes)
Lecture & Discussion	Day 1/Day 2 (≈85 minutes)
Posttest	Day 3

Instructional Design – Intervention Group

Students in the intervention class participated in the following events: (a) pretest (CINS #1-10) to establish a quantitative value for students' prior understanding of natural selection; (b) viewing of an instructional movie excerpt (same as the control class); (c) intervention in which student quartets, determined by students' performance on the CINS, engage in argumentative discourse to solve 3 problem sets (Appendix A) involving evolutionary change; (d) immediate posttest (CINS #11-20) to assess any changes in an understanding of natural selection; (Table 5). In addition to the above sequence, three students were interviewed before and after instruction in order to provide the qualitative data that was combined with the quantitative data in order to develop a comprehensive conclusion regarding any change in students' understanding of natural selection. During the peer argumentation session, each group member was assigned one of four possible answers to the presented natural selection problems. Three of these answers were based on common alternative conceptions of students (Table 1), while the remaining answer contained the correct scientific concept of natural selection. Each group member was required to argue for their answer in an attempt to convince the group that their answer was the most "scientific". Each argumentative discourse session lasted approximately 20 minutes. At the end of these sessions, groups were required to come to a consensus as to which of the four possible answers was the most scientific, and submitted their choice to the class for further discussion, with the correct scientific explanation revealed within this process (either as a result of whole class discussion, or revealed by the teacher if necessary). The quartet group arrangement was used to foster student-student argumentative discourse, as it may have allowed for a more dynamic

dialogue, as compared to dyads, where dialogue may have been stalled if a student felt inhibited to talk. Additionally, I attempted to include at least one high performing and one low performing student in each group (as evidenced by their pre-test score on the CINS) in hopes to facilitate discourse due to a difference in an understanding of natural selection.

Table 5
Timeframe for Intervention Group Instructional Design

Event	*Time Frame*
Pre-test	Given 1 week before intervention
Instructional Movie	Day 1 (≈16 minutes)
Argumentative Discourse (Problem Set 1)	Day 1 (≈20 minutes)
Class Discussion	Day 1 (≈14 minutes)
Argumentative Discourse (Problem Set 2)	Day 2 (≈15 minutes)
Class Discussion	Day 2 (≈10 minutes)
Argumentative Discourse (Problem Set 3)	Day 2 (≈15 minutes)
Class Discussion	Day 2 (≈10 minutes)
Post-Test	Day 3

Instructional Video

The instructional video was an excerpt from the HHMI Biointeractive Video collection, Galapagos Finch Evolution. The video details the observable change in finch beak sizes over the past 40 years in the Galapagos Islands, and it provided an authentic example of the forces at play during natural selection, without explicitly stating them in a more traditional lecture format. Thus, it delivered an excellent model of natural selection that students may have used to construct their own understanding of this evolutionary topic.

Description of Data Collection & Analysis

Quantitative data was collected from student performance on a pre and post-test assessment focused on key concepts of natural selection. As shown in Appendix B, an

altered version of the Conceptual Inventory of Natural Selection (CINS) (Anderson, 2002), modified for use with high school students (Evans & Anderson, 2013), was used to provide the scores for statistical analysis. While the pre and post-test did not negatively impact students' grades, the scores from both tests were counted as extra credit as an incentive to motivate students. Significant differences between the pre and post-test scores of both classes were determined via a two-sample t-test ($p<0.05$). In order to evaluate differences in student knowledge after the intervention and non-intervention periods normalized gains for each student were calculated, and an average score from these values was determined for each class. Furthermore, Cohen's d was calculated in order to evaluate the effect size of any difference in the scores between these two classes.

Additional qualitative data was collected during the course of this study via pre and post intervention interviews with students; details on the interview tasks are shown in Appendix C. Three students from each class (6 total) were individually interviewed for approximately 20 minutes after school in Mr. H's classroom prior to the intervention, with follow-up post-interviews, containing the same interview tasks, occurring after the intervention. Audio from these interviews was transcribed and coded based on the categories displayed in Table 1 (previously mentioned) and Table 6. Using this scheme, student responses were dissected, and the components categorized as "non-scientific" (Table 1) or "scientific" (Table 6), with the relative percentages of occurrence determined for each.

Table 6

Six Darwinian Conception Categories and Corresponding Key Ideas (Jensen & Finley, 1996)

Category	*Commonly Used Phrases*
Variation within a population (VWP)	Variation within a population; genetic differences; mutation in the genes/DNA; mutation as a source of variation; change due to a mutation; there was a mutation; there was a change in the genes/DNA.
Inheritance (lnh)	Passing on selected genes; passed on to the next generation; something in the genes is passed on to the next generation; genes were passed on; passed it to their offspring; passing on genes; the dead one's genes were not passed on.
Survival of the fittest (SF)	Limit in resources; some survived, many died; survival of the fittest; I think they will all die; potential fertility/geometric reproductive rate; the total population size usually remains about the same; struggle for existence; fitness: the number of offspring produced; death/many died/some died/all died; some were able to survive; enabled them to survive/live/eat/re- produce; limits in natural resources (e.g., the food was limited); extinction.
Changing percentages (CP)	Adaptation (e.g., an increase in the frequency of a structure or behavior within a population as a result of natural selection); there were more of them than in the previous generation; more and more individuals with the trait/ genes; more and more were resistant to DDT; changes in the percentage of individuals within the population with specific traits or genes (sometimes students use the word "dominant" to denote this concept- this was acceptable if adequately explained).
Identifying inconsistencies (II)	That one is teleological, that's Lamarckian, etc.; mutation can't happen on demand; I know they can't do that; they can't evolve just by wishing to evolve; they can't just change because they need to; I don't think they were always changing/evolving.
Other correct ideas (OCI)	Any correct statement pertaining to evolution that does not fit into the other categories.

