

POINT LOMA NAZARENE UNIVERSITY

**High school students' conceptual understanding of natural selection, specifically variation
in a population and origin of variation, as influenced by traditional Concept Cartoons, or
an animated software program**

A thesis submitted in partial satisfaction of the
requirements for the degree of

Master of Science

in General Biology

by

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2014

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The thesis of Jessica Pimentel Sphar is approved, and it is acceptable in quality and form for publication:

Chair

Point Loma Nazarene University

2014

I dedicate this thesis to my supportive husband, Daniel L. Sphar,
and to my parents, Josefa and Roberto Pimentel,
who helped me achieve this monumental task.

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Abstract of the Thesis

High school students' conceptual understanding of natural selection, specifically variation in a population and origin of variation, as influenced by traditional Concept Cartoons, or an animated software program

by

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Concepts in evolution are introduced at the middle school level, but are taught in more depth at the high school level. Students come in with prior conceptions of evolution that influence student learning in the classroom. There are multiple ways of assessing students' understanding of various concepts of evolution that include interviews, tests, labs, and writing activities. A mixed-method design was used to analyze students' understanding of variation in a population and origin of variation, subtopics of evolution. Methods of collecting data included using Conceptual Inventory of Natural Selection (CINS) to implement pre and post tests across a high school biology department (n=483) and six student pre and post interviews. Our findings suggest that using classroom intervention activities including Traditional Concept Cartoons, photo cartoons, and animations improved student understanding of variation in a

population and origin of variation. Comparing student groups, there was no overall statistical significance between the pre and post-test score in the biology classes ($p=0.08$); a statistical significance in the pre and post-test score for the medical biology group ($p=0.001$). When comparing the overall CINS post-test scores for biology, medical biology, and AP biology, there was a statistical difference between the AP biology post-test scores and both medical biology ($p<0.05$) and biology ($p = 0.05$) post-test scores.

Introduction

In recent years, education researchers, as well as public and private leaders have identified a need in addressing the science performances in the U.S. school system and concluded that math and science understanding is important in order for American workers to compete and thrive in the modern workforce (NGSS Lead States, 2013). However the United States science, math, and science education system is not facilitating the acquisition of workable knowledge needed to articulate science concepts thus resulting in unacceptable science performance (NGSS Lead States, 2013). This type of performance will leave Americans unprepared to succeed in the global economy. To better prepare students for a future in science or science related fields, California has adopted the Next Generation Science Standards (NGSS). Four of the fourteen life science standards are closely related: LS2B - Inheritance of Traits, LS3B – Variation of Traits, LS4B - Natural selection, and LS4C – Adaptation. All four of these topics are important in educating today's citizens since science literacy can be a great advantage when making decisions about health care, retirement planning, and other controversial medical issues that will play a critical role in our society (NGSS Lead States, 2013).

An understanding of evolution requires knowledge of genetics concepts that include principles of inheritance, DNA replication, and mutation in relation to phenotype. People's perception and knowledge of evolution is important when considering health care issues such as antibiotic resistance of bacteria in hospitals and prisons. Understanding how certain bacteria evolve under various conditions and settings is critical in public, medical, and government fields (Teachers Domain, 2008). As noted in prior research, evolution continues to be an ambiguous and not well understood topic for adults and students in the United States and in our public schools (Smith, 2009). It is clear that by promoting scientific literacy on the topic of evolution, natural selection, and inheritance, we create a workforce capable of answering questions and challenges that will arise

concerning evolution of pathogens and other microbes, as well as understanding the diversity of life on earth. The purpose of the present study is to use three variations of interventions to promote high school science students' understanding of the following NGSS subset standards, with particular focus on 3-2:

Life Science Standard 3-1: Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.

Life Science Standard 3-2: Make and defend a claim based on evidence that inheritable genetic variation may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication and/or (3) mutations caused by environmental factors

Life Science Standard 4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

Life Science Standard 4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

Life Science Standard 4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Literature review

Theoretical Perspective

Students are always in a constant state of learning their role in various social settings including the home, classroom, and/or clubs. As students encounter challenges in academic settings, these challenges may provide the stimulus necessary for them to learn. When a student enters this area in which new and old schema collide it triggers a mental reorganization event or disequilibrium (Piaget, 1963/2003) in which students are confronted with the disconnect between what they know and what they can explain through application of their knowledge. Learning or accommodation involves resolving this challenge. Progressive reorganization of knowledge through reflections, peer interactions, and collaborative work allows for revision and expansion of what one understands, in addition to constructing new knowledge (Bransford, Brown, & Cocking., 1999; Steiner & Mahn, 1996). Providing a space and time for these experiences allows for a meaningful progression of understanding and the application of knowledge to new scenarios both in class and out of class (Julyan & Duckworth, 2005). By examining the relationship between bodies of knowledge and its reorganization in students' minds, rather than replacing alternative conceptions, we begin to understand and uncover what a student has learned during a given event and we can begin using the relationships as a gauge for learning (Smith, diSessa, & Roschelle, 1993). For Smith et.al., "learning involves the interpretation of phenomena, situations, and events, including classroom instruction, through the perspective of the learner's existing knowledge" (p55). In this study students will be asked to bridge what they know to explain topics of natural selection, specifically the origin of variation and population variation using concept cartoons and animations.

The Biology of Variation

Genetics concepts are challenging, and making the connection to evolution is even more difficult for students. Topics such as genes, DNA, and chromosomes are difficult to conceptualize and articulate its application to society or a given evolution scenario (Boujemaa, Pierre, Sabah, Salahedinne, Jamal, & Abdellatif, 2010; Mbajiorgu, Ezechi, & Idoko, 2007). A gene as defined by Hartwell, et al., (2004) is “the basic unit of biological information” (p 13). An organisms’ genetic makeup or genotype will influence survival of an organism and its ability to reproduce. Genetic variation, in sexually reproducing organisms, is a product of genetic recombination, and gene flow. Genetic variation may arise from two events in meiosis: independent assortment of chromosomes and crossing over, both events taking place during the first nuclear division. In humans having 46 chromosomes (23 pairs), random fertilization through the fusion of one male and one female gamete yields a zygote with any of the 64 trillion diploid combinations ($2^{23} \times 2^{23}$) (Campbell & Reece, 2005). Genetic variation also originates from mutations or changes in DNA, either in the genes themselves or in the surrounding non-coding segments of DNA that controls gene expression. Only mutations that occur in germ cells or sex cells are passed on to offspring (Campbell & Reece, 2005).

Differential reproductive success that results from genetic variation within a population results in evolution. Organisms with favorable genetic variations and specific phenotype have higher chances of survival (Campbell & Reece, 2005). Individuals with traits better suited to the local environment are more likely to survive and to leave the most offspring, thus passing on their genes.

Linking Genetics and Evolution

Conceptual difficulties related to genetics and evolution. As mentioned earlier in the paper, genes, and thus genotype, influences reproductive success of organisms. Fitness is a termed used to describe an organism’s ability to transmit their genes to the next generation (Hartwell et al., 2004) and

unfortunately, it is often misunderstood by students. The more offspring the organism leaves behind the more fit that organism is. Fitness does not have to describe the health, speed, or size of the organism (University of California Museum of Paleontology, 2008), rather if the organism has the genetic variation that allows them to compete for resources, reproduce, and survive in a changing environment it would possess a relatively high fitness. The process by which variants of lower fitness are eliminated and those with higher fitness survive in nature is known as natural selection (Hartwell et al., 2004; University of California Museum of Paleontology, 2008).

From a student's perspective, connecting these genetics and evolution topics require a space in which it is safe to talk about what they know and don't know. It is through explicit paired interactions, like student-student or teacher-student interactions (Jensen & Finley, 1996), that students can engage in conversations where fragmented and unclear ideas can be sorted into a coherent scheme (Seymour & Hewitt, 1997) and where they can reinforce their understanding of the content material. Student-student interaction through discussion groups has increased understanding of evolution concepts as reported by Gross. Providing this space enables students to mindfully articulate their understanding of genetics and evolution while applying both personal and academic intellect (Gross, 2011; Seymour & Hewitt, 1997).

A conversational setting, or interview, will provide a means of understanding students' concepts about evolution, and will provide students with the freedom to navigate through their reasoning (Gross, 2011). Using visuals, specifically cartoons, provide an additional focus for discussion and can be used to guide the interview discussion or think-aloud (Gross, 2011). Expressing the connections that exist in various science topics through a semi-structured peer discussion and interview will allow students to reconstruct their understanding of science phenomena and lead to conceptual change. Using visual scaffolds like conceptual cartoons during these structured social interactions could also provide a scaffold for ELL (Gross, 2011; Herrell &

Jordan, 2008) and foster discourse while increasing productive accountable talk where participants expect their peers to clarify, explain, and justify their statements (Koba & Tweed, 2009; Gross, 2011). Semi-structured interviews can provide insight into students' reasoning ability, which is an important factor in successfully describing genetic concepts (Cavallo, 1996). Cavallo found that students who attempt to make sense of their learning and have a higher reasoning ability are better able to solve problems pertaining to genetics, but are they able to bridge genetic and evolution concepts? A written extended response may provide additional evidence of alternative conceptions and reasoning abilities (Nieswandt & Bellomo, 2009). Writing after these structured social interactions or focus group can help students construct meaning from the Traditional Concept Cartoon, or problem presented. "Writing ...and drawings all help students make meaning of science learning experiences.. it is a tool with which to think (p55)" (Koba & Tweed, 2009). Anderson, Fisher, and Norman (2002), used individual interviews to examine student conceptual understanding between evolution and genetics. As a researcher, listening and analyzing student connections and articulations recorded during interviews will provide a clearer insight of student learning in the classroom (Feldman & Minstrell, 2000; Hogan & Fisherkeller, 2000; Nieswandt & Bellomo, 2009) and for this reason, my research will analyze pre and post interviews pertaining to natural selection.

Alternative Conceptions

Student conceptions. In science education the use of terms like *misconceptions* and *alternative conceptions* are used to describe students' understanding of concepts, however it's important to describe the differences. Terms like *misconceptions*, *erroneous concepts*, *misunderstandings*, and *mistakes* have been used to describe "wrong knowledge" and to explain students' performance in the classroom (Abimbola, 1988). From this perspective, the pattern of students' errors are meant to be replaced by appropriate expert concepts (Abimbola, 1988; Larkin, 2012). Other related words and phrases seen in the literature include *alternative frameworks*, *preconceptions*, *prior knowledge*, *student ideas*, *conceptions*

(Larkin, 2012), *alternative conceptions* (Abimbola, 1998; Jensen & Finely, 1996; Palmer, 1999) and *scientifically-acceptable conceptions* (Palmer, 1999). In this study, I will be using *alternative conceptions* to describe students' conceptions about subjects in science and imply that students' non-scientific ideas have value, rather than simply something to be replaced. Teachers in the science classroom may perceive students' alternative conceptions as either obstacles that hinder learning or as resources to build upon their understanding (Larkin, 2012). As resources, students' prior experiences and knowledge can be used to foster deeper and more meaningful learning. However, if students' alternative conceptions are not addressed through thoughtful lesson planning or activities, they may continue to build upon their alternative conception.

Alternative conceptions influence students' understanding of science concepts and differ from corresponding scientific explanations (Anderson, Fisher, & Norman, 2002). In evolution, these alternative conceptions include ideas related to anthropomorphism, teleology, and Lamarckian evolution (Jensen & Finely, 1996) and may be held by a significant proportion of students (Anderson, Fisher, & Norman, 2002). These alternative conceptions may be highly resistant to instruction but can serve as anchoring conceptions to foster learning in a structured setting (Anderson, Fisher, & Norman, 2002; Koba & Tweed, 2009). Anchors are influenced by prior concepts, societal expectations, and classroom expectations (Mohan, Chen, & Anderson, 2009). These anchoring alternative conceptions can later be used to guide students through a scientifically accurate interpretation of how topics are integrated to understand nature in terms of evolution and genetics.

More than one alternative conception can reside in a student's mind during the learning process. However, given appropriate opportunities to discuss their ideas and to practice applying them, conceptual change can occur. Conceptual change happens in increments and is driven by emotional, social, and irrational factors (Harrison, Grayson, & Treagust, 1999). The first conceptual

model is the process of assimilating new information (Harrison, et. al., 1999; Piaget, 1963/2003). The second level involves changing core concepts (Harrison, et. al., 1999) and is largely influenced by social contexts during instruction (Warren, Ballenger, Ogonowski, & Rosebery, 2001; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001).

Identification of alternative conceptions. Ways of measuring conceptual understanding or alternative conceptions include interviews, focus groups, journals, student writing, illustrations, and field notes (Harrison, Grayson, & Treagust, 1999; Koba & Tweed, 2009; Zohar & Aharon-Krevetsky, 2005). Secondary school teachers use a variety of measures to assess students' genetics and evolution understanding that include multiple choice tests or carefully designed conceptual inventories, written essays, presentations, and informal assessments such as exit slips. Exit slips are one way of informally assessing student learning in which students are asked to either write a reflection on what they learned or answer a couple of teacher-posed questions during the last five minutes of class. Other informal classroom assessment techniques include journal writing, laboratory writing, group discussions, think-aloud, double-entry journals, or logs that provide a window into the students' mental activities and connections created with the content taught (Angelo & Cross, 1993; Koba & Tweed, 2009). Many teachers use social interactions to identify preconceptions. Structured social interactions such as group discussions and labs allow them to make sense of science learning experiences while listening to multiple points of view and to explore ideas they would otherwise not have (Koba & Tweed, 2009).

Mbajjorgu identified 17- 18 year-old secondary school students' preconceptions of genetics in his study of which included the idea that "kinship explains heredity, whereas chance and religious beliefs explain variation and abnormalities" (p. 442). He goes on to identify the difficulty children have comprehending the possible effects of mutations, rare recessive traits in the population, and explanations of variations seen in the populations. Boujemaa, et al. (2010) identified various

conceptions of the word “gene” in university students; some of the students (34%) incorporated the knowledge that DNA sequences code for a protein in their responses, while fewer students (28.6%) incorporated the knowledge that genes are a unit that determines a character. However, from their sample (94 students) only 4.2% were able to describe genes as being responsible for variation. Finally, Boujemaa, et. al., found that it was hard for students to transfer knowledge across sub-disciplines of biology and across different organizational levels (DNA to chromosome to protein to variation in traits).

In addition to having genetic alternative conceptions, students also have alternative conceptions pertaining to evolution. These alternative conceptions are resistant to change and may persist well into the college setting and adulthood and conceptually challenging for many learners (Smith, 2009). Students perceive that evolution is random (University of California Museum of Paleontology, 2008). While mutations and gene shuffling are random, selection for the adaptations or traits that have a selective advantage is non-random. Understanding the relationship between genetics and evolution requires an in depth understanding of both topics (Anderson, et al, 2002). In this current study, I explore ways of uncovering students’ alternative conceptions on both topics.

Conceptual Inventory of Natural Selection

The Conceptual Inventory of Natural Selection (CINS) developed by Anderson, Fisher, and Norman, (2002) is a multiple-choice diagnostic assessment designed for identifying conceptions of natural selection in post-secondary students using real events in evolution. For example, the CINS uses scenarios in its prompts that involve the Galapagos Finches and the Canary Island Lizards. The authors of this inventory took speech patterns into consideration when designing this tool. The structure of the CINS is different from other multiple choice tests in that it takes alternative conceptions about natural selection into account and integrates them into possible responses. This is valuable in “identifying gaps in instruction and student knowledge that contribute to

misunderstandings about how populations change over time [and the multiple choice responses] paralleled information obtained in interviews, but could be used effectively with large classes (Anderson, et.al., 2002 p 954).” Assessing students’ understanding of basic principles in genetics, genetic variation, the origin of variation, and the inheritance of variation, and its impact on changes in populations is critical in order to understand students’ conceptions of natural selection.

There are a total of 10 evolution concepts on the CINS and the qualitative component of this research will focus specifically on the origin of variation .The following are the ten concepts assessed in CINS:

1. *Biotic potential*
2. *Carrying capacity*
3. *Resources are limited*
4. *Limited survival*
5. *Genetic variation*
6. *Origin of variation*
7. *Variation is inherited*
8. *Differential survival*
9. *Change in population*
10. *Origin of species*

The CINS was revised in 2013 to reduce the reading level so that the inventory can be used with students from middle school through college (Evans & Anderson, 2013).