Results and Discussion

Performance on the CINS

Students' initial understanding of natural selection was limited, as indicated by low pre-test scores for both the control and experimental classes for questions 1-10 on the CINS (100 pts. possible). At the time of this study, the instructor had not broached the subject of evolution in anyway, and students appeared to possess a weak foundation of understanding concerning the mechanisms of change among populations. It is important therefore, that this deficiency is an essential part of the context of these results as they begin to show the potential that argumentative discourse may have on students' understanding of natural selection.

Results from a paired t-test show no significant difference in the means between the pre-test and post-test scores for the control class, nor for the experimental class pre-test and post-test, as shown in Table 7. It does reveal, however, that the experimental class outperformed the control class. The effect size of the argumentative discourse intervention was small (d=0.25) for the experimental class; nevertheless it does indicate a greater effect than the lecture-based control class (d=-0.1). In order to provide a comprehensive statistical analysis of any conceptual change evident on the CINS over a diverse student population, normalized gains were determined for the control and experimental classes, where the average difference between post and pre-tests were divided by the maximum possible increase for each class. When normalized gains values are calculated, once again, the experimental class (<g>=0.08) outperforms the control class (<g>=-0.02). While these results quantitatively support a greater performance on formal assessments for the experimental class, a more in depth examination of the change in students understanding of natural selection is required before any discussion of the effect of argumentative discourse can take place.

Table 7
Two sample t-test results with normalized gains and effect size for CINS pre and post-test for both biology classes.

	n	Mean (Pre-test)	Mean (Post-test)	Standard Deviation (SD)	t-value	Normalized gain (<g>)	Effect Size (d)	p-level
Biology (Control)	28	39.28	37.85	15.95	0.47	-0.02	-0.1	**0.31**
Biology (Experimental)	29	41.37	47.24	17.29	1.29	0.08	0.25	**0.1**

It should be noted that the lack of statistical significance for the experimental group may have been influenced by the small sample size (n=28c/29e) used for this study. For example, one student in the experimental group scored a 90% on the CINS pre-test,

followed by a score of 50% on the post-test. When asked the reason for his poor performance on the post-test, the student remarked *"I'm having a bad day, so I wasn't really into it."* If his scores are omitted from the calculations, a paired t-test indicates a significant increase in pre to post-test scores for the experimental group (Table 8).

Table 8
Two sample t-test results with normalized gains and effect size for CINS pre and post-test for both biology classes without the Experimental Class outlier.

	n	Mean (Pre-test)	Mean (Post-test)	Standard Deviation (SD)	t-value	Normalized gain (<g>)	Effect Size (d)	p-level
Biology (Control)	28	39.28	37.85	0.47	0.47	-0.02	-0.1	**0.31**
Biology (Experimental)	29	40	46.2	1.71	1.71	0.1	0.35	**0.04**

Student Interviews

Student interviews provide a deeper glimpse into the construction of an understanding of natural selection for students from both the control and experimental classes. Once again, prior to the intervention, student interviews indicate a limited understanding of natural selection for students in both classes with over half of the descriptions of mechanisms of natural selection rooted in non-scientific explanations for both the control (56%) and experimental (57%) groups. During interviews after the instructional block, both groups increased their frequency of scientific explanations as expected, however, there is a greater increase for the experimental group (+14%) when compared against the gains made by the control group (+9%), as seen in Table 9.

Table 9
Percent of scientific and non-scientific responses during pre and post student interviews for both the control and experimental groups.

	Pre-Interview		Post-Interview		
	Explanations Rooted in Non-Science	Explanations Rooted in Science	Explanations Rooted in Non-Science	Explanations Rooted in Science	Change in Scientific Explanations
Biology (Control)	56%	44%	47%	53%	+ 9%
Biology (Experimental)	57%	43%	43%	57%	+14%

Upon further dissection, these responses were placed into various categories that reflected the nature of the scientific or non-scientific response. *Other Alternate Conceptions* was the most common explanation for the control group prior to the instructional session (38%), as seen in Table 10, which usually involved statements indicating the environment directly causing a change in the organism or population. For example, when asked to explain how the current whale tail evolved from the tail of four-legged ancestors, Student B replied:

Interviewer: *Because he didn't need them any more? Can you explain to me what's going on with the tail? How did the tail change and what might be a reason for that?*

Student B: *It was smaller. It's shrinking.*

Interviewer: *It's shrinking, okay.*

Student B: *Due to that hot weather and ...*

Interviewer: *Due to the hot weather.*

Student B: *... And from starving.*

Interviewer: *And from starving. So it ate less and the tail got shorter?*

Student B: *Yeah, because it looks like too bony, too skinny.*

In this exchange, Student B clearly misapplies an understanding of environmental effects on the evolution of organisms. This pattern can be seen throughout the interviews with control group students and does not seem to change dramatically in the post interview.

The *Other Alternate Conception* (32%) category had implied undertones of change due to the environment, and is the most common type of explanation of natural selection for this group. For example, Student Y is asked to explain the mechanism for the evolution of the size of whales:

Interviewer: *Okay, how did it change size though? Just tell me, did it get bigger? Did it get smaller?*

Student Y: *It got bigger.*

Interviewer: *It got bigger. Okay. So, how did that happen over time?*

Student Y: *The change in environment caused different changes in the animals and the species over time.*

Interviewer: *Okay, like size?*

Student Y: *Yeah, and like the food they ate, probably.*

In this excerpt, although Student Y hints at environmental pressures being a catalyst for natural selection, this thought is never fully developed in this exchange. Instead, the environment seems to be the direct cause of change, as seen in the last line when Student Y states, "Yeah, and like the food they ate, probably."

Table 10
Percentages of scientific and non-scientific responses for pre and post-interviews for the Control Group.

	Non-scientific				Scientific					
	Teleology	Lamarck	Natural Theology	Other Alternative Conceptions	Variation Within a Population	Inheritance	Survival of the Fittest	Changing Percentages	Identifying Inconsistences	Other Correct Ideas
Pre	13%	5%	0%	38%	13%	13%	14%	4%	0%	0%
Post	13%	2%	0%	32%	15%	12%	17%	6%	0%	2%
Change	No Change	-3%	No Change	-6%	+2%	-1%	+3%	+2%	No Change	+2%

Similarly, the most common explanation for the experimental group prior to the instructional session was *Other Alternate Conceptions* (28%), as seen in Table 11. Unlike the control group however, the responses that fell within this category include a wide scope of explanations. For example, when asked about the evolution of antibiotic resistance in bacteria, Student D responded with an explanation that implies learning to adapt to changes in the environment:

Interviewer: *Okay. How are they getting that new protection?*

Student D: *By growing.*

Interviewer: *By growing? Growing larger? Or growing in number?*

Student D: *In number.*

Interviewer: *In number. The more they grow in number the stronger they are too. How does that work?*

Student D: *Maybe if a person gets infected by that disease maybe the bacteria grows slowly but at the same time it's multiplying a lot.*

Interviewer: *How would multiplying a lot help it to survive antibiotics?*

Student D: *For each bacteria will know what will happen. If they get attacked the bacteria will know that they should be immune against it.*

However, in another interview for the experimental group, Student K seems to reject the learning hypothesis and instead embraces the idea that the environment (antibiotics) may have directly caused a change in the bacteria:

Student K: *I think that they don't work anymore because they slowly adapted to the chemicals in the antibiotics. I'm thinking they sort of knew that antibiotics were killing them off, and they weren't able to infect cells.*

Interviewer: *The bacteria knew that the antibiotics would kill them?*

Student K: *No. I don't think they knew that, but I'm thinking like their numbers started to drop, and the antibiotics was the problem, so I'm thinking [they] sort of became immune to the chemicals in the antibiotics.*

While it could be argued that Student K is beginning to express ideas related to the concept of survival of the fittest when he states that “antibiotics was the problem”, this idea is never developed. This same observation does not hold true for the post interviews of the experimental group.

Table 11

Percentages of scientific and non-scientific responses for pre and post-interviews for the Experimental Group.

	Non-scientific				Scientific					
	Teleology	Lamarck	Natural Theology	Other Alternative Conceptions	Variation Within a Population	Inheritance	Survival of the Fittest	Changing Percentages	Identifying Inconsistences	Other Correct Ideas
Pre	7%	21%	0%	28%	17%	18%	4%	3%	0%	1%
Post	15%	12%	0%	15%	7%	10%	24%	10%	3%	4%
Change	+8%	-9%	No Change	-13%	-10%	-8%	+20%	+7%	+3%	+3%

Following instruction, there is a considerable change in the nature of natural selection explanations for the experimental group. As Table 11 indicates, most non-scientific explanations decrease in frequency, although explanations rooted in ideas of teleology rise. This may be, in part, explained due to the limited time frame in which this study was conducted, as students may not have had adequate enough time to work through teleological reasoning that may have developed during student-to-student discourse. Within the scientific categories, there is a substantial increase in the frequency of responses related to survival of the fittest (+21%), with modest increases in other scientific concepts including *Changing Percentages/Ages*, *Identifying Inconsistencies* and *Other Correct Ideas*. It should be noted that while each question within the intervention focused on various aspects of natural selection, the concept of survival of the fittest was embedded across the three. This may account for the relatively large increase in this category of response during post interviews, while the increases in other scientific responses were minimal. Responses involving *Variation Within a Population* and *Inheritance* were not as common during post interviews with this group. This post-intervention excerpt from the experimental group interviews provides a glimpse into the nature of this change in understanding. During this exchange, Student D is attempting to explain the change in appearance of the front legs/feet during whale evolution.

Interviewer: *Okay. Can you give me any more detail on how that change might have happened or what would have caused that change?*

Student D: *Maybe caused because there was a lot of water and all the land prey left. All the land left and there was only water. They had to adapt by swimming.*

Interviewer: *Okay, when you say they had to adapt, what do you mean by that?*

Student D: *Some died and some lived because they were chosen for each to live*

in that environment.

Interviewer: *What do you mean, chosen?*

Student D: *The animals that didn't have any webbed feet died because they didn't swim fast enough and their prey left.*

Interviewer: *Okay.*

Student D: *The ones that got webbed feet started to get more and reproduce and the genetics went to each of their kids.*

Although Student D's initial explanation seems to be teleological in nature, he quickly clarifies his idea to reveal an understanding of the mechanism of survival of the fittest. Not only does Student D seem to understand that organisms best suited to a change in the environment survive, but he also relates that survival to an ability to reproduce and pass on successful genes to offspring.