English Language Learners

A culturally dynamic high school campus has the responsibility to teach students with an array of cultural backgrounds. While all students struggle to understand genetics and evolutionary concepts, for English Language Learners (ELL) the challenge is particularly great: Western states, including California, have an enrollment of 29% ELL students; however the number of ELL students in other non-western states has increased in recent years (National Center for Education

Statistics, 2014; Garcia, O., Kleifgen, J.A., & Falchi, L, 2008). Students are designated as ELL and limited English Proficient (LEP) if another language other than English is spoken at home and if the student has not mastered the English language to score proficiently on state standards tests (Garcia, et. al., 2008). The California ELL population includes those from Spanish, Vietnamese, Filipino, Cantonese, Hmong, and Korean speaking-homes as well as other languages. The majority (85%) of ELL's in California speak Spanish at home. Nearly 25% of public school students in California are classified as ELL students, while a higher percentage has transitioned out of this category and has been reclassified into non-language support classes. It's important to note that not all ELLs are born out of this country; in fact most ELLs are native-born. However, both groups, current and reclassified ELL students, often struggle in understanding academic content as they continue on to higher education (Hill, 2012).

Some research has identified scaffolding strategies that help ELL students in understanding science content. Conceptualization of science content and the ability to transfer relevant knowledge in science is influenced by one's primary language. The ways in which students solve problems and respond to teachers' questions are influenced by their culture and thus influence students' interpretation of the questions. Culture also affects the conceptualization, transfer of knowledge, and interpretation of content all of which are important in any meaningful learning process (Fathman & Crowther, 2006). Scaffolds during assessments include the integration of illustrations that helps transfer knowledge from a learning experience to an assessment (Fathman & Crowther, 2006). Other scaffolds that benefit ELL students include think-alouds, use of images with new vocabulary, creating illustrations of processes, and structured peer interactions like think-pair-shares, and lab groups (Willoughby, 2005). In addition to the above scaffolding strategies, using short, less complex sentences to teach complex concepts and one-on-one student teacher interactions benefits an ELL's experience in a science classroom (Willoughby, 2005). Some districts offer professional

development on ELL learning strategies to integrate into the classroom and include the use of sentence starters, sentence frames, and cloze summaries.

Connecting the topics of genetics and evolution is challenging for many high school students, particularly English Language Learners (ELL). Purposeful scaffolding becomes critical to ensure that ELL have access to basic knowledge needed to build models, make predictions, and most importantly, to help them apply learned content to various non-text scenarios. The purpose of this research, then, is to determine if 1) using the cartoons and other interventions related to origin of mutations would increase student understanding of natural selection and 2) determine what students identify as sources of genetic variation in any given population. In my research, I used sentence starters to help ELL students bridge their learning experiences to answer questions on the concept cartoon assessments and software animation.

Traditional Concept Cartoons as a means of identifying alternative conceptions

As mentioned earlier, ELLs benefit from group interactions and illustrations in a science setting. In science education, Traditional Concept Cartoons illustrate a specific concept and typically have a group of characters each with a different explanation of the topic illustrated as a dialogue cloud (Akamca, Ellez, & Hamurcu, 2009). Each explanation is plausible, with some being alternative conceptions, and one being an accepted scientific explanation. Using Traditional Concept Cartoons during a focus group or activity fosters a social learning environment that allows the teacher to further probe students' understanding of the particular science concept (Akamca, et.al, 2009). Traditional Concept Cartoons (TCC) provides a focal point for productive talk in a group setting (Gross, 2011). During an interview TCC allow both interviewee and interviewer to elaborate on students' conceptual understanding in a short time (Koba & Tweed, 2009; Ekici, Ekici, & Aydin, 2007). The outcome of the TCC interview or group discussions can inform teachers on ways to supplement, enrich, or hone future lessons, activities, and labs.

Research question(s)

The modified 2013 CINS (Evans & Anderson, 2013) was used to evaluate students' conceptions of evolution. The CINS was used as both a pre and posttest to assess the impact of three classroom interventions to identify students' alternative conceptions on the origin of variation and variation in a population. In addition to the CINS, six students from the biology cohort were individually interviewed before and after the evolution unit. This research project is aimed at answering the following questions:

- 1) *What are students identifying as variation in a population and origin of variation in a given population?*
- 2) *How does the use of traditional concept cartoons, photo concept cartoons, and animations impact students' understanding of genetic variation in a population and origin of variation?*

Methods

Research Design

This research will use a triangulation mixed methods approach to answer the research questions. To better understand students' conceptual understanding of natural selection, multiple assessments types were used including pre and posttests, written responses, and two interviews with a small subset of students. The purpose of using this mixed-method approach was to use each method's strengths (Creswell & Clark, 2007) to compile a more sophisticated and complete assessment of the students' understanding of the concepts in the study.

The qualitative component consisted of two one-on-one interviews (pre and post) with six students. These interviews were recorded using an audio recorder and later transcribed and analyzed. The quantitative component consisted of using the two halves of the 2013 CINS as a ten question pre-unit and post-unit test. High school students enrolled in biology were divided into four groups: 1) control 2) traditional concept cartoon 3) photo-based concept cartoon and 4) animation (Figure 1). Both the qualitative and quantitative data were collected over a seven-week timeline as shown in Table 1. Spring break took place during week 5 and week 6 of the study. This was not ideal, and is recognized as one of the limitations of the study. The pre-intervention, pre-interviews took place the week prior to starting the evolution unit. The CINS was implemented prior to starting evolution content. Transcripts of the interviews provided an in-depth understanding of six students' alternative conceptions and explanations surrounding the origin of variation and variation in a population. Data from 483 students was collected using the CINS items as a pre and post-test.

Table1

Overview of mixed methods timeline

Week 1	Week 2	Week 3	Week 4	Week 7
First set of interviews (qualitative data) (n=6)	CINS (Pre-test) (quantitative data)	Classroom Intervention (students were in one of four groups: control, animation, Traditional Concept Cartoon, photo cartoon)	CINS (Post-test) (quantitative data)	Second set of interviews (qualitative data) (n=6)

Participants and setting

The study took place in a large urban public high school in southern California. Over 86% of the student population of 2,440 qualifies for free or reduced lunch, and 52% of the students are ELL (California Department of Education: DataQuest, 2011-2012). In the study site, genetics is taught prior to the evolution unit. In the genetics unit, basic vocabulary and concepts are introduced that help students predict possible offspring characteristics. A total of 6 teachers and 20 classes were involved in the study. Most of the faculty members in the biology department agreed to administer the CINS during the second semester both prior to and after the evolution unit. Various biology classes were assigned to be in one of four groups: control (typical unit), Traditional Concept Cartoon embedded, photo cartoon embedded, or animation embedded.

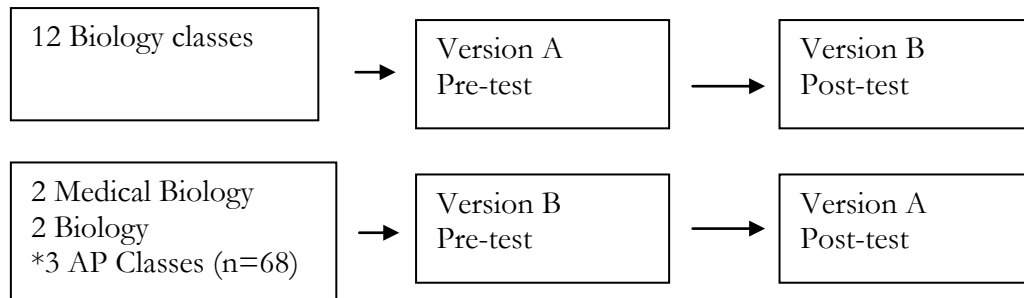
Pre-test and post-test data were collected as part of the regular class informal pre-assessment and integrated into a common summative assessment culminating the unit. A total of 475 students in grades 9-12 of varying academic levels took the 2013 CINS as follows: 361 students enrolled in biology, 50 students enrolled in medical biology, and 68 students enrolled in AP biology (Figure 1). Some students had previously taken a biology course. Of the 340 biology students, 6 students were selected to participate in the student pre and post interviews. These students were selected based on

their ability to express their thoughts and accurately represented the diverse academic range. The interviews were conducted in accordance with Point Loma Nazarene University's IRB guidelines and recorded using a digital audio recorder. The pre-interviews took place after school on February 19th, 20th, and 24th. The post-interviews took place after school on April 8th, 9th, and 15th. Each student was given a small gift card after completing both pre and post interviews as a token of appreciation for participating in this research study.

Quantitative Data Collection and Analysis

CINS is a 20- question test that has been split into two versions, version A consisting of the first ten questions, 1-10, and version B consisting of questions 11-20. Each version addresses the 10 topics previously listed (pg10). Each teacher administered the 2013 CINS pre-test prior to starting the evolution unit during the second semester of the academic school year. Version A was administered as a pre-test in 12 Biology classes while version B was administered as a pre-test in 2 biology courses and 2 Medical Biology courses. Since the 2013 version of the CINS is still undergoing field testing, this allowed for a comparison of student performance on the two halves of the test, whether used as a pre- or post-test. Three AP Biology classes were given Version A as their post-assessment; no pre-test was administered to this class since they had started the unit before the research began. To ensure that the students were committed to thoughtfully answering the questions, and in an effort to reduce the likelihood of guessing, they were informed that they would earn extra credit points based on the number of questions answered correctly. Students bubbled in their answer choices on a scantron sheet provided. The posttest pertaining to the same ten concepts listed earlier was given alongside their evolution unit test, and if answered correctly counted as extra credit points. Classes who took version A as the pre-test took version B as a posttest and classes who took version B as a pre-test took version A as the post-test (Figure 1). A paired t-test was used to determine if there were any statistically significant differences between the pre-test and post-test

means for all students in each particular class (Medical Biology, Biology, and AP Biology), in each particular treatment (Control, Photo-based concept cartoon, Traditional Concept Cartoon, and animation), as well as a whole. In addition to examining the overall mean scores of the various classes and treatments, students' responses on two particular questions addressing the topic of variation in a population and the origin of variation were examined and analyzed in more detail.



Class	n	Pre-test Version	Intervention	Post-test Version
Biology	105	A	Control	B
Biology	80	A	Animation	B
Biology	67	A	TCC	B
Biology	21	B	TCC	A
Biology	70	A	PBCC	B
Biology	18	B	PBCC	A
Medical Biology	46	B	None	A
AP Biology	68	X	None	A

Figure 1. Pre-test and Post-test version implementation in the various classes. *AP Biology classes were given version A as their post-test; no pre-test was administered to this class since they had started the evolution unit prior to data collection.

The Classroom evolution unit

The evolution unit for the biology department spanned four weeks and examples of topics incorporated were natural selection, modeling allele frequency fluctuations as a result of predation and disease, Darwin's voyage, and survival of the fittest were taught. The genetics and principles of inheritance unit were taught prior to evolution in an effort to bridge these two concepts together.

During the evolution unit students had an opportunity to work with online animations, watch

videos, complete guided reading assignments, take vocabulary quizzes, watch PowerPoint lessons, and complete population frequency activities in which they were exposed to genetic frequencies and the effect of epidemics on the population. The control group in the study participated in all of the in-class assignments listed above. To address the second research question in this study, the biology classes were divided into four groups, one control and three treatments (Figure 1). The concept cartoons and animations used during the classroom interventions and interviews of this study were retrieved from three different sources as listed in Table 2 below.

Table 2
Concept cartoons and animations used in the study

Cartoon Topic	Image Style (Traditional Concept Cartoon, Photo Based Concept Cartoon, or animation)	Used in the Pre-interview, classroom intervention, or post interview	Source
Beetle - Origin of Variation	Traditional Concept Cartoon	Pre-interview	M.A. Rall, 2008
Flamingo – Variation in a population	Traditional Concept Cartoon	Pre-interview & Classroom intervention	Fisher/Anderson,
People – Origin of Variation	Traditional Concept Cartoon	Classroom intervention	Fisher/Anderson,
Flamingo – Variation in a population	Photo Based Concept Cartoon	Class intervention & Post-interview	Dianne Anderson, personal communication
Penguin – Origin of Variation	Photo Based Concept Cartoon	Class intervention & Post-interview	Dianne Anderson, personal communication
Animation – Origin of variation and population variation	Animation	Class intervention	Discovery Communications, LLC 2014

Qualitative data collection

In addition to the collection of data using the CINS, a subset of pre-selected biology students from my classrooms participated in after-school pre and post interviews. These students were selected based on their ability to communicate their thought processes, and were an accurate representation of the biology student population. Two students were selected from each performance level: low, medium, and high. These students were selected based on their participation in class. Biology at this school site is taken mostly by freshmen and sophomore students, but we also have junior and senior students that were taking this class. My interviewees consisted of 9th, 11th, and 12th grade students. Alfredo was a 12th grade high level performer; Esteban was a 9th grade high level performer; Monica was an 11th grade medium level performer; Daisy was a 9th grade medium level performer; Harry was a 9th grade low level performer; and Valerie was a 9th grade low level performer. As shown in Table 3, the goal of this preliminary interview was to use a Traditional Concept Cartoons on the topics of genetic variation (Appendix C) and origin of variation (Appendix E) to identify any alternative conceptions pertaining to genetic variation in a beetle population. In addition to the cartoon, students answered CINS questions pertaining to genetic variation and origin of variation in a population. The post interview was conducted after the evolution unit and after the 2 week spring break. Each post-interview took place after school and the goal was to better understand student concepts of natural selection, specifically what they understood on the topic of population variation. A new type of Concept Cartoon, Photo-Based Concept Cartoon was used in the second interview: variation in a population (Appendix I) and origin of variation (Appendix K).

Table 3

Timeline for qualitative component including interviews and classroom interventions

Interview Prior to CINS pre-test	Classroom intervention integrated into the Evolution Lesson	Interview After Evolution Unit & CINS post-test
<ul style="list-style-type: none"> • 6 student interviews • Cartoon #1 Beetle Cartoon Topic: Origin of variation (see Appendix C & D) • Cartoon #2 Flamingo Cartoon: Variation in a population (see Appendix E & F) • CINS Questions pertaining to genetic variation and origin of variation 	<ul style="list-style-type: none"> • Control Group (regular unit) • Animation Group (Appendix A & B) • Traditional Concept Cartoon Group (Appendix G) • Photo-Based Concept Cartoon Group (Appendix H) 	<ul style="list-style-type: none"> • 6 student interviews • Photo-based Traditional Concept Cartoon #1 Flamingo Topic: Variation in a population (Appendix I & J) • Photo-based Concept Cartoon #2 Penguin Topic: Origin of variation (Appendix K & L) • CINS Questions pertaining to genetic variation and origin of variation

Classroom Interventions

Biology students were further categorized and placed into 1) control group 2) animation group 3) Traditional Concept Cartoon Group or 4) Photo-based Concept Cartoon Group. The Animation group interacted with an on-line tutorial and game “Who Wants to Live A Million Years?” This animation was selected since it focuses on how random mutations may influence the reproductive success of species in response to the environment. This animation emphasizes that mutations are not always beneficial to the species survival, but there are times in which some of the random mutations do have a positive impact on the species reproductive success. Students in the Traditional Concept Cartoon group were exposed to two Traditional Concept Cartoons that introduced students to the importance of variation in the population and the origin of variation. (Mary Ann Rall, 2008; Hazen & Trefil, 2013). The Photo-based Cartoon group was exposed to two

Photo-based Concept Cartoons that introduced students to the importance of variation in the population and the origin of variation sometime within the evolution unit at the teacher's discretion.

Animation Group Description. The animation group consisted of 80 students. These students were instructed to read through the animation activity introduction, then students walked themselves through the “Learn About Natural Selection” component of the animated cartoon website (<http://science.discovery.com/games-and-interactives/charles-darwin-game.htm>) where three principles are introduced. Directly from the site, these include:

1) Every species exhibits variations; not all members within a species are exactly the same. Individuals frequently exhibit variations in color, size, strength, etc. Some variations are subtle, others can be more extreme.

2) Many traits are passed from parents to their offspring; you can see how this happens just by looking in the mirror. You may have inherited your mother's eye color, or your father's height.

3) Life in the wild is competitive, and organisms with the most beneficial traits will prosper. This is commonly known as “survival of the fittest.” If an organism is born with traits that help it survive or attract mates, it will likely produce more offspring than rivals without those traits. Eventually, beneficial traits can spread throughout a species.

Once this short digital lesson was complete, the website prompted students to play “Who Wants to Live a Million Years?” See Appendix A for screen shots of the mini lesson and Appendix B for screenshots of the game. During the game students were asked to choose three possible variations of the lineage of creatures. During multiple generations, mutations arose that yielded different phenotypes. These random changes in phenotypes were later randomly exposed to one of the following events: 1) predation 2) disease 3) limited food resources 4) climate change. These

selective pressures were introduced into the game and influenced which creature survived based on the particular inherited traits. Students ran the simulation individually three times and were requested as part of the classroom assignment to make observations of which creatures were surviving the series of catastrophes As shown in Appendix B.

Traditional Concept Cartoon Group Description. The Traditional Concept Cartoon (TCC) group consisted of four biology classes with a total of 88 students. This group only worked with TCC interventions that were integrated into the evolution unit at each teacher's discretion and usually took 10 minutes for each TCC (Table 2). Each teacher was given the exact set of instructions on how to implement the use of the TCC. Sentence starters, which are an effective practice and writing scaffold used for ELL students (DelliCarpini, 2008), were used to modify the instructions for our ELL population (Appendix G). After the cartoon was passed out, each student was instructed to work individually and, as directed on paper, asked to circle the answer that they thought best answered the question. Then each student wrote why they decided the other choices were not the correct answer. Once the warm-up activity was collected, the teacher spent about five minutes discussing with the class and as a class indentified the correct response.

Photo-based Concept Cartoon Group Description. The Photo-based Concept Cartoon (PBCC) group consisted of four different biology classes and totaled 88 students. The cartoon activity was integrated into the evolution unit at the teachers' discretion. The penguin and flamingo PBCC followed the same TBCC procedural implementation. This group also received the sentence starters (Appendix H). Once the warm-up activity was collected, the teacher would discuss the cartoons with the class and indentify the correct response.

Qualitative data analysis

Student verbal responses from the interviews were transcribed for analysis to assess students' thoughts on population variation and the origin of variation. Students were scored on the scientific accuracy of their description and/or explanation by using a modified coding scheme from Gross (2011) as shown in Table 4. Each prompt response was given a score between -2 and +2 based on their scientific accuracy when elaborating on the population variation and the origin of variation. Students' understanding of natural selection was analyzed and their average interview score was compared to their overall CINS score.

Table 4

Coding Scheme used to provide the student with the overall interview score (modified from Gross, 2011).

Score	Descriptor	Verbatim Exemplars from Interviews in the study
-2	<p>Scientifically incorrect and justification does not support their concept (clear statement of alternative conception)</p> <p>or</p> <p>“ I don’t know”.</p>	<p>“The bird age or traits. If the bird has different traits.”</p> <p>“...they can tell because they know already. They communicate in the way they know. If you are not informed about them then you can’t tell. Only people who study flamingos can tell.”</p>
-1	<p>Minor scientific error in which students unscientifically describe their concept.</p> <p>Minor scientific error in which students scientifically describe their concept.</p> <p>(alternative conception)</p>	<p>“Depending on where they live they need to adapt or their beaks needs to change size according to what type of food there is for that finch...Whichever beak size or shape can fit what they need to eat in order to survive.”</p>
0	<p>Scientific without justification</p> <p>Scientific with justifications that are not aligned to topic or question posed.</p> <p>Scientifically w/ inaccurate (unclear) justification.</p>	<p>“A. The lizards needed to change in order to survive so new helpful traits formed.”... “Well I think again depending on where they live and their surroundings and what available sources there are for that specific species of lizards.”</p>
+1	<p>Scientifically correct, with few accurate justifications.</p>	<p>“ Individuals in a species can mutate some of these mutations can be linked to appearance.”</p>
+2	<p>Clear statement of scientifically accurate idea with details, evidence and/or examples.</p>	<p>“Well I think if they inherit a mutation or any like genetic disorder that can affect how long they live. Also predation um like that can affect their population and how long they can live”</p>

Results

Quantitative Analysis:

Pre-test and Post-test comparisons. The results in Table 5 indicate no difference in the overall CINS score when comparing the implementation of two different versions as a pre-test and two different versions for the post-test. As mentioned earlier, version A are questions 1-10 of the CINS and version B are questions 11-20 of the CINS. When given version A or version B as a pre-test there was no significant difference in the overall score ($p=0.29$); when students were given version A or version B as a post-test there was no significant difference in the overall scores ($p=0.061$). To review which groups were given version A or version B as pre or post-tests refer back to Figure 1. Each version tests the same natural selection principles. The higher p-value (>0.05) indicates that there is no statistical difference between these groups, and supports the use of Version A and B as being equivalent for assessment purposes.

Table 5

Pre-test and Post-test statistics comparing Version A and Version B within the general biology group

Version of CINS used	N	Mean	p-value
		(SD)	(two-tailed)
Version A Pre	295	4.19 (1.59)	0.29
Version B Pre	39	3.90 (1.93)	
Version A Post	39	4.87 (1.44)	0.061
Version B Post	295	4.29 (1.87)	

Pre-test and post-test comparisons among classes

The results in Table 6.1 show the CINS scores broken down by the type of class being taken by the students. Paired t-tests were done to determine if there were statistically significant differences between the pre and post-test scores for each group of students. These results indicate

that there is not a significant difference in the overall pre and post-test scores for the biology classes ($p=0.08$) and indicate that the student overall performance on the CINS did not increase after instruction. In addition these results also indicate a significant difference in the pre and post-test score for the medical biology classes ($p=0.001$) and indicate that the student overall performance on the CINS increased after instruction. The AP Biology class followed a different pacing guide and therefore the study was only able to capture student’s understanding after the lesson. The AP Biology classes’ mean overall score was higher compared to the general biology and medical biology classes (Table 6.1).

Table 6.1
Descriptive Data for Each Treatment

Type of Class	N	CINS Mean		CINS Mean		p-value (two-tailed)
		Pretest (SD)	Pre-test Range	Posttest (SD)	Post-test Range	
General Biology	334	4.15 (1.63)	0-8	4.35 (1.83)	0-9	0.136
Medical Biology	46	3.65 (1.53)	1-7	4.52 (1.38)	2-8	0.005
AP Biology	68	NA	NA	6.82 (1.81)	2-10	NA

The results in table 6.2 show that there is a statistically significant difference in the pre-test CINS scores of the Medical Biology and Biology classes prior to the evolution unit. There is no pre-test comparison between the Biology & AP Biology and Medical Biology & AP Biology due to research timeline limitations resulting in the AP class not taking the pre-test. These results further indicate that there is no statistically significant difference between the overall CINS post-test scores between the medical biology and biology class. However, there is a statistically significant difference in the overall CINS post-test score between the medical biology and AP biology classes, with the AP class scoring the highest mean in both cases.

Table 6.2

T-test results for pair-wise comparison of overall CINS pre-test and post-test scores for three types of classes

Pre				Post		
Type of Class	General Biology	Medical Biology	AP Biology	General Biology	Medical Biology	AP Biology
Bio			NA			<0.05
AP Bio		NA			<0.05	
Med Bio	0.05			0.56		

Observed Improvement for each classroom intervention

Each type of class addresses the California State Standards to different extents. The medical biology class focuses on the biotechnology aspects of evolution, the AP biology class focuses on evolution, cellular processes, energy & communication, genetics & information transfer, and biological interactions. The majority of the students in the study were biology students.

Throughout the year these biology students learn the basic of cells, cell structure, genes, protein synthesis, genetics, evolution, and physiology. After examining the two CINS questions pertaining to the population variation and the origin of variation it is possible to determine whether students made progress on these ideas.

The data presented in Figure 2 reflects Biology student responses that were given version A as a pre-test and version B for the post-test. The control group represents classes that did not experience a teaching intervention. These results indicate an improvement in students' understanding on two particular CINS questions: one addressing variation within a population and another addressing the origin of variation. The percent improvement is the improvement seen between the pre-test and post-test score for each topic. For the topic of variation, there was a 30% improvement in PBCC group compared to the TCC group (27%), a 28% improvement in the animation activity and a 22% improvement in the control group. However, there was a less of an

improvement seen in the topic of origin of variation throughout the treatments. When looking at the origin of variation responses, there was the greatest improvement in the control group (32%) followed by the animation activity with a 27% improvement and the Photo-based Concept Cartoon group (26%), and then the traditional concept cartoon (22%) group.

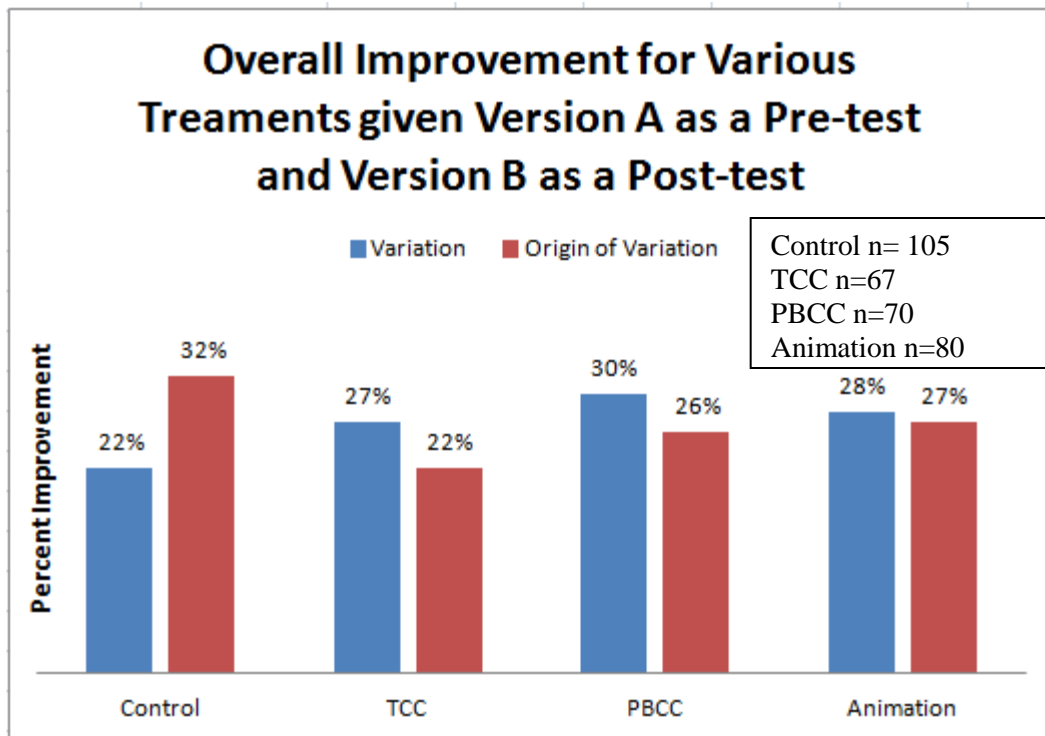


Figure 2. Improvement of General Biology student performance on CINS items pertaining to the understanding of variation within a population and origin of variation- Version B post-test.

The data shown in Figure 3 reflects responses for students who took version B as a pre-test and version A for the post-test. A total of two biology classes were part of this group; one class worked with the TCC and a second one worked with the PBCC. The TCC group had a decline in performance (-21%) for the variation question and no change in performance (0%) for the origin of variation question. The second class worked with the PBCC and they also had a decline in performance when answering the variation question (-27%) as well as origin of variation (-23%). The difference in results between Figures 2 and 3 were perplexing since the items on Versions A and B were designed to assess the same concepts, and there were no statistically significant differences

between student pre-test scores on Version A and Version B as reported earlier in this study. This prompted further analysis of the patterns of answers chosen by students on both pre- and post-tests.

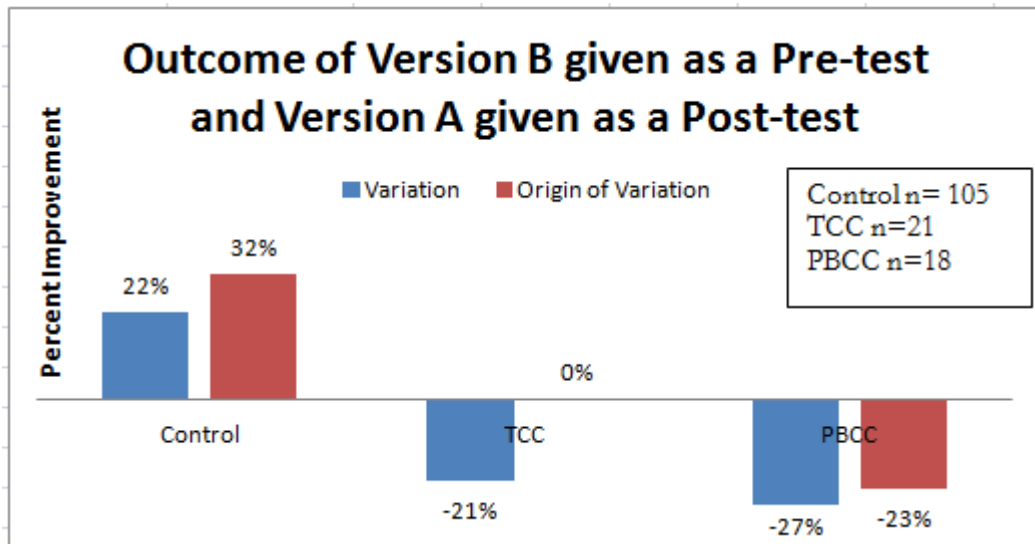


Figure 3. Improvement of General Biology student performance on CINS items pertaining to students' understanding of variation within a population and origin of variation- Version A post-test.

Table 7.1 below organizes the questions pertaining to one of the topics of interest: *variation in a population* and the *origin of variation*. Version A and Version B questions are not exactly the same, but address the same topic. Table 7.1 and Table 7.2 lists the possible answer choices for each question and the correct answer has been marked by an asterisk.

Table 7.1

Wording of each CINS question pertaining to the research study- Topic of variation in a population.

Topic: Variation in a population	Question	Answer Choices
Version A	A population of finches has hundreds of birds of a single species. Which sentence best describes the group of finches?	A= no difference
		B= important shared traits, differences do not affect reproduction
		C = external differences only
		*D = important shared traits, but important differences that may affect reproduction
Version B	A population of lizards is made up of hundreds of individuals. How similar are they to other lizards in the population?	A= no difference
		B= internal differences only
		C = external differences only
		*D = many similarities, but important differences

In the series of pie charts that follow, data is provided to show the patterns in student answer choices on the two versions, first for *the variation in a population* questions, and then for the *origin of variation* questions, in an effort to provide an explanation for the difference in student performance seen in Figures 2 and 3. All of these results are for students in general biology classes. The results in Figure 4 indicate that the students within this Traditional Concept Cartoon Group initially were attracted to three of the distractors in the pre-test. This overwhelmingly changed in the post-test where 70% of the students selected the correct response “*all lizards share many similarities, but have some important differences in their traits*” as shown in Figure 4, part b. The “*External differences...*” answer was still a viable distractor for some and only a few selected “*internal differences not affecting reproduction*” and “*no difference*” answer choices. When the versions of the test were switched—Version B given as pretest and A as post-test—the results changed. Figure 5 indicates that 81 % of the students within the cartoon group (a) chose the accurate answer in the pre-test as compared to their

post-test where 60% (b) of students answered this question accurately; a similar, but reversed, pattern is seen when version B is taken as a post-test (Figure 4).

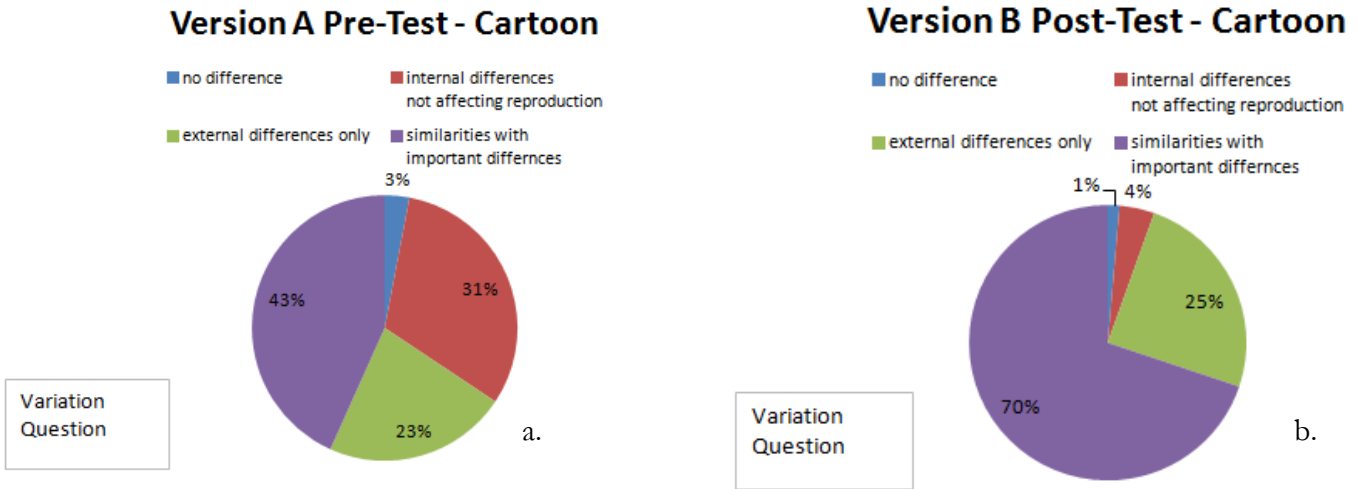


Figure 4. Traditional Concept Cartoon group (A) - Students’ pre and post responses pertaining to variation in a population. *Similarities with important differences* the scientifically accurate response.