While an increase in frequency does not occur with every category of scientific responses during interviews for the experimental group following the intervention, a comparison to the categorical changes observed in the Control Group (Table 12) may provide a greater indicator for the effectiveness of the experimental condition.

Table 12
Changes in scientific and non-scientific responses the Control and Experimental Group.

	Non-scientific				Scientific					
	Teleology	Lamarck	Natural Theology	Other Alternative Conceptions	Variation Within a Population	Inheritance	Survival of the Fittest	Changing Percentages	Identifying Inconsistences	Other Correct Ideas
Control	No Change	-3%	No Change	-6%	+2%	-1%	+3%	+2%	No Change	+2%
Experimental	+8%	-9%	No Change	-13%	-10%	-8%	+20%	+7%	+3%	+3%

Conclusion

Numerous studies have examined the authenticity of using argumentative discourse to promote the construction of scientific ideas. While research supports the use of argumentative discourse to advance students' understanding of various scientific concepts, few address the concept of evolution, and more specifically, natural selection. Therefore, this thesis aimed to address the research question "*Does limited participation of students in student-to-student argumentative discourse promote a greater scientific understanding of natural selection among high school biology students when compared to a more traditional lectured-based instructional model?"*

Analysis of CINS quantitative data collected during this study suggest that using argumentative discourse to promote a scientific understanding of natural selection may be a valid instructional strategy. While analysis reveals that gains in test scores from the experimental class are not statistically significant, they are greater than those of the control class, which showed no improvement at all.

Although relatively small, the effect size and normalized gains for the experimental group was not surprising given the brief time period for the intervention. Numerous research articles flavored with a constructivist's learning philosophy stress the importance of allowing students time to build a personal understanding of scientific concepts. Due to logistical time constraints of the teacher and school curriculum, this study did not have the luxury of an extensive time frame. Instead, the intervention was conducted during two consecutive 50-minute class periods, which may have not provided ample time for students to fully develop a scientific understanding of natural selection. This is evident in the aforementioned examples of student post-intervention interview

excerpts, where students allude to mechanisms of natural selection, but never fully develop or articulate these ideas. It should be noted that post-test scores for the experimental class increased by 6% over this limited time frame.

A special consideration should also be acknowledged concerning the content focus of each argumentative discourse phenomenon. These phenomena only addressed five of the ten natural selection concepts assessed in the CINS. As a result, statistical analysis of CINS scores may not reveal the true nature of the magnitude of change in conceptual understanding of natural selection for the intervention class.

A qualitative examination of the thought processes of students revealed a more in-depth representation of any change in understanding for both the control and experimental groups. While the change in scientific and non-scientific explanations of natural selection for the control group moved in an expected direction, the lackluster values associated with these changes provides little enthusiasm for lecture-based instructional strategies. The same does not hold true when data from the experimental group interviews are examined. While an increase in explanations rooted in teleology (+8%) was witnessed in the post-intervention interviews, it is not enough to offset the overall decrease in non-scientific explanations (-14%). Once again, the brief time period in which this study occurred might have facilitated the increase in teleological explanations, as students were not provided enough time to offset the teleological reasoning that developed during student-to-student dialogue. A similar phenomenon occurs within the category of scientific explanations, where a decrease in explanations involving variation within a population (-10%) and inheritance (-8%) occurs. Although these values could indicate a decrease in understanding within these contexts, it is more

likely that the explanations previously infused with these ideas were shifted to explanations involving survival of the fittest (+21%), indicating a greater understanding of this mechanism of change. This idea is supported with the research of Jensen and Finley (1996), who also found considerable gains in students' understanding of survival of the fittest after implementation of an intervention based on argumentative discourse.

Although quantitative and qualitative data analysis suggests the argumentative discourse is a valid instructional strategy for promoting a greater understanding scientific understanding of natural selection, it is evident that this study is afflicted with various issues related to the small sample size and limited time-frame. Further research, with larger sample sizes that have an ability to absorb data outliers, may provide a more accurate description of the effect of argumentative discourse. Additionally, research with a less restrictive time frame, would help to clarify the extent at which an intervention based on argumentative discourse influences the development of a scientific understanding of natural selection. On a related note, the fact that the researcher, instead of the regular classroom teacher, completed the intervention for this study may have affected the comfort level of students thereby impeding their willingness to engage in argumentative dialogue. A more substantial timeframe might have allowed a better rapport to build between the researcher and students, as well as establish a culture of classroom dialogue and thereby facilitate greater participation in discourse among students. It should be noted that the cumulative time of the intervention reflects current practices of evolutionary instruction in high school biology classrooms (Shankar & Skoog, 1993). As it stands, the qualitative results of this study may provide evidence that even with the restricted timeframe, instruction based on argumentative discourse may be

an effective way to deal with current time constraints issues within the curriculum. Furthermore, even with the limited time frame and small sample size of this study, a consideration of data from pre and post-student interviews can help establish a basic frame of reference for future studies within the scope of this research.

With the advent of the Next Generation Science Standards, there is a need for instructional practices that focus on providing students opportunities to construct a personal understanding of scientific concepts in authentic learning situations. As a unifying concept in biology, a scientific understanding of evolutionary theory, and more specifically natural selection, is paramount for students' success in biology. The results of this study suggest that the use of student-to-student argumentative discourse can facilitate the cognitive construction of this topic. Moreover, if the trends of quantitative and qualitative data analysis were to continue with an expanded time period, the results could have a substantial impact on the way educators approach teaching within the context of the Next Generation Science Standards.