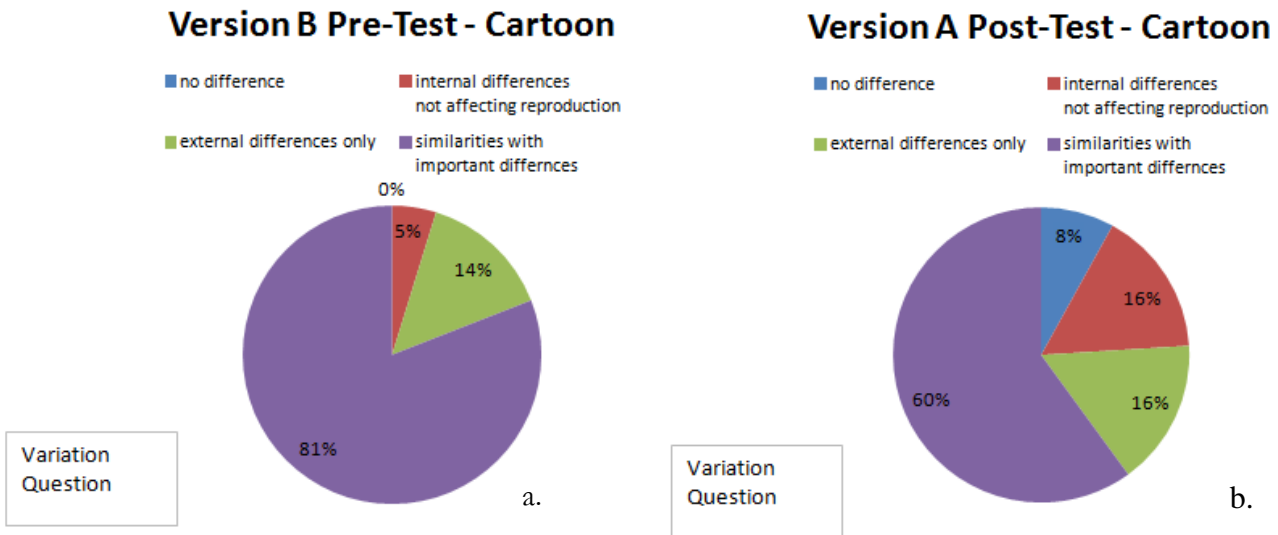


Figure 5. Traditional Concept Cartoon group (B)- Students’ pre and post responses pertaining to variation in a population. This subset of students took version B as a pre-test and version A as their posttest. This group will be noted as (B). “*Similarities with important differences*” is the scientifically accurate response

Figures 6 and 7 show the results of the Photo-based Concept Cartoon groups. As seen in Figure 6, version A as the pre-test and version B as the posttest the results indicate that the students

are initially distracted by all possible answer choices (6a) and later the majority (6b) selected the correct response *all lizards share many similarities, but have some important differences in their traits*. Once again, many students continued to be distracted by the alternative conception of *all lizards are the same on the inside, but have differences in their external traits* when answering the question pertaining to population variation. When the test versions are switched, Figure 7 indicates that students are choosing the correct answer at a higher rate when given version B as the pre-test: 56% pre-test and 28% their post-test. In the post-test, many students were attracted to two distractors. Forty-eight percent selected the answer describing external differences and 24% selected the answer describing internal differences not affecting reproduction.

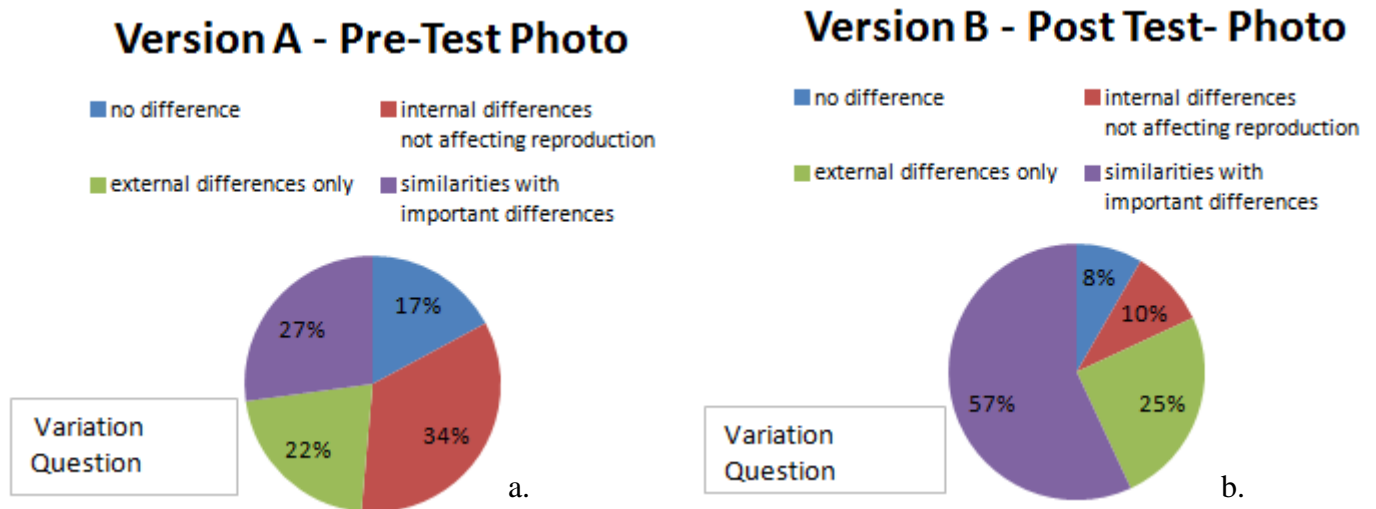
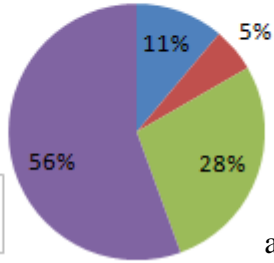


Figure 6. Photo-based Concept Cartoon group (A)- Biology students' pre and post responses pertaining to variation in a population. "Similarities with important differences" is the scientifically accurate response

Version B Pre-test- Photo

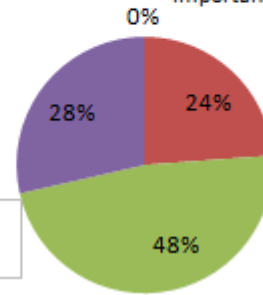
■ no difference
■ internal differences not affecting reproduction
■ external differences only
■ similarities with important differences



a.

Version A - Post-Test - Photo

■ no difference
■ internal differences not affecting reproduction
■ external differences only
■ similarities with important differences



b.

Figure 7. Photo-based Concept Cartoon group (B) – Biology students’ pre and post responses pertaining to population variation. “*Similarities with important differences*” is the scientifically accurate response

Figure 8 displays the results from the animation intervention, and indicates that more students (68 %) accurately answer the variation in a population post-test question compared to the 40% seen on their pre-test. Students are not selecting the *no difference* option indicating that students are no longer distracted by this answer choice. There is a decrease (27%) in the selection of the alternative conception *internal differences not affecting reproduction*, yet *external differences* still remained as an alternative conception.

Figure 9 displays the results from the control group and indicates an increase in accurate student responses when comparing their pre and post answer choices. Students’ selection of the alternative conception, *internal differences not affecting reproduction* drastically decreases in their posttest. This is a difference of 32%.

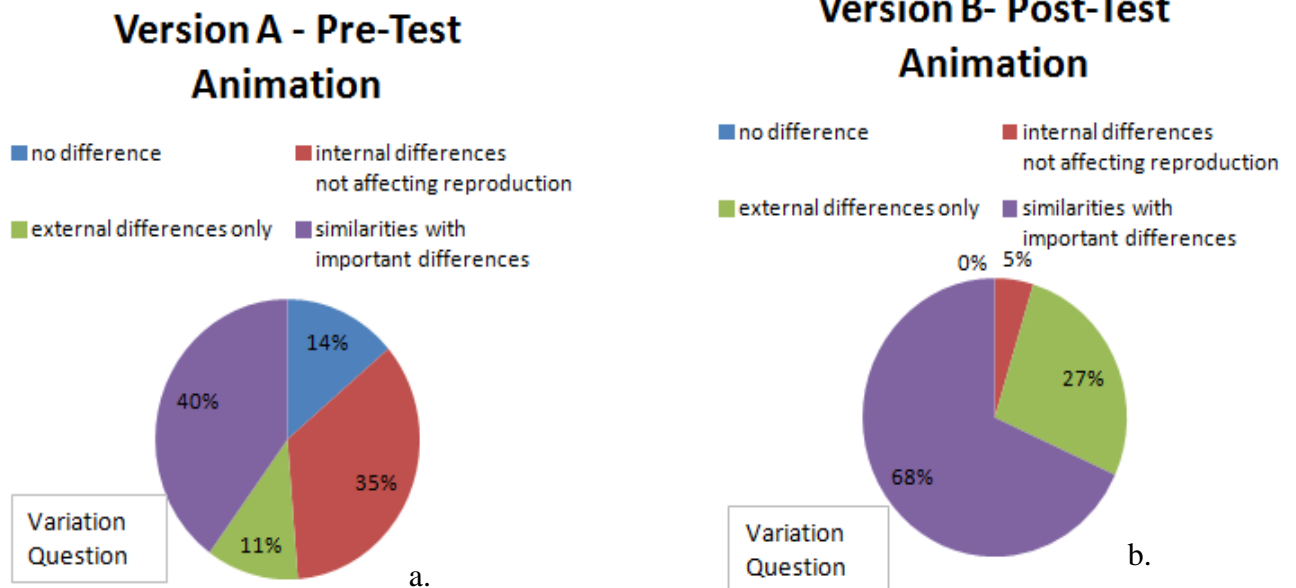


Figure 8. Animation group – Biology students’ pre and posttest responses pertaining to population variation. “Similarities with important differences” is the scientifically accurate response

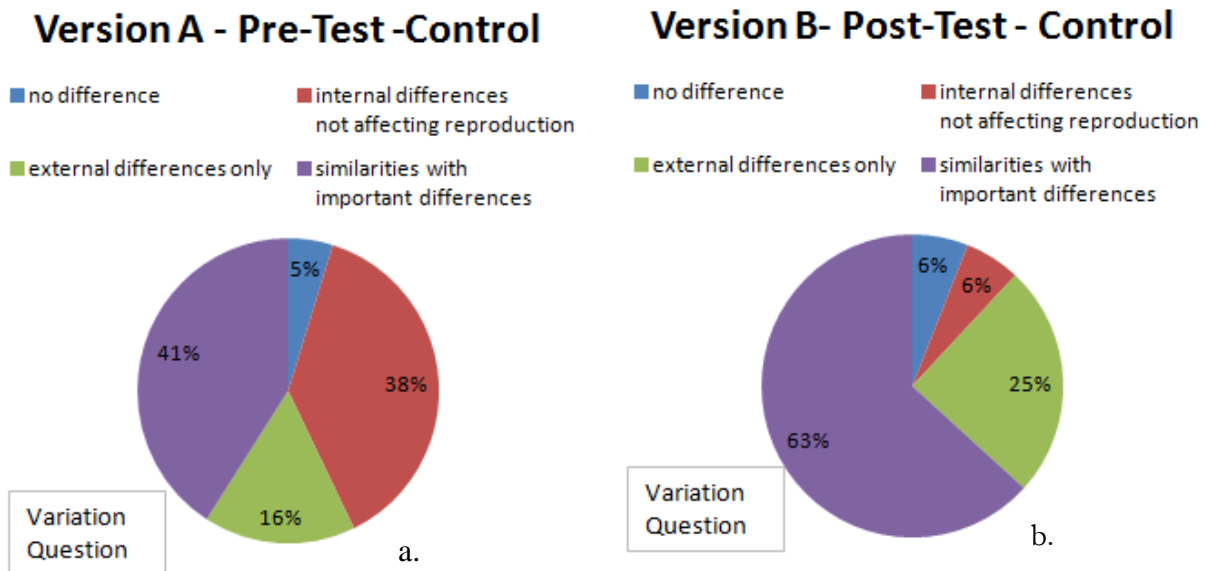


Figure 9. Control group- Students’ pre and posttest responses pertaining to population variation.

The charts (Figure 4 -9) are General Biology students’ responses to the *variation in a population* question (Table 7.1). When comparing all the Version B pie charts for this question, the patterns are similar. When comparing the entire set of Version A pie charts, students predominately chose “internal differences not affecting reproduction”. In the next series of pie charts (Figure 10-15)

diagrams a comparison of students' responses to the question regarding the *origin of variation*. See Table 7.2 for the wording of the question for Version A and Version B.

Table 7.2

Wording of each CINS question pertaining to the research study- Topic on origin of variation.

Topic: Origin of Variation	Question	Answer Choices
Version A	How did the different types of beaks first appear in in the finches?	A= need based
		*B= random changes
		C = environmental influence
		D = gradual change
Version B	Where did the variation in the body size of the three species probably first come from?	A = need based
		*B= random changes
		C = environmental influence
		D = want and gradual change

For the cartoon group, the results in Figure 10 (Version A as pre-test) indicate that most of the students (51%) had a prior alternative conception that variation arises on a need basis.

However, the posttest results as seen in Figure10b indicate that some of these students (38%) were able to accurately select the correct answer for the origin of variation from the answer choices.

However, the need based alternative conception was still a viable distractor, even after instruction.

Figure 11 represents students' responses that belonged to a subset of students given version B as their Pre-test and version A as their posttest. These results indicate that students continue to hold their prior alternative conceptions on the origin of variation (19% chose the scientific answer before and after the intervention).

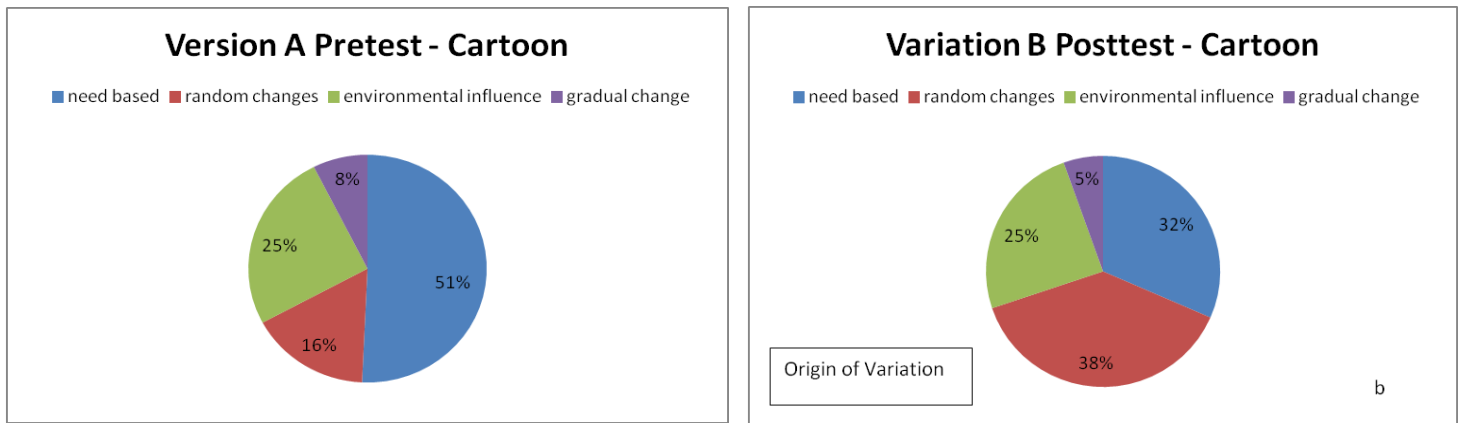


Figure 10. Traditional Concept Cartoon Biology students' pre and posttest responses pertaining to origin of variation. "Random changes" is the scientifically accurate response.

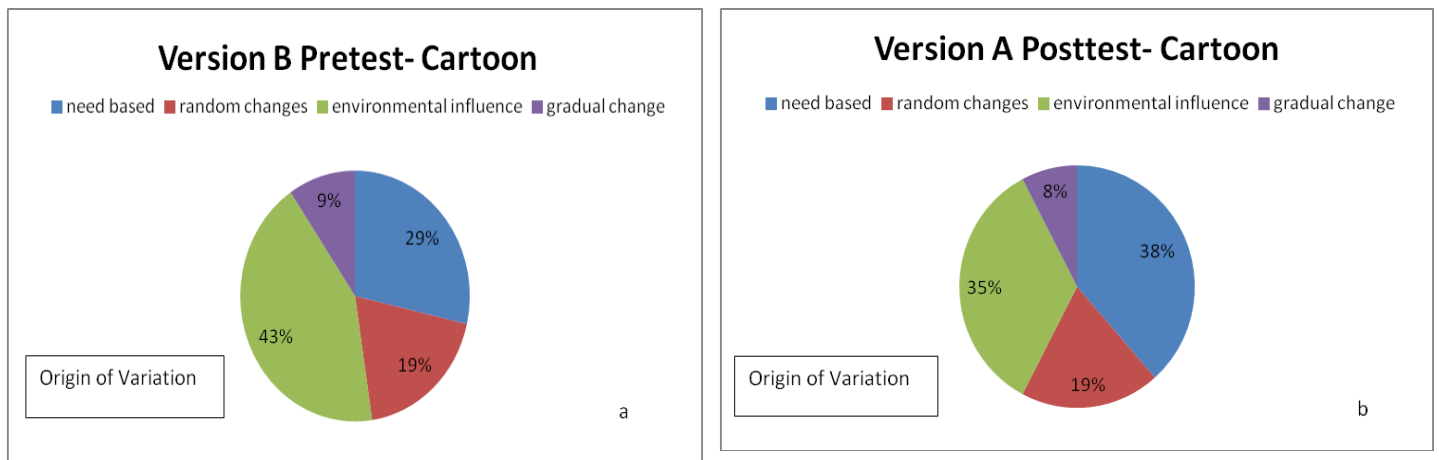


Figure 11. Traditional Concept Cartoon Biology students' pre and posttest responses pertaining to the origin of variation. "Random changes" is the scientifically accurate response.

For the photo group, the results in Figure 12 (Version A as pre-test) indicate that many students who held the prior alternative conception of variation being introduced gradually over time (12a) shifted to either environmental influences or random changes as ways that variation is introduced (12b).

With Version B as the pre-test (Figure 13) many students (47%) held the prior alternative conception that the environment influenced the origin of variation (Fig. 13a). The correct scientific

explanation of random changes was not selected by the majority of the students during the posttest (14%) rather, the need based alternative conception (52%) had a stronger appeal to these students (Fig 13b).

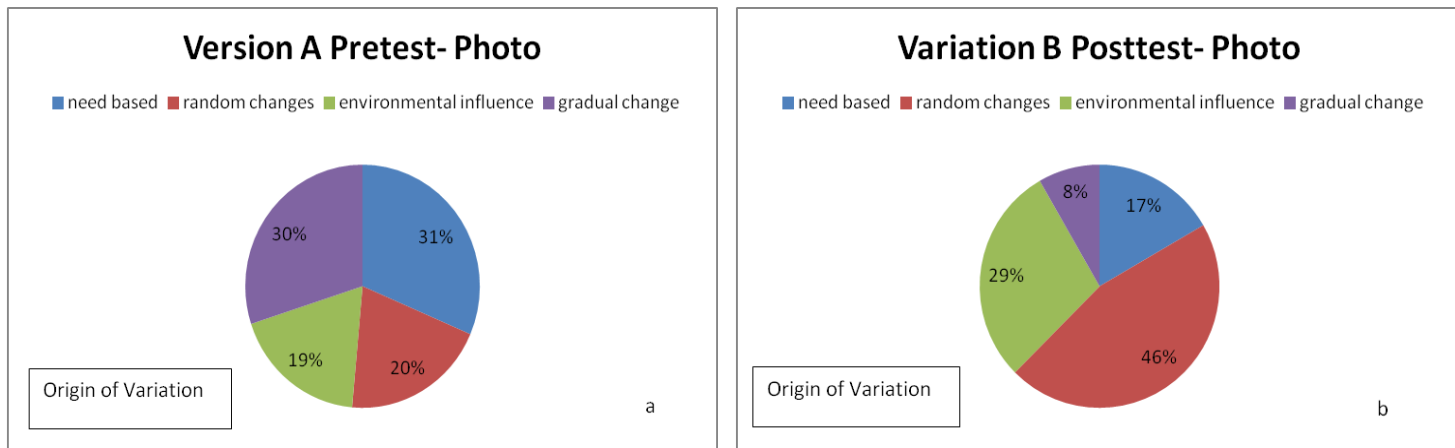


Figure 12. Photo-based Concept Cartoon - Biology students' pre and posttest responses pertaining to the origin of variation. "Random changes" is the scientifically accurate response.

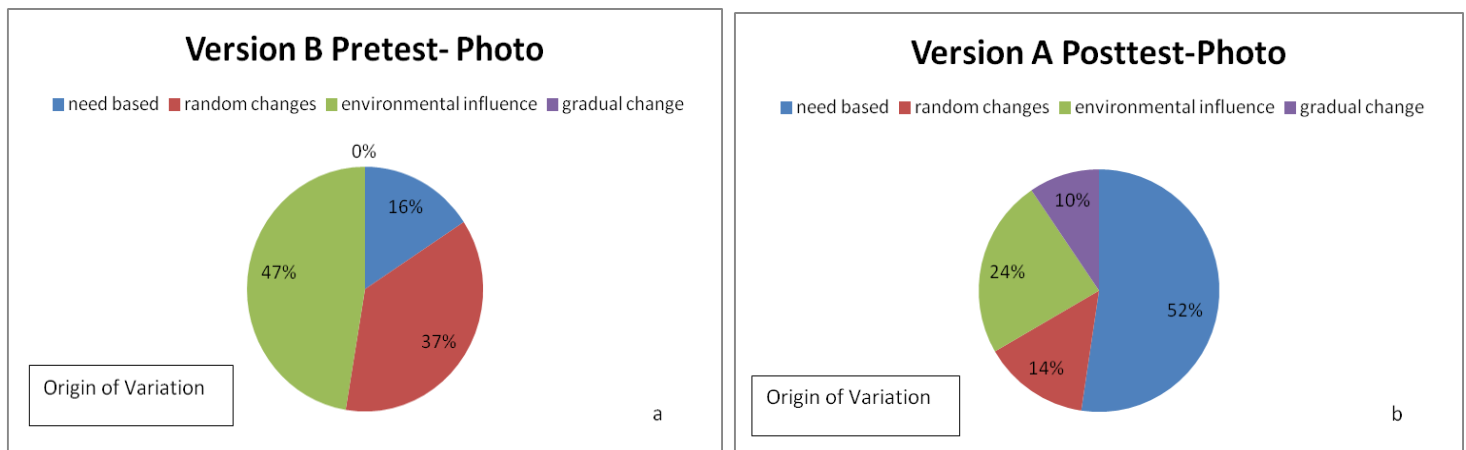


Figure 13. Photo-based Concept Cartoon Biology students' pre and posttest responses pertaining to the origin of variation. "Random changes" is the scientifically accurate response

For the animation group (Figure 14) the results indicate that most students (53%) had an initial alternative conception that variation resulted from a need. After instruction, students that were part of the PBCC mostly selected two answers. Thirty-five percent selected the alternative

conception that the environment caused changes in the DNA and therefore the origin of variation. Forty-seven percent selected the scientifically accurate concept that random change in DNA is an origin of variation. For the control group, the results in Figure 15 indicate that the majority of students had an alternative conception that variation in the population originated based on need (52%). After the unit, students strongly gravitated toward three of the four choices: 37% selected the scientifically accurate conception that variation originates from random changes in DNA, 42% had an alternative conceptions that the environment was the origin of variation, while 20% continued to gravitate toward the need based alternative conception.

Within the TCC group (Figure 10 and 11), there is a similar response pattern in both pre and post-test scores. Within the PBCC, version B had a similar response pattern with a higher percent of students selecting “random changes” followed by “environmental influences”, and third “need based” being selected the least.

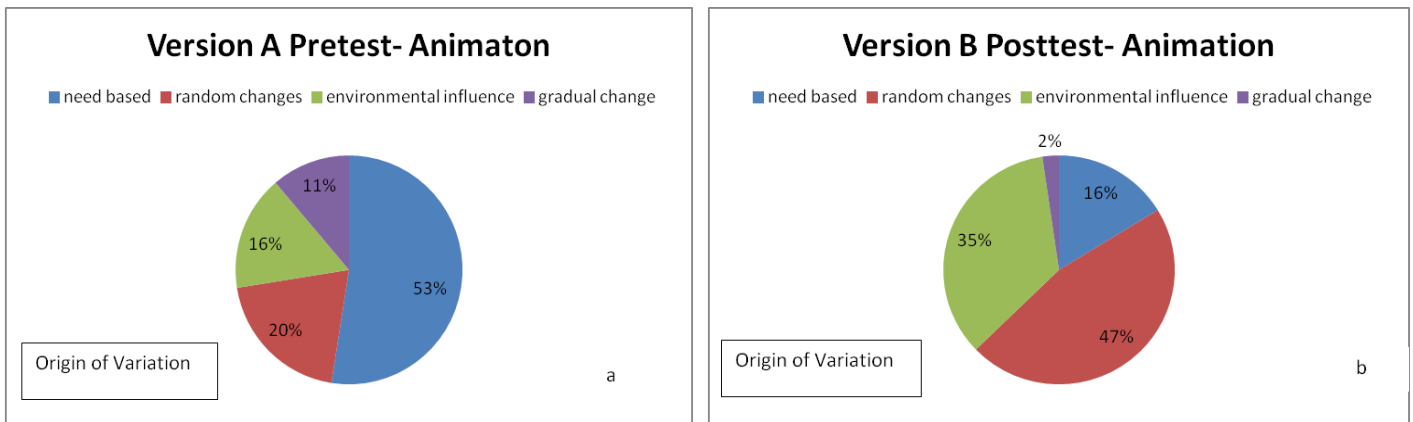


Figure 14. Animation Biology students’ pre and posttest responses pertaining to the origin of variation. “Random changes” is the scientifically accurate response

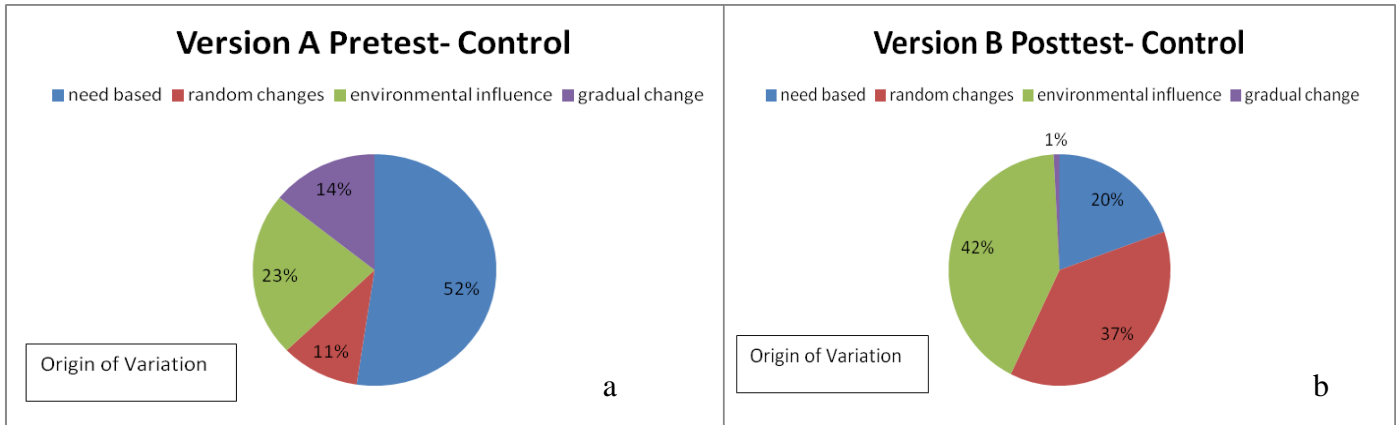


Figure 15. Control students' pre and posttest responses pertaining to the origin of variation.

Qualitative Analysis of Student Interviews

Audio recorded interviews for each student were transcribed. Pre-interviews took place prior to the evolution unit and post-interviews took place after the evolution unit and after the students' spring break. Students completing interviews took the CINS just after the first interview and before the second interview. The goal of my research question was to better understand students' conceptions of natural selection with a specific focus on the concepts of population variation and origin of variation. During the interview students were given three tasks, each task was scored using the rubric in Table 3. This coding scheme rubric was modified from Gross, 2011 and contains sample quotes from data collected during this research project. Each task was scored individually and then an overall score was given to each student. Pseudonyms were used for anonymity purposes.

Table 8.1

Overview of student pre- and post-instruction interviews in relation to the concepts of variation in a population and origin of variation. Green indicates improvement; orange indicates a decline in understanding.

Interview Subject	Variation in a population		Origin of Variation	
	Pre	Post	Pre	Post
Valerie	-1	0	-1	1
Harry	-1	-1	-1	-1
Monica	0	-1	-1	-1
Daisy	-1	1	-1	-1
Alfredo	2	2	2	2
Esteban	1	2	-1	0

The results in Table 8.1 indicate that some change occurred in students' understanding of natural selection in relation to population variation, but not as much for origin of variation. Valerie, Esteban, and Daisy all demonstrated a better understanding of natural selection as seen in by their interview scores, with all three students showing improvement on *variation in a population*, and Valerie and Esteban showing improvement on their *origin of variation* part of the interview. Harry, Monica, Daisy, and Alfredo maintained their understanding of the *origin of variation*.

Part of the analysis consisted of comparing each student's interview score with their overall CINS performance. The CINS post-test mean score for the General Biology group was 4.31 out of 10 (SD=1.83) (Table 6.1), and was used to determine the high score range of 4-10 and low score range of 0-4 for the CINS. The California Standardized Testing Proficiency bands were used to determine what was Basic understanding of scientific concepts (California Department of Education, 2011, p131).

Table 8.2

Overview of student post-interview score on “variation in a population” and post-CINS score

		Post-CINS Overall Score	
		Low (0-4)	Basic and Higher (5-10)
Post-Interview Score for the Variation	2		Alfredo (7/10) Esteban (7/10)
	1		Daisy (6/10)
	0		Valerie (5/10)
	-1		Monica (5/10)
	-2		

These results (Table 8.2) indicate that the interviewed students participating in the post-CINS test scored basic or higher on the CINS as compared to other non-interviewed general biology students, who had a post-test mean score of 4.35 (SD =1.83). One student, Harry was absent on the day the post-test was taken and does not have a post-test CINS score. The data show that two of the interviewed students continued to have alternative conceptions regarding *variation in the population*. Many students, like Valerie, linked accurate genetics concepts and evolution concepts to substantiate their alternative conceptions. In the example below Valerie is distracted with the phrase *same on the inside* in the answer choices, yet links different phenotypes to random changes in DNA for the following question:

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

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

I: Can you describe examples of some parts on the inside?

S: They all have a heart, they all have a stomach, they have blood, they have cells, meat that's all I have

I: Can you explain the differences between the long and short tail, why would they have those differences?

S: Probably some of them might be grown with small tail and another would be large, it just happens at random changes in the DNA. (sic)

I: Changes in the DNA, do all changes in the DNA lead to variation in their appearance you think?

S: Umm yes

I: Okay. So these changes in the DNA when do you think they happen?

S: I believe it's just random. Or when you were born sometimes or just random

I: Is there a relationship between the random changes in DNA you mentioned and differences in appearance?

S: Yeah I do believe because the differences in their parents all have to do with the changes in the DNA which is random.

I: What makes it random?

S: It's random like you don't expect it to happen in life like you don't expect it to um like you were just random like its random it comes out of nowhere throughout the process of them growing...development.

Table 8.3

Overview of student post-interview on "origin of variation" score and post-CINS score

		Post-CINS Overall Score	
		Low (0-4)	Basic or Higher (4-10)
Post-Interview Score for the Origin of Variation	2		Alfredo (7/10)
	1		Valerie (5/10)
	0		Esteban (7/10)
	-1		Monica (5/10) Daisy (6/10)
	-2		

These results indicate all of the interviewee students scored relatively basic or higher on the post-test, however, Esteban, Monica, and Daisy continued to maintain a strong hold on their alternative conceptions pertaining to the origin of variation as evidenced by their post-interview score (Table 8.3). A common alternative conception was the role the environment played in introducing variation as seen in Esteban's transcript below. Esteban received a 0 for his interview score since he identified a non-scientific alternative conception (environment causes the genetic changes), yet he connected the idea that mutations may cause changes in phenotype.

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.

I: How can the environment cause changes in the lizard's DNA?

S: Umm, like by their surroundings... how their environment was, could have caused DNA in the lizards change and could have just caused certain changes in the DNA of the lizards.

I: What would those changes cause?

S: Just variation throughout the lizards.

I: Can you give me an example of an environmental factor that can do that, that can change the DNA?

S: I think that the color of their surroundings, weather, and the type of food they were eating.

I: How do you think the weather or food causes the change in the DNA?

S: I think it just caused some changes in the DNA like helped the lizards like be better adapted to the environment around them...I don't think they have to be in a certain area for them for the changes to happen. I think it could be any part depending on where they live like that can cause changes in the DNA of the lizards.

Student interviews were valuable because they shed some light on areas that teachers can focus on in future lessons. Students had some level of understanding that variation in a population exists. However, there is a mixed understanding of the origin of variation. As seen across the biology department and through interviewees, students see the environment as playing a very important role in the origin of variation and an understanding that if the organisms needs to change, they will.