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Appendix A

Natural Selection Questions to Promote Argumentative Discourse

(Retrieved from website: https://www.chegg.com/homework-help/questions-and-answers/14-species-finches-galapagos-islands-evolved-single-species-migrated-islands-several-milli-q8427207)

1. The 14 species of finches on the Galapagos Islands evolved from a single species that migrated to the islands several million years ago. Different finch species live on different islands. A major difference among finch species is in their beaks: both size and shape vary greatly. Assume that a population of one of these finch species is undergoing evolution by natural selection with respect to beak size and shape. What changes occur gradually over time that indicates the population is evolving?

Alternative Conception Answers

Within their lifetimes, some individual finches' beaks change in size or shape.

Each finch's learned ability to use its beak is automatically passed on to its offspring.

All finches in each new generation develop the same new, improved beak size and shape.

Scientific Answer

The proportions of finches having different beak sizes/shapes change across generations.

Concept Focus

Change in population
Variation inherited

2. Ducks are aquatic birds. Their feet are webbed and this trait makes them fast swimmers. Biologists believe that ducks evolved from land birds that did not have webbed feet. The amount of webbing on a duck's feet is a heritable trait. Consider the following hypothetical scenario: An ancestral species of duck had a varied diet that included aquatic plants and terrestrial plants and insects. These ducks spent time on both land and water. Individuals of this species varied in the amount of webbing in their feet, with some individuals having more webbing and some having less. As many years went by, the environment changed such that the aquatic food sources were much more plentiful than those on land. Many generations later, almost all ducks had more webbing on their feet. How is this best explained?

Alternative Conception Answers

Ducks with less webbing worked harder than ducks with more webbing to eat aquatic plants. The more they used their feet, the more webbed their feet became, so they got enough food to survive and reproduce.

Due to chance mutations, all the ducks' feet in the next generation had more webbing. They were therefore able to eat aquatic plants and get enough food to survive and reproduce.

Ducks with less webbing needed to grow more webbing in their feet in order to improve their access to aquatic plants, which allowed them to survive better and reproduce more.

Scientific Answer

Ducks with more webbing were better at eating aquatic plants than ducks with less webbing, so the ducks with more webbing survived and reproduced better than ducks with less webbing.

Concept of Focus

Variation
Variation inherited
Differential survival
Change in population

3. DDT is an insecticide that was used extensively in the mid-1900s to kill mosquitoes. It was very effective at first, but after a few decades DDT became less effective at killing mosquitoes because many populations had evolved resistance to DDT. Which of the following conditions would biologists say was required for the evolution of DDT resistance in a population?

Alternative Conception Answers

Mosquitoes in the population learned to adapt to the high levels of DDT in the environment.

The mosquito population needed to evolve DDT resistance in order to avoid extinction.

Exposure to DDT caused specific, nonrandom mutations for DDT resistance within the population.

Scientific Answer

A few mosquitoes in the population were resistant to DDT before it was ever used.

Concept of Focus

Origin of variation
Variation
Change in population
Differential Survival

Appendix B

Conceptual Inventory of Natural Selection

2013 High School/College Version

Developed by D.L. Anderson and P.L. Evans as a modification of the original CINS published in Fisher, K.M., Anderson, D.L. & Norman, G. (2002). Development and evaluation of the Conceptual Inventory of Natural Selection. Journal of Research in Science Teaching, 39(10), 952-978.

List of concepts and answer key

Concept name	Concept description	CINS 2013 version items	Answer key
Biotic potential	All species have such great potential fertility that their population size would increase exponentially if all individuals that are born would again reproduce successfully.	1, 11	C
Stable populations	Except for minor annual fluctuations and occasional major fluctuations, populations normally display stability.	2, 12	B
Limited resources	Natural resources are limited. In a stable environment, they remain relatively constant.	3, 13	A
Limited survival	Since more individuals are produced than can be supported by the available resources, but population size remains stable, it means that there must be a fierce struggle for existence among the individuals of a population, resulting in the survival of only a part, often a very small part, of the progeny of each generation.	4, 14	D
Variation	No two individuals are exactly the same; rather, every population shows enormous variability.	5, 15	D
Origin of variation	New variation appears randomly through mutation and sexual reproduction.*	6, 16	B
Variation inherited	Much of this variation is heritable.	7, 17	C
Differential survival	Survival in the struggle for existence is <u>not random</u>, but depends in part on the hereditary constitution of the surviving individuals. This unequal survival constitutes a process of natural selection.	8, 18	B
Change in population/ Origin of species	Over the generations this process of natural selection will lead to a continuing gradual change of populations, that is, to evolution and to the production of new species.	9,19 (change in population) 10, 20 (origin of species)	B A

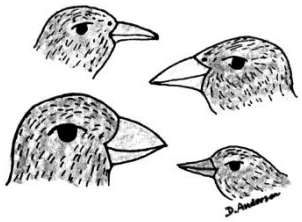
*Concept included in the CINS because it is essential for natural selection to act even though, technically, it must come before natural selection takes place.

Conceptual Inventory of Natural Selection

2013 High School/College Version

Your answers will test your understanding of the Theory of Natural Selection. Please choose the answer that best shows how a **biologist** would answer each question.

Introduction to Galapagos finches



- Finches have been studied on the Galapagos Islands by many scientists.
- The original finches most likely came to the islands one to five million years ago.
- Scientists have evidence that 14 species of finches on the Islands evolved from a single species.
- Species found on the islands have different beak sizes and shapes.

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1. What will probably happen if a breeding pair of finches is placed on an island with no predators and plenty of food so that all the birds live?

   a. The population of finches would stay small because finches only have enough offspring to replace themselves when they die.
   b. The population of finches would double and then stay about the same.
   c. The population of finches would grow to a large number and would keep growing.
   d. The population of finches would grow slowly and then stay the same.

2. A population of finches lives on an island for many years where there are predators and limited food. What will probably happen to the population if conditions on the island are stable?

   a. The population will grow rapidly each year.
   b. The population will remain stable, with few changes each year.
   c. The population will get larger, then smaller each year.
   d. The population will get smaller, then larger each year.

3. Finches on the Galapagos Islands require food to eat and water to drink. Which statement is true about the finches and the available resources?

   a. Sometimes there is enough food and water, but at other times there is not enough food for all of the finches.
   b. When food and water are limited, the finches will find other kinds of food so there is always enough.
   c. When food and water are limited, the finches all eat and drink less so there is always enough.
   d. There is always plenty of food and water to meet the finches' needs.

4. Depending on the size and shape of the beak, some finches get nectar from flowers, some eat insects in the bark, some eat small seeds, and some eat large nuts. Which sentence best describes how the finches will interact with each other?

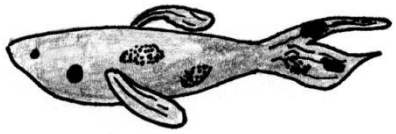
   a. Many of the finches on an island cooperate to find food and share what they find so that they all live.
   b. Many of the finches on an island fight with one another, and the physically strongest ones win.
   c. There is more than enough food to meet all the finches' needs, so they don't need to compete for food.
   d. Finches compete with other finches that eat the same kinds of food, and some die because they do not get enough to live.

5. A population of finches has hundreds of birds of a single species. Which sentence best describes the group of finches?
   a. The finches share all the same traits and are identical to each other.
   b. The finches share all of the most important traits, and the small differences between them do not affect how well they reproduce or how long they live.
   c. The finches are all identical on the inside, but have many differences in appearance.
   d. The finches share all of the most important traits, but also have differences that may affect how well theyreproduce or how long they live.

6. How did the different types of beaks <u>first appear</u> in the finches?

   a. Changes in the finches' beak size and shape happened because of their need to be able to eat different kinds of food to survive.
   b. Changes in the size and shape of the beaks of the finches because of random changes in the DNA.
   c. Changes in the beaks of the birds happened because the environment caused beneficial changes in the DNA.
   d. The beaks of the finches changed a little bit in size and shape during each bird's life, with some getting larger and some getting smaller.

Introduction to South American guppies



- These are small, colorful fish found in streams in Venezuela.
- Scientists have studied guppies in both natural streams and in lab experiments.
- Males have black, red, blue and reflective spots.
- Brightly colored males are easily seen and eaten by predators, however females tend to choose more brightly colored males.
- In a stream with no predators, the number of males that is bright and flashy increases in the population.
- If predators are added, the number of brightly-colored males gets smaller within about five months (3-4 generations).

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7. What kind of variation in the traits of the guppies is passed on to their offspring?

   a. Only behaviors that were learned during a guppy's life.
   b. Only traits that were beneficial during a guppy's life.
   c. Only traits that were coded for by a guppy's DNA.
   d. Only traits that were affected by the environment in a beneficial way during a guppy's life.

8. Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Which trait would someone who studies these fish think is the most important in deciding which fish are the "most fit"?

   a. Large body size and able to swim quickly away from predators.
   b. High number of offspring that live to reproductive age.
   c. Excellent at being able to compete for food.
   d. High number of matings with many different females.

9. What is the best way to describe the evolutionary changes that happen in the guppy population over time?

   a. The traits of each guppy in the population change slowly.
   b. Guppies with certain traits reproduce and become more common.
   c. Behaviors learned by certain guppies are passed on to their offspring and become more common.
   d. Mutations happen in the guppy population to meet the needs of the fish as the environment changes.

10. What could cause populations of guppies in different streams to become different species?

    a. Groups of guppies could accumulate so many differences that they would not be able to breed with each other, and this would make them different species.
    b. All guppies are alike and there are not really different species.
    c. Guppies that need to attract mates could change their spots in many ways, and this would make them different species.
    d. Guppies that want to avoid predators in the different streams could change their patterns so they are not so bright, and this would make them different species.

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11. If food and space are abundant, and there are no predators, what will likely happen if a mating pair of guppies is placed in a large pond?

    a. The guppy population will grow slowly. The guppies will have only the number of offspring that are needed to replace those that have died.
    b. The guppy population will never become very large, because only organisms such as insects and bacteria reproduce that way.
    c. The guppy population will grow slowly at first, then will grow to a large number, and thousands of guppies will fill the pond.
    d. The guppy population will keep growing slowly over time.

12. A population of guppies lives for a number of years in a pond with other organisms and predators. What will probably happen to the population if everything in the pond remains the same?

    a. The guppy population will keep growing in size.
    b. The guppy population will stay about the same size.
    c. The guppy population will slowly get smaller until no more guppies are left.
    d. It is impossible to tell because populations do not follow patterns.