Conclusion

Research questions

This mixed methods research project aimed to answer the following questions:

1) *What are students' conceptual understanding of evolution, in particular what are they identifying as variation in a given population and as sources of genetic variation?*

2) *How does the use of Traditional Concept Cartoons, Photo-based Concept Cartoons, and animations impact students' understanding of genetic variation in a population using CINS as a quantitative measure?*

To address research question one, it appears that students continue to have strong alternative conceptions of both *variation in the population* and the *origin of variation*. As evident in Figure 2, most students were able to choose the accurate scientific answer when asked to describe the *variation in a population* and in identifying the *origin of variation* (Figure 2). There was improvement in their understanding of *origin of variation*; however the control group had greater improvement compared to the teaching TCC, PBCC, and animation interventions (Figure 2). Many students were distracted by the alternative conceptions and unclear about the role the environment plays in natural selection (Figures 10-15). Most of the students interviewed maintained their level of understanding on the *origin of variation*. Esteban's post-test interview response could have reflected general biology students' understanding of the role the environment has on the *origin of variation*, but we do not know for sure since we did not follow every general biology student in the study.

To address research question two, classroom interventions were integrated into the lesson to determine if they have an impact on students' understanding of population variation and genetic variation. We examined two CINS questions pertaining to *variation in a population* and examined the answers students were selecting. The following analysis examined biology students who took version A as a pre-test and version B as a post-test. When comparing the pre-test responses of the

variation in a population question of all groups (TCC, PBCC, animation) students were initially attracted to one of the following choices: *similarities with important traits*, internal differences not affecting reproduction, and external differences only. In the pre-test the majority of the students selected the correct answer: 70% of the TCC, 57% of the PBCC, 67% of the animation group, and 63% of the control group selected the correct answer.

These conceptions shifted after the classroom intervention. In all groups, roughly 25% of the students selected *external differences only* or verbatim from CINS: “*All lizards are the same on the inside, but have differences in their external traits*” (Appendix N). Valerie elaborated on her understanding of this selection by mentioning that all these organisms “have a heart, they all have a stomach, they have blood, they have cells, meat ...”. This suggests that some students are not making the connection between variation in a population and how some variations may affect reproduction for some individuals in the population. Some students may not be connecting the importance of genetic variation and its role on reproductive success.

When comparing the responses to the *origin of variation* question for all treatment groups (Control, TCC, PBCC, and Animation), most students were initially attracted to the *need based* answer choices (Figure 10, 12, 14, and 15). After the evolution unit and class intervention activities, most students were attracted to other answer choices. In all intervention groups, the majority of students selected the accurate response on the post-test, “*Random changes in the DNA created new traits*”: 38% of the TCC group, 46% of the PBCC group, 47% of the animation group, and 37% of the control group.

Those students in the PBCC group, animation group, and control group who did not select the accurate response select the following answer choice: “*The environment of the island caused certain changes in the DNA of the lizards*”; 29% of the photo cartoon, 35% of the animation group, and 42% of the control group selected the environmental answer. The group with the highest accurate

response was the PBCC group. Esteban elaborated on this response during his interview. He mentioned that “how their [lizards’] environment was, could have caused DNA in the lizards change and could have just caused certain changes in the DNA of the lizards.” He went on to suggest that the color of the lizards’ environment can change its DNA, the food it consumes, all alter the DNA. These results suggest that teachers expand on phenotypic plasticity and describe how certain animals, like lizards, appear to change color, but not because of DNA alterations or mutations, rather due to chromatophores underneath their skin in response to stress levels, body temperature, etc. Because students seem to want to explain changes within individuals, it might be helpful for teachers to introduce phenotypic plasticity to students to help them distinguish between changes within an individual and changes among a population. Students in the cartoon group who did not select the accurate response, (32%) selected the following answer choice: *The lizards needed to change in order to survive, so new helpful traits formed.*

Overall students may have been distracted by the words in the answer choices. The similarity in the pattern seen in Version B for the topic on population variation, lends me to think that the way answer choice D is written may attract students regardless of when the evolution lesson was implemented (Figure. 4 and 5, & Figure 6 and 7). To make the answer choices more parallel, I suggest changing the wording so the answer choice incorporates reproductive success like that seen in Version A. The new answer choice for D can say: “*All lizards share many similarities, but have some important differences in their traits that may affect how well they reproduce or how long they live*”. For the question about the *origin of variation*, the C answer choice (environmental influence) was the most selected distractor for this question. I recommend changing version B’s answer choice to include *beneficial changes* as it does in Version A. (Change B from, “*The environment of the island caused certain changes in the DNA of lizards*” to “*The environment caused beneficial changes in the lizards’ DNA.*”)

Based on the data, it is evidence that all interventions had a positive impact in students' understanding of *variation within a population*; however students continued to hold strong alternative conceptions for the *origin of variation* (Figures 10-15). In order of effectiveness the following teaching interventions helped students understand the topic of *variation in a population*: Traditional Concept Cartoon, animation, control, and Photo-based Concept Cartoons. In order of effectiveness the following teaching interventions helped students understand the topic of *origin of variation*: animation, Photo-based Concept Cartoon; the control, and Traditional Concept Cartoon had the same effectiveness for this question. I would recommend that while integrating these two activities, teachers can expand on topics like color changing chameleons and lizards that may affect students' understanding of *variation in a population* and *origin of variation* in a given population.

In addition, when comparing both Version A and Version B post-test results there was no significant difference ($p=0.061$; Table 5). However, when we viewed the results for the two particular questions in my research study, *variation in a population* and *origin of variation*, there was a difference in performance (Figure 2 & 3). Table 9 below compares the distribution of student post-intervention responses for both Version A and Version B. We can notice that there is a 21% difference in the correct response for the *variation in a population* question. This is much higher than the 6% difference seen in equally written question pertaining to *gradual change in the population* seen in Table 10. Further research that may impact student performance on the CINS is outlined in Table 11; this table provides the current wording and the suggested wording for further research.

Table 9.

Post-test answer distribution of non-equally written questions. This question pertains to variation in a population. The asterisk identifies the correct response.

	Post Question- Version A	Post Question- Version B	Difference
Question:	A population of finches has hundreds of birds of a single species. Which sentence best describes the group of finches?	A population of lizards is made up of hundreds of individuals. How similar are they to other lizards in the population?	
Answer:	D. The finches share all of the most important traits, but also have differences that may affect how well they reproduce or how long they live.	D. All lizards share many similarities, but have some important differences in their traits.	
A	7%	4%	3%
B	26%	7%	19%
C	24%	26%	2%
*D	43%	64%	21%

Table 10.

Post-test distribution of equally written questions. This question pertains to gradual changes in a population. The asterisk identifies the correct response.

	Post Question- Version A	Post Question- Version B	Difference
Question:	What is the best way to describe the evolutionary changes that happen in the guppy population over time?	What is the best way to describe the evolutionary changes that happen in the lizard population over time?	
Answer:	B. Guppies with certain traits reproduce and become more common	B. Lizards with certain traits reproduce and become more common	
A	19%	21%	2%
*B	32%	26%	6%
C	15%	15%	0%
D	34%	38%	4%

Table 11.

Suggested wording for CINS Version B for variation in a population and origin of variation answer choices.

<i>Variation in a population Question</i>		Current Wording of the Correct Answer	Suggested Wording of the Correct Answer
Version A	A population of finches has hundreds of birds of a single species. Which sentence best describes the group of finches?	D. The finches share all of the most important traits, but also have differences that may affect how well they reproduce or how long they live.	Same wording
Version B	A population of lizards is made up of hundreds of individuals. How similar are they to other lizards in the population?	D. All lizards share many similarities, but have some important differences in their traits.	D. All lizards share many similarities, but have some important differences in their traits <u>that may affect how well they reproduce or how long they live</u>
<i>Origin of Variation Question</i>		Current Wording of the Correct Answer	Suggested Wording of the Correct Answer
Version A	How did the different types of beaks <u>first appear</u> in the finches?	B. Changes in the beaks of the birds happened because the environment caused beneficial changes in the DNA.	Same wording
Version B	Where did the variation in body size of the three species probably <u>first</u> come from?	B. The environment of the island caused certain changes in the DNA of the lizards.	B. The environment of the island caused beneficial changes in the lizards' DNA.

Limitations

There are three limitations of this study. First, the study was limited to six student interviews. Students vary in how they connect certain genetic and evolution concepts to make meaning of new content, and this small sample size could not possibly represent all students well. Second, although the goal was not to identify retention of evolution topics over time, the two week break between March 20th – April 7th, 2014 may have influenced student interview responses and interview scores. Lastly, I only focused only on two topics of evolution. Evolution is a complex topic and for many students it is an abstract concept that takes longer than five weeks to understand. The responses in their post-test overall scores may reflect a transitional understanding of evolution for these students, and negotiating through the answers may have been difficult for many as some were not ready to let go of their alternative conceptions.

Implications for teachers

When comparing classes, as expected we see that the AP biology students have a higher mean overall post-test score (6.81) compared to that of the General Biology (4.31) and Medical Biology classes (4.44) (Table 5.1). AP Biology students have had one year of biology content prior to taking AP Biology class, yet for the other two groups, this is their first biology course. In addition, the rigor and depth of AP Biology is similar to what college level students experience and most likely attributed to the higher mean scores observed in this research. The CINS helps teachers identify alternative conceptions when it comes to teaching these topics and can help tailor appropriate lessons and activities to help students better understand genetic variation and its role in natural selection. In all interventions, most students selected one of the following answer choices to describe how variation first arises in a population: *environmental influence*, *need based*, and *random changes* (Figure 10-15). Classroom discussions around the alternative conceptions could aid students' understanding of how variation arises in the population. Emphasis on the origin of variation may

vary slightly in each class due to different teaching approaches. In addition the emphasis of evolution and natural selection differs in each class which is also reflected in their overall CINS scores (Table 5.1). In Medical Biology, there is a focus of natural selection in terms of bacteria and antibiotic resistance. In General Biology, an emphasis is placed on the various types of selection and population variation. In AP biology, students focus on population genetics and Hardy Weinberg Equilibrium in addition to other higher-level concepts. AP teachers can use the CINS to better gauge students' understanding of natural selection.

In addition, after talking to some of the teachers, they stated that they would like to incorporate the Photo-based Concept Cartoons and animation into their classrooms as a think-pair-share activity. In this activity students think about their answer, then discuss their response with their partner, and then share out their response with the class. Teachers mentioned that they would incorporate the animation with additional teacher scaffolds and guidance.

Contribution to science education

When comparing the results seen in Figure 2 to Figure 3, it is evident that Version B answer choices seem to influence students' selection in unintended ways. I recommend that a future study examine the answer choices in more detail and identify key terms within the answer choice that lead students to make a particular selection. Students given version B as their pre-test and version A as their post-test had no improvement in the scores addressing the topics of *variation in a population* and *origin of variation*. It is unknown whether this is due to the differences between the question pairs on Versions A and B or if it accurately reflects differences in student understanding.

Interviews are a good assessment tool for student learning. In a high school setting, it is not feasible for one teacher to conduct 150 student interviews, however the use of CINS to determine students' conceptions is an appropriate tool to use in a high school setting. This study also brings

to light that all classroom interventions had a positive impact in students' learning. The use of these classroom interventions, are highly recommended for in-class activities, online tutorials, or after school tutoring, and this study sets the stage for further work on refining both assessments and interventions to be used in teaching students the topic of natural selection.

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Appendix A: Natural Selection Mini Digital Lesson Prior to “Who wants to live 1million years?” activity Retrieved from <http://www.sciencechannel.com/games-and-interactives/charles-darwin-game.htm>

INTRO **NATURAL SELECTION** SURVIVAL GAME QUIZ DARWIN'S BIO GLOSSARY

Part 1: Every species exhibits variations.



Not all members within a species are exactly the same. Individuals frequently exhibit variations in color, size, strength, etc. Some variations are subtle, others can be more extreme.



GO TO NEXT PART!

INTRO **NATURAL SELECTION** SURVIVAL GAME QUIZ DARWIN'S BIO GLOSSARY

Part 2: Many traits are passed from parents to their offspring.




You can see how this happens just by looking in the mirror. You may have inherited your mother's eye color, or your father's height.




GO TO NEXT PART!

INTRO **NATURAL SELECTION** SURVIVAL GAME QUIZ DARWIN'S BIO GLOSSARY

Part 3: Life in the wild is competitive, and organisms with the most beneficial traits will prosper. This is commonly known as “survival of the fittest.”



If an organism is born with traits that help it survive or attract mates, it will likely produce more offspring than rivals without those traits. Eventually, beneficial traits can spread throughout a species.



Appendix B: Who Wants to Live a Million Years? Student instructions and screen shots of one game variant.

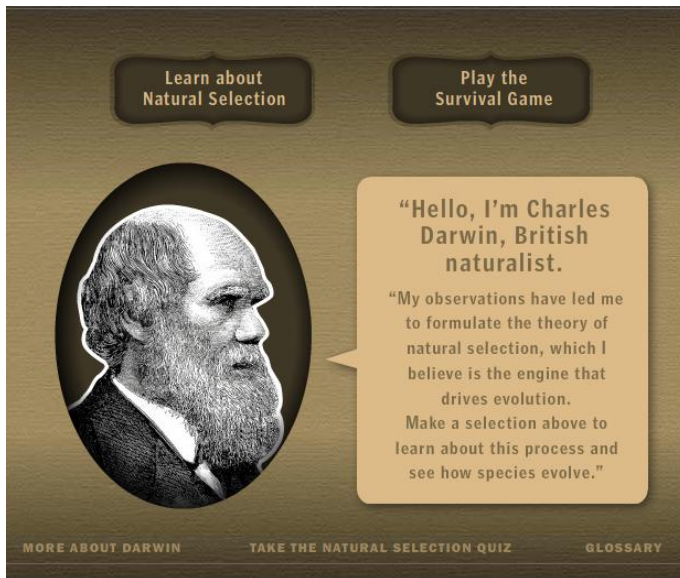
Student instructions:

Directions: Visit the following website:

<http://www.animalplanet.com/wild-animals/darwin-survive-game.htm>

or [can click here](#)

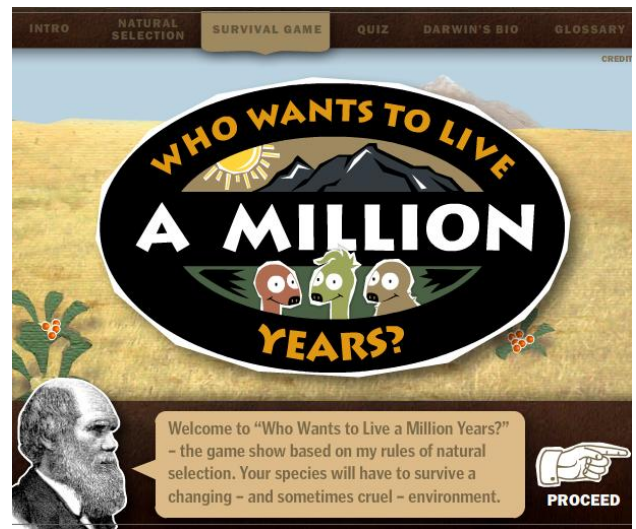
You should see the following screen:



virtual lesson you will be prompted to start the game.

4. Read through each slide on the game.
5. **Your goal is to establish a viable evolutionary lineage, or lineage that is capable of reproducing.** You have 10 minutes to achieve this goal.

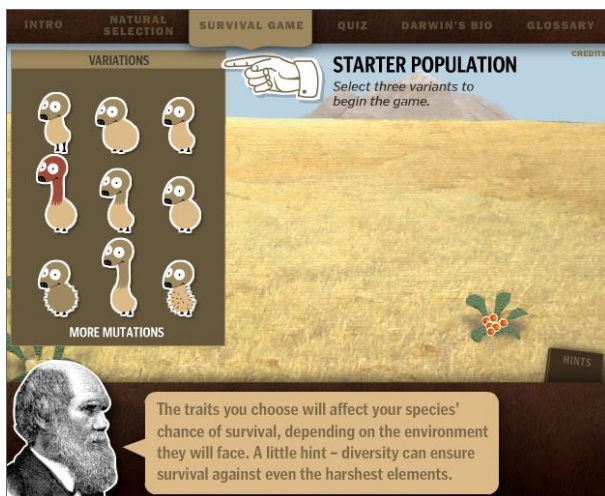
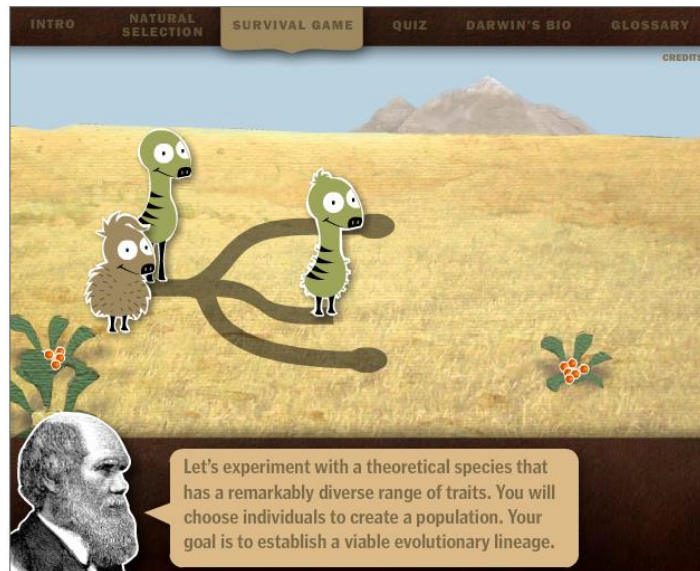
1. Click on “**Learn About Natural Selection**”
2. Read through each slide (including the parts and Darwin’s caption)
3. One you are done with the short



Directions: After logging off the computer/tablet answer the following questions using complete sentences. Write legibly.

1. In the activity, “Who wants to live 1 million years” where did the variation seen in the population of creatures come from?
2. In the activity, “Who wants to live 1 million years” how did the creatures in the animated population vary?
3. What’s the relationship between genetics and natural selection?
4. What do you think causes variation in a population (seals, birds, bears, penguins, turtles, bacteria, etc.)?
5. Explain how variation in a population may affect which organisms survive.

Screen Shots



INTRO NATURAL SELECTION SURVIVAL GAME QUIZ DARWIN'S BIO GLOSSARY

VARIATIONS

STARTER POPULATION
Select three variants to begin the game.

MORE MUTATIONS

HINTS

The traits you choose will affect your species' chance of survival, depending on the environment they will face. A little hint - diversity can ensure survival against even the harshest elements.

INTRO NATURAL SELECTION SURVIVAL GAME QUIZ DARWIN'S BIO GLOSSARY

Close book

Thin PROS: Stays cool CONS: Cold weather	Long neck PROS: Reach food easier CONS: Cold weather
Bulky PROS: Stays warm CONS: Overheats	Short legs PROS: Less likely to freeze CONS: Not very fast
Furry PROS: Resistant to cold CONS: May overheat	Long legs PROS: Agile CONS: Weakness to cold
Hairless PROS: Cooler in heat CONS: Weakness to cold	Stripes PROS: Hide from predators CONS: Can't wear plaid

You've made your selections. Now, as the environment changes, the animals with traits most suited to the new environment will thrive. Your goal: help your species survive the next 1 million years.

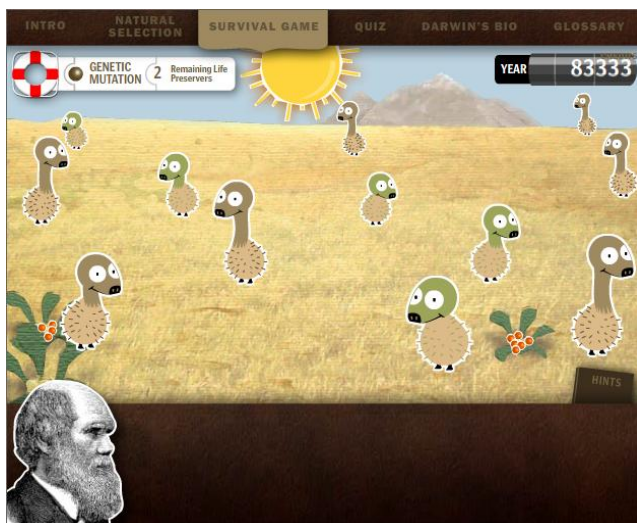
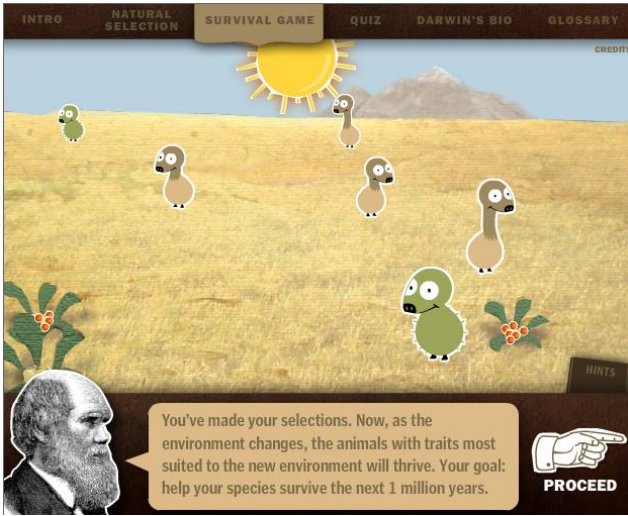
PROCEED

INTRO NATURAL SELECTION SURVIVAL GAME QUIZ DARWIN'S BIO GLOSSARY

HINTS

The traits you choose will affect your species' chance of survival, depending on the environment they will face. A little hint - diversity can ensure survival against even the harshest elements.

PROCEED



INTRO NATURAL SELECTION SURVIVAL GAME QUIZ DARWIN'S BIO GLOSSARY

GENETIC MUTATION 2 Remaining Life Preservers

YEAR 138888

A delicious fruit has begun to grow on tall stalks in your habitat. Are your animals tall enough? Remember, you can use a Life Preserver at any time to pause the game and make a selection.

HINTS

PROCEED

INTRO NATURAL SELECTION SURVIVAL GAME QUIZ DARWIN'S BIO GLOSSARY

GENETIC MUTATION 2 Remaining Life Preservers

YEAR 416666

Brrrr, it's getting colder. Some animals will die off if they can't stay warm. Remember, you can use a Life Preserver at any time to pause the game and make a selection.

HINTS

PROCEED

INTRO NATURAL SELECTION SURVIVAL GAME QUIZ DARWIN'S BIO GLOSSARY

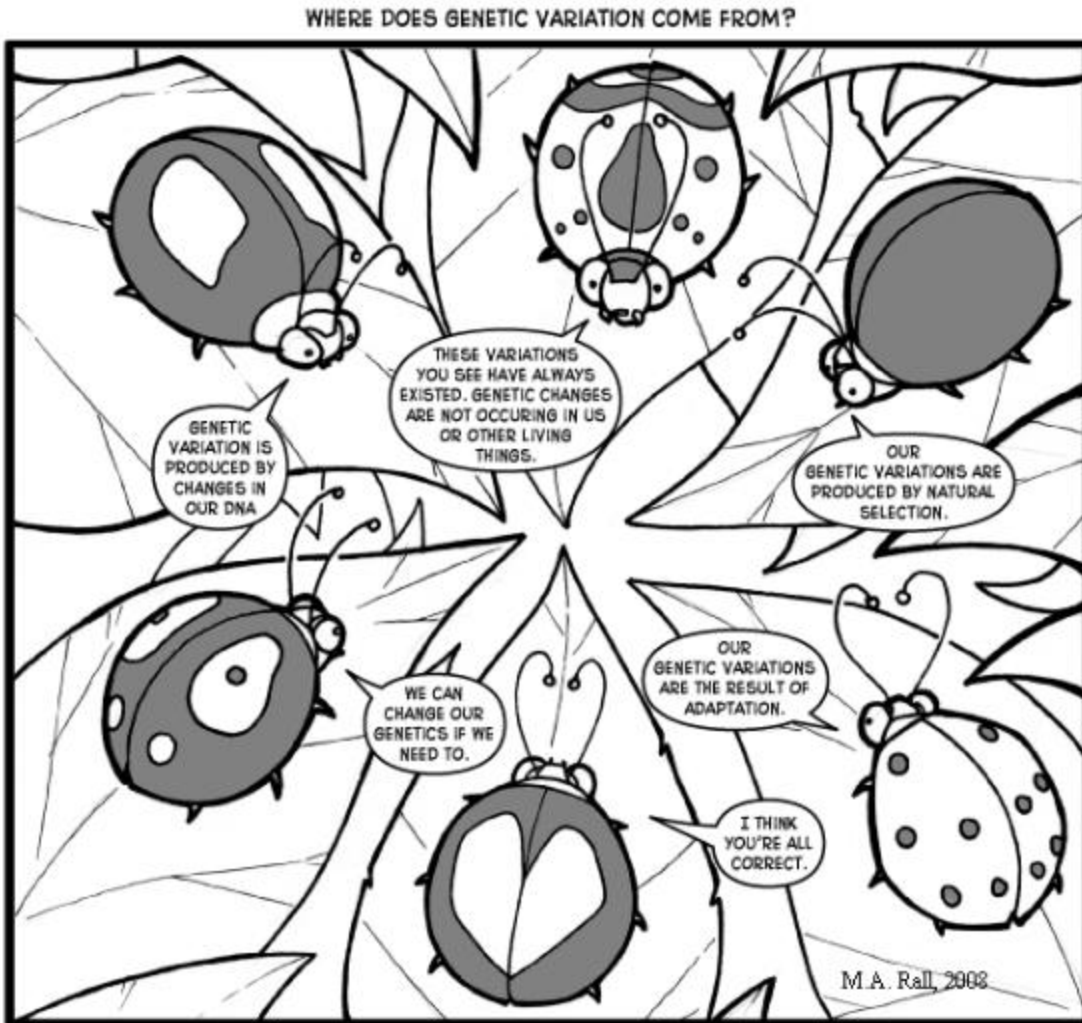
YEAR 583333

**YOU'RE NOT A SURVIVOR.
TOO BAD!**

Sorry, your species just couldn't stay warm in this cold, harsh environment. If they had their own fur coats they might have fared better. Would you like to start from the beginning?

TRY AGAIN!

Appendix C: Traditional Concept Cartoon- Where does genetic variation come from?

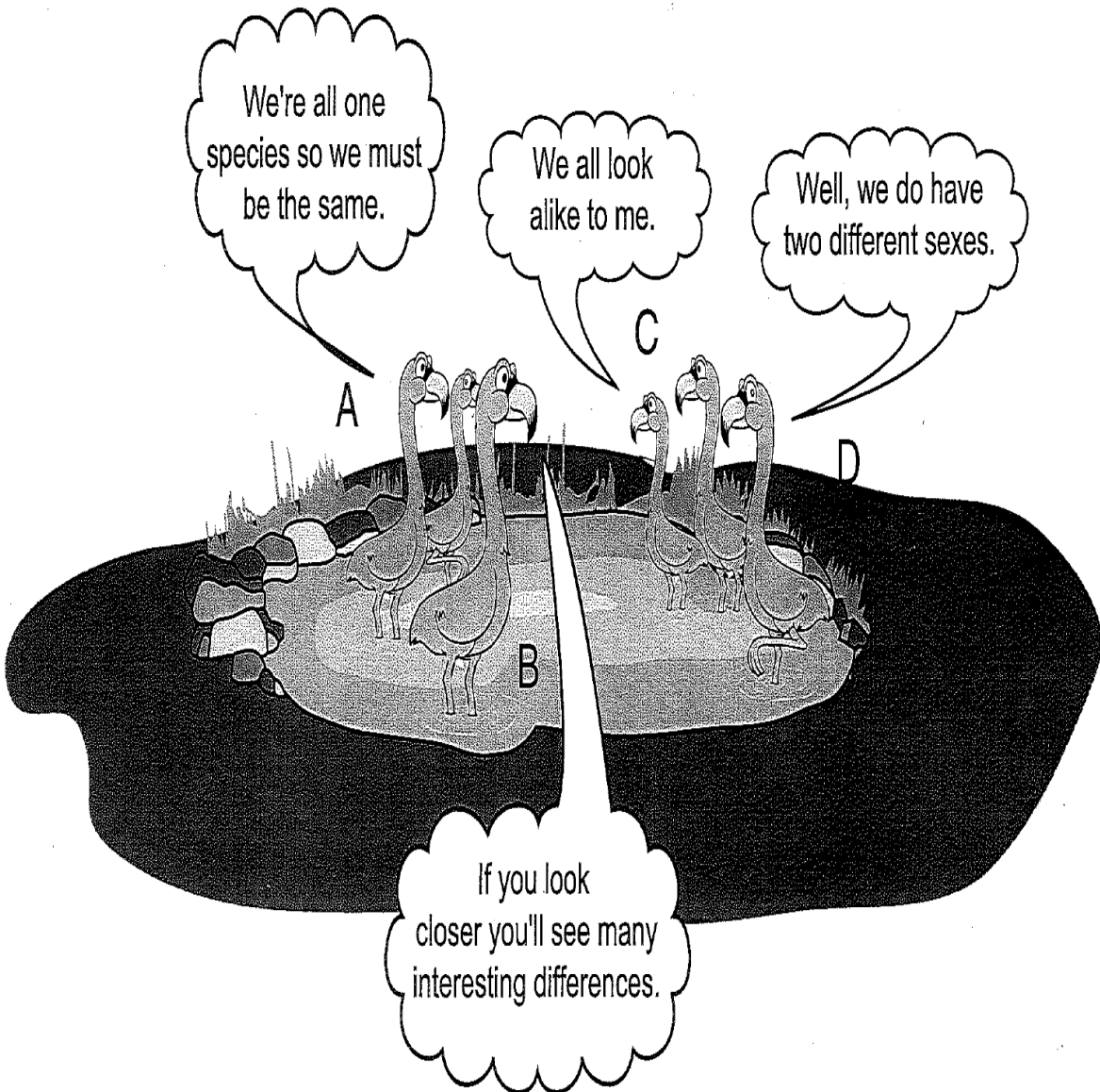


Appendix D: Beetle Traditional Concept Cartoon Prompt

Traditional Concept Cartoon Task- Beetles Cartoon		
<p>Provide student with the beetle cartoon. Have student read the question out loud: “Where does genetic variation come from?”</p>	<p>Option A: These variations you see have always existed. Genetic changes are not occurring in us or other living things.</p>	<ul style="list-style-type: none"> • Explain how these variations were introduced. • Can you give me an example of these genetic changes? • Where do these genetic changes occur in our bodies? • Where do these genetic changes occur in cells?
	<p>Option B: Our genetic variations are produced by natural selection.</p>	<ul style="list-style-type: none"> • What are some examples of genetic variations? • How does natural selection produce genetic variations? • From your perspective, can you observe these genetic variations?
	<p>Option C: Our genetic variations are the result of adaptation.</p>	<ul style="list-style-type: none"> • What are some examples of genetic variations? • What is an adaptation? • Can you give me an example of an adaptation? • How do adaptations affect genetic variations?
	<p>Option D: I think you are all correct.</p>	<ul style="list-style-type: none"> • Any questions from other options are valid here.
	<p>Option E. We can change our genetics if we need to.</p>	<ul style="list-style-type: none"> • Describe how the beetles can change their genetics. • How do you think the message is transmitted to send this message? • When would the beetles need to change

		their genetics?
	Option F: Genetic variation is produced by changes in our DNA	<ul style="list-style-type: none"> • What are some possible changes in beetle's DNA? • Can you describe the effect of these changes on the beetle? • Can genetic variation be detected?

How do flamingos vary?



Appendix F: Flamingo Traditional Concept Cartoon Interview Prompt

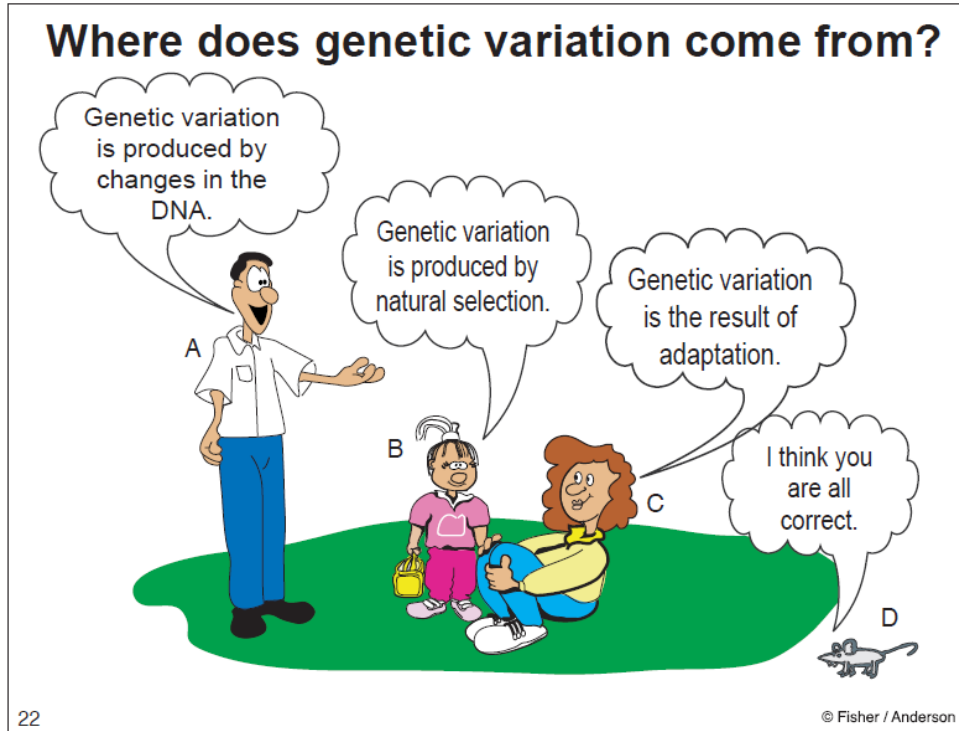
Traditional Concept Cartoon Task – Flamingo: How do flamingos vary?	
<p>A: We're all one species so we must be the same.</p>	<ul style="list-style-type: none"> • What are ways that a species is known as its own species? • How can you tell two different species of flamingo's apart? • Are there other ways of telling them apart? • What are factors that influence whether they are the same species?
<p>B: If you look closer you'll see many interesting differences.</p>	<ul style="list-style-type: none"> • What are examples of differences that you would see? • How close do you have to look to see the differences? • How can these differences manifest themselves? • What are the underlying differences in these flamingos? • Why would there be differences in this population?
<p>C: We all look alike to me.</p>	<ul style="list-style-type: none"> • Are there any other underlying differences in the population of flamingos? • If all the flamingos are the same, what do you think would be the outcome of an epidemic/disease in this population?
<p>D: Well, we do have two different sexes.</p>	<ul style="list-style-type: none"> • Are there any other additional differences besides the two sexes? Explain.