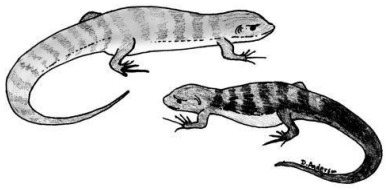
13. Guppies eat a variety of insects and plants. Which statement describes the availability of food for guppies?

    a. Sometimes there is enough food, but at other times there is not enough food for all of the guppies.
    b. Guppies can eat a variety of foods, so there will always be enough food for all of the fish.
    c. Guppies can get by on very little food, so the food supply does not matter.
    d. Finding food is not a problem since there is always plenty of food.

14. What will probably happen in a guppy population when the amount of food is low?

    a. The guppies cooperate to find food and will probably share what they find.
    b. The guppies fight for the available food, and the stronger guppies will kill the weaker ones.
    c. Genetic changes that allow guppies to eat new types of food will appear.
    d. The guppies that cannot compete for food well will die from a lack of food.

Introduction to Canary Island Lizards



- The Canary Islands are seven islands just west of the African continent.
- The islands gradually became colonized with life: plants, lizards, birds, etc.
- Three different species of lizards are found on the islands.
- These three species are similar to one species found on the African continent.
- Scientists think that the lizards traveled from Africa to the Canary Islands by floating on tree trunks washed out to sea.

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15. A population of lizards is made up of hundreds of individuals. How similar are they to other lizards in the population?

    a. All lizards are the same.
    b. All lizards are the same on the outside, but have differences in their internal traits.
    c. All lizards are the same on the inside, but have differences in their external traits.
    d. All lizards share many similarities, but have some important differences in their traits.

16. Where did the variation in body size of the three species probably first come from?

    a. The lizards needed to change in order to survive, so new helpful traits formed.
    b. Random changes in the DNA created new traits.
    c. The environment of the island caused certain changes in the DNA of the lizards.
    d. The lizards wanted to become different in size, so helpful new traits slowly appeared in the population.

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17. How are traits in lizards inherited by their young?

a. When a parent lizard learns to catch certain insects, its young can inherit the ability to catch those insects.
b. When a parent lizard gets stronger claws through repeated use in catching prey, its young can inherit the stronger claw trait.
c. When a parent lizard is born with an extra claw on each limb, its offspring can inherit the extra claw.
d. When a parent lizard's claws are weak because the available prey is easy to catch, its young can inherit the weakened claws.

18. Fitness is a term often used by biologists to explain the success of certain organisms. Below are descriptions of four lizards. According to a biologist, which lizard is the most fit?

	Lizard A	Lizard B	Lizard C	Lizard D
Body length	20 cm	12 cm	10 cm	15 cm
Offspring surviving to adulthood	19	32	22	21
Age at death	4 years	3 years	4 years	6 years
Other information	Lizard A is very healthy, strong, and clever	Lizard B is dark-colored and very quick	Lizard C has the largest territory of all the lizards	Lizard D has mated with many males

a. Lizard A b. Lizard B c. Lizard C d. Lizard D

19. What is the best way to describe the evolutionary changes that happen in the lizard population over time?

a. The traits of each lizard in the population change slowly.
b. Lizards with certain traits reproduce and become more common.
c. Behaviors learned by certain lizards are passed on to their offspring and become more common.
d. Mutations happen in the lizard population to meet the needs of the lizards as the environment changes.

20. What could have caused one species to change into three species over time?

a. Groups of lizards lived on different islands. Over time, many genetic changes may have happened in each group so they could no longer breed with each other, and this made them different species.
b. There are small variations between the lizards, but all the lizards are mostly alike, and are all members of a single species.
c. Groups of lizards needed to adapt to the different islands, so the lizards in each group slowly changed over time to become a new lizard species.
d. Groups of lizards found different island environments, so the lizards needed to become new species with different traits in order to survive over time.

Appendix C

(Antibiotic resistant bacteria prompt retrieved from website: https://www.chegg.com/homework-help/questions-and-answers/14-species-finches-galapagos-islands-evolved-single-species-migrated-islands-several-milli-q8427207)

Interview Protocol

Topic

Natural Selection

Goal

I want to understand students' conceptions concerning Natural Selection. Furthermore, I would like to identify the reasoning used to support these conceptions; as well as any possible alternative conceptions students may possess about this topic.

Introduction Script

Thank you for taking time out of your day to help me with my research. I am interested in students' ideas concerning how organisms change over time, and I would like to ask you some questions about this topic. I am only interested in your thought processes, not whether you answer these questions correctly or incorrectly. As a matter of fact, these questions are not designed for a 'right' or 'wrong' answer, rather their purpose is simply to get you to think about this topic. As you answer each of these questions, I would like you to 'think-out-loud' so that I may be able to accurately understand your internal thoughts.

Task #1

Student is shown a diagram depicting six figures demonstrating whale evolution, and asked to describe how whales evolved (characteristics) and reasons for these changes.

Possible Student Responses	Possible Follow-Up Questions
Size	- What does the term 'evolve' mean to you? - Can you use these pictures to help you explain the word 'evolve'? - Why would they evolve into a larger size? (What is the benefit?) - Can it evolve to be smaller?
Reduction of Limbs	- What do you think happened to the back legs? - Give a possible explanation for why the back legs are no longer present.
Appendages to Flippers	- The first organism in this picture has four legs. This organism only has two flippers. What might be the reason for this?
Nose Placement	- Notice that the nose moved to the top of the head. Why/how do you think it moved? - Are there any other adaptations to the nose besides placement you think may have taken place?

Task #2

Student is given the prompt ''Current medical research has begun to focus on disease-causing antibiotic resistant bacteria. These bacteria used to be easily treated with antibiotics, but this method is no longer effective. Could you explain why many types of bacteria don't die anymore when antibiotics are used on them?'' and asked to 'think out-loud" about the answer.

Possible Student Responses	Possible Follow-Up Questions
Immunity	- How did the bacteria get this immunity? - Do you think the next generation of bacteria will be immune? Why? - Did these bacteria have immunity to antibiotics before they were used? - Why didn't the other bacteria (the ones that died) have this immunity?
Change in genetics	- Explain what change occurred within the genetics of the bacteria. - Did it develop in an individual bacterium once antibiotics were used, or do you think it was "born" with it? - Why did only some bacteria 'change' genetically?
Only the strongest survive/Variation	- What do you mean by 'stronger'? - Why are some bacteria stronger than others? (Or, why is there variation in this population?) - Does that mean that stronger humans have a better chance of surviving exposure to poison? - Are there any other characteristics besides strength that would allow these bacteria to resist antibiotics?

Task	Name of Task	Purpose
#1	Whale Evolution	To determine students' conceptions of change over time due to natural selection, and reveal the reasoning behind these ideas.
#2	Bacteria and Antibiotic Resistance	To reveal the reasoning students apply when confronted with a modern day example of natural selection.

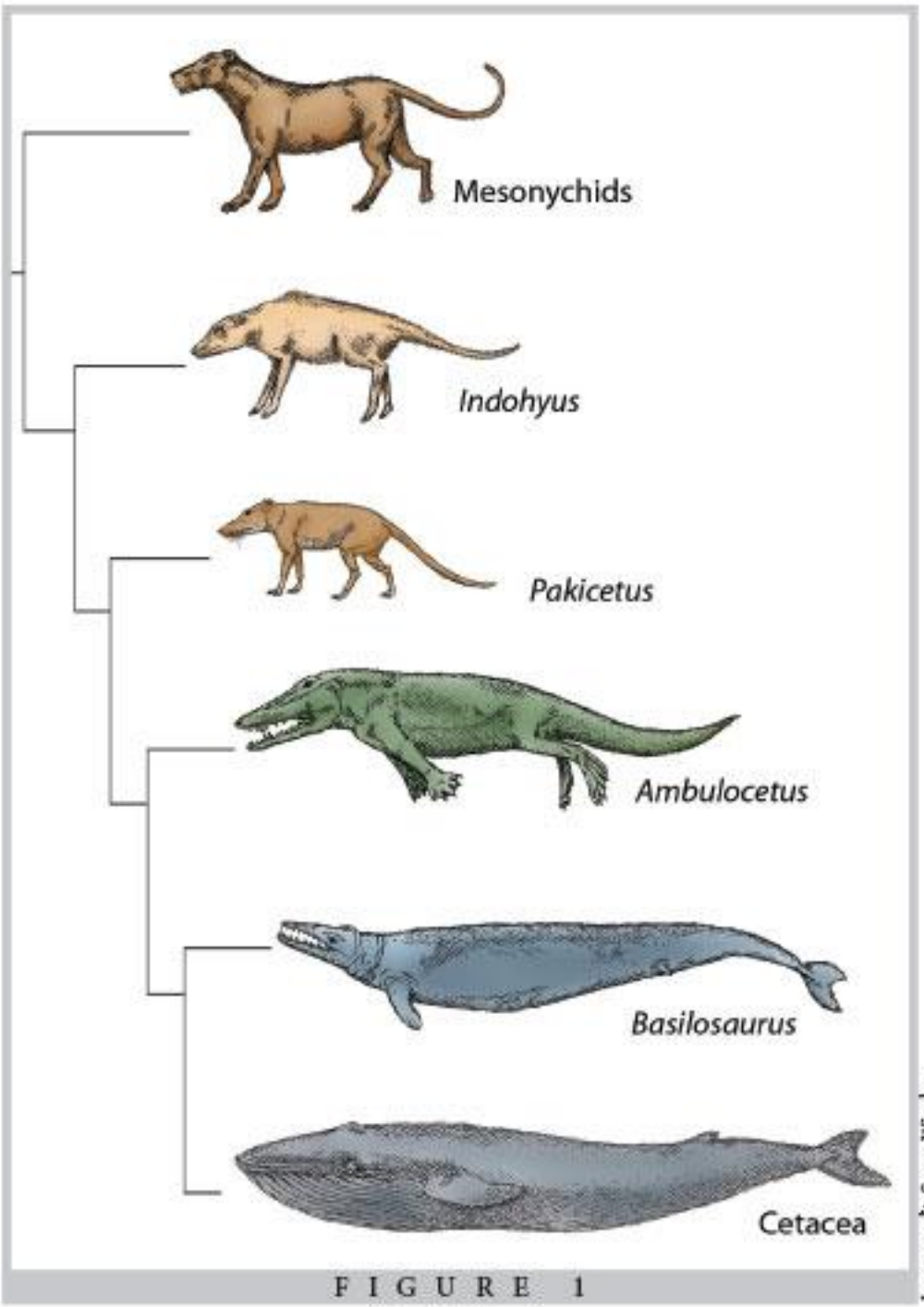

FIGURE 1

Note: Not to scale