	<ul style="list-style-type: none">• Are there any other ways of telling these flamingos apart? • Why would this population have two different sexes? If they mention (sexual selection)<ul style="list-style-type: none">-mate selection, what about it, is there any effect of mate selection on reproduction or how long they live If they mention (Meiosis)<ul style="list-style-type: none">- What about this process?- How is this process connected to the appearances of the finches? - How does this process affect the inside of the finches? If they mention (genes/genetics)<ul style="list-style-type: none">-what do you mean genes? <ul style="list-style-type: none">-explain how this relates to appearance.
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Appendix G: Cartoon Group Warm-up

Directions: This is an individual warm-up writing activity.

- 1) Silently read the question around the photo and **circle the letter** that you think is the **most accurate answer**.



- 2) Now that you have circled the accurate answer, **legibly** write why you **DID NOT** choose the other answer choices.

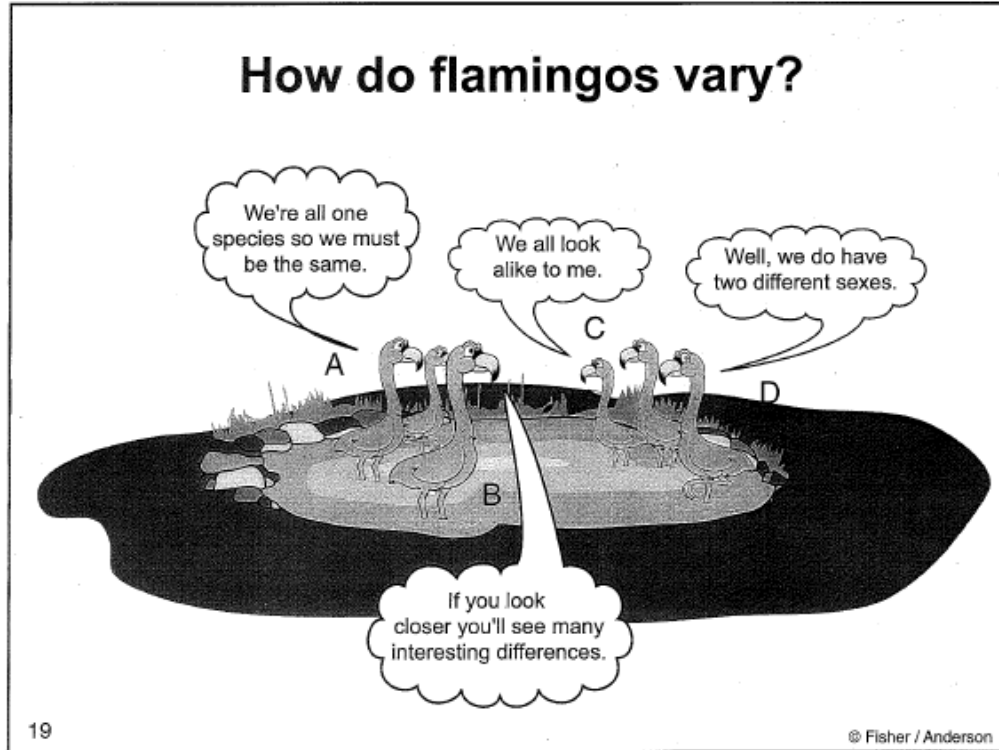
"I didn't choose _____ (A/B/C/D circle one) because..."

"I didn't choose _____ (A/B/C/D circle one) because..."

"I didn't choose _____ (A/B/C/D circle one) because..."

Directions: This is an individual warm-up writing activity.

- 1) Silently read the question around the photo and **circle the letter** that you think is the **most accurate answer**.



- 2) Now that you have circled the accurate answer, **legibly** write why you **DID NOT** choose the other answer choices.

"I didn't choose _____ (A/B/C/D circle one) because..."

"I didn't choose _____ (A/B/C/D circle one) because..."


"I didn't choose _____ (A/B/C/D circle one) because..."

Appendix H: Photo-based Concept Cartoon Group Warm-up

Directions: This is an individual warm-up writing activity.

- 1) Silently read the question around the photo and **circle the letter** that you think is the **most accurate answer**.

How do Caribbean flamingos vary?



A We don't. We are all one species, so we must be the same.

B Well, we do have two different sexes.

C Some of us can digest food faster or take better care of our babies .

D Some of us look different, but there are no differences on the inside.

D.L.Anderson 2014

- 2) Now that you have circled the accurate answer, **legibly** write why you **DID NOT** choose the other answer choices.






"I didn't choose _____ (A/B/C/D circle one) because..."

"I didn't choose _____ (A/B/C/D circle one) because..."

"I didn't choose _____ (A/B/C/D circle one) because..."

Directions: This is an individual warm-up writing activity.

- 1) Silently read the question around the photo and **circle the letter** that you think is the **most accurate answer**.

		Where does variation in these penguins come from?	
A Individual penguins can develop traits that will help them to survive. 	B Natural selection causes all kinds of variations to appear in the population. 	C Some penguins have random changes in their DNA that result in variation. 	D Dramatic changes in the environment cause helpful variations to appear in the population. 

D.L. Anderson 2014 /Photo credit J.B.Hester 2014

- 2) Now that you have circled the accurate answer, **legibly** write why you **DID NOT** choose the other answer choices.


"I didn't choose _____ (A/B/C/D circle one) because..."

"I didn't choose _____ (A/B/C/D circle one) because..."

"I didn't choose _____ (A/B/C/D circle one) because..."

Appendix I: Flamingo Photo-based Concept Cartoon (Interview)

How do Caribbean flamingos vary?



A We don't. We are all one species, so we must be the same.

B Well, we do have two different sexes.

C Some of us can digest food faster or take better care of our babies .

D Some of us look different, but there are no differences on the inside.






D.L.Anderson 2014

Appendix J: Flamingo Photo-based Concept Cartoon Interview Script

Photo-based Concept Cartoon Task – Flamingo: How do Carribbean flamingos vary?	
<p>A: We don't. We're all one species so we must be the same.</p>	<ul style="list-style-type: none"> • What are ways that a species is known as its own species? ¿Cuáles son las formas de que una especie se conoce como su propia especie? • How can you tell two different species of flamingo's apart? ¿Cómo puedes distinguir entre dos especies diferentes de flamencos? • Are there other ways of telling them apart? ¿Hay otras formas de distinguirlos? • What are factors determine whether they are the same species? ¿Cuáles son los factores que determinan en si son la misma especie?
<p>B: Well, we do have two different sexes.</p>	<ul style="list-style-type: none"> • Are there any other additional differences besides the two sexes? Explain. ¿Hay otras diferencias adicionales además de los dos sexos? Explica. • Are there any other ways of telling these flamingos apart? ¿Hay otras maneras de distinguir estos flamencos aparte? • Why would this population have two different sexes? ¿Por qué esta población tienen dos sexos diferentes? • What type of variation do you think the question is referring to? ¿Qué tipo de variación crees que la pregunta se refiere? • How does having two sexes influence variation in the population? ¿Teniendo dos sexos en la población, esto como afecta la variación en la población? <p>If they mention (sexual selection) -mate selection, what about it, is there any effect of mate selection on reproduction or how long they live ¿hay algún efecto de la selección de la pareja sobre la reproducción o el tiempo durante el que viven</p> <p>If they mention (Meiosis)</p> <ul style="list-style-type: none"> - What about this process? ¿Qué pasa con este proceso? ¿Cómo es este proceso conectado a las apariencias de los flamencos? - How does this process affect the inside of the flamingos? ¿De

	<p>qué manera este proceso afecta a la parte interior de los flamencos?</p> <p>-</p> <p>If they mention (genes/genetics)</p> <p>-what do you mean genes? ¿qué quieres decir genes?</p> <p>-explain how this relates to appearance. explica cómo esto se relaciona con la apariencia de los flamencos</p>
<p>C: Some of us can digest food faster or take better care of our babies.</p>	<ul style="list-style-type: none"> • Why did you select this answer? ¿Por qué escogiste esta respuesta? • Explain why this variation would exist Explica por qué existiría esta variación • Explain the role of this variation in the flamingos. Explica el propósito de esta variación en los flamencos. • What factors would influence the rate at which these flamingos digest their food. Que afecta o influye la rapidez de la digestión de los flamencos? • What is the significance of taking better care of their babies? ¿Cuál es la importancia de cuidar mejor de sus hijos?
<p>D: Some of us look different, but there are no differences on the inside.</p>	<ul style="list-style-type: none"> • Why would some of these flamingos look different? ¿Por qué algunos de estos flamencos tienen una apariencia diferente? • What are examples of similarities on the inside? • How would this variation affect the population?

Appendix K: Penguin Photo-based Concept Cartoon (Interview)

	<p>Where does variation in these penguins come from?</p>		
<p>A</p> <p>Individual penguins can develop traits that will help them to survive.</p> 	<p>B</p> <p>Natural selection causes all kinds of variations to appear in the population.</p> 	<p>C</p> <p>Some penguins have random changes in their DNA that result in variation.</p> 	<p>D</p> <p>Dramatic changes in the environment cause helpful variations to appear in the population.</p> 

D.L. Anderson 2014 /Photo credit J.B.Hester 2014

Appendix L. Penguin Photo-based Concept Cartoon Interview Script

Photo-based Concept Cartoon Task- Penguins: Where does genetic variation in these penguins come from?	
<p>A- Individual penguins can develop traits that will help them to survive</p>	<ul style="list-style-type: none"> • How do these penguins develop the traits that will help them survive? <i>¿De qué manera estos pingüinos desarrollan las características que le ayudarán a sobrevivir?</i> • Does the environment have a role in influencing which penguins survive? <i>¿El medio ambiente afectara cuales pingüinos van a sobrevivir?</i> • The traits that are in the population, are they varied or the same? Explain <i>Los rasgos que se encuentran en la población, se variaron o son iguales? explica</i> • What are examples of some of these traits? <i>Cuales son ejemplos de rasgos que se encuentran en la población? Estos rasgos se variaron o son iguales? explica</i>
<p>B – Natural selection causes all kinds of variation to appear in the population.</p>	<ul style="list-style-type: none"> • Explain why you selected your answer. Explicar porque escogiste la respuesta. • Can you describe the kinds of variation in the population? <i>¿Puede describir el tipo de variación en la población?</i> • From your perspective what is natural selection? <i>Desde su perspectiva ¿cuál es la selección natural (natural selección)?</i> • Was there variation in the population prior to Natural Selection? <i>¿Hubo variación en la población antes de la selección natural?</i>

<p>C – Some penguins have random changes in their DNA that result in variation.</p>	<ul style="list-style-type: none"> • Explain your answer. <i>Explica tu respuesta.</i> • What are some of these variations that result? <i>¿Cuáles son algunas de estas variaciones que resultan de estos cambios?</i> • Explain how these variations remain in the population. <i>Explica cómo estas variaciones se mantienen en la población.</i> • Can these random changes happen in humans? <i>¿Pueden estos cambios aleatorios ocurrir en los seres humanos?</i> • If random changes cause mutations, what’s the impact of mutations in the population? <i>Si los cambios aleatorios causan mutaciones, ¿cuál es el impacto de las mutaciones en la población?</i>
<p>D – Dramatic changes in the environment cause helpful variations to appear in the population.</p>	<ul style="list-style-type: none"> • Explain your answer. <i>Explica tu respuesta</i> • Do dramatic changes sometimes cause non-helpful traits to appear? Explain or provide examples. <i>¿Los cambios dramáticos a veces causan cambios en los rasgos que no son útiles? Explica esto o da unos ejemplos.</i> • How does the environment affect variation in the population? <i>¿El medio ambiente como afecta la variación de la población?</i> • Can the environment ever affect DNA? <i>¿Puede el medio ambiente afectar el ADN?</i> • Can the environment ever affect genetic material? <i>¿Puede el medio ambiente afectar la materia genética?</i>

Appendix M: CINS Questions pertaining to the research questions

	Variation Question	Origin of Variation Question
Version A	A population of finches has hundreds of birds of a single species. Which sentence best describes the group of finches?	How did the different types of beaks <u>first appear</u> in the finches?
Version B	A population of lizards is made up of hundreds of individuals. How similar are they to other lizards in the population?	Where did the variation in body size of the three species probably <u>first</u> come from?

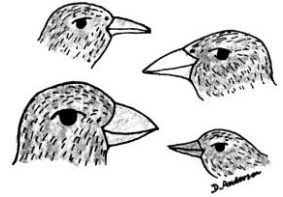
	Version A Answer Choices	Version B Answer Choices
Variation Question	A= no difference	A= no difference
	B= important shared traits, differences do not affect reproduction	B= internal differences only
	C= external differences only	C= external differences only
	*D= shared important traits, but important differences that may affect reproduction	*D=many similarities, but important differences
Origin of Variation Question	A= need based	A= need based
	*B= random changes	*B= random changes
	C= environmental influence	C= environmental influence
	D= gradual change	D= want and gradual change

Appendix N: Conceptual Inventory of Natural Selection (CINS)
Version A: 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.

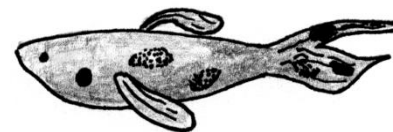


-
1. What will probably happen if a breeding pair of finches is placed on an island with no predators and plenty of food so that all the birds live?
 - a. The population of finches would stay small because finches only have enough offspring to replace themselves when they die.
 - b. The population of 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 they reproduce or how long they live.

6. How did the different types of beaks first appear in the finches?
- Changes in the finches' beak size and shape happened because of their need to be able to eat different kinds of food to survive.
 - Changes in the size and shape of the beaks of the finches because of random changes in the DNA.
 - Changes in the beaks of the birds happened because the environment caused beneficial changes in the DNA.
 - 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).



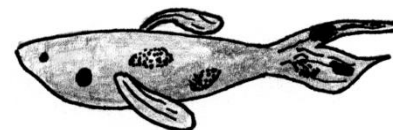
-
7. What kind of variation in the traits of the guppies is passed on to their offspring?
- Only behaviors that were learned during a guppy's life.
 - Only traits that were beneficial during a guppy's life.
 - Only traits that were coded for by a guppy's DNA.
 - Only traits that were affected by the 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"?
- Large body size and able to swim quickly away from predators.
 - High number of offspring that live to reproductive age.
 - Excellent at being able to compete for food.
 - 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?
- The traits of each guppy in the population change slowly.
 - Guppies with certain traits reproduce and become more common.
 - Behaviors learned by certain guppies are passed on to their offspring and become more common.
 - 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?
- 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.
 - All guppies are alike and there are not really different species.
 - Guppies that need to attract mates could change their spots in many ways, and this would make them different species.
 - 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.

Version B: 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 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).

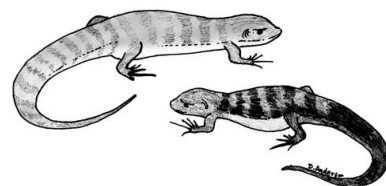


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1. If food and space are abundant, and there are no predators, what will likely happen if a mating pair of guppies is placed in a large pond?
 - a. The guppy population will grow slowly. The guppies will have only the number of offspring that are needed 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.
 2. 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.
 3. 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.
 4. 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.

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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.



- A population of lizards is made up of hundreds of individuals. How similar are they to other lizards in the population?
 - All lizards are the same.
 - All lizards are the same on the outside, but have differences in their internal traits.
 - All lizards are the same on the inside, but have differences in their external traits.
 - All lizards share many similarities, but have some important differences in their traits.
- Where did the variation in body size of the three species probably first come from?
 - The lizards needed to change in order to survive, so new helpful traits formed.
 - Random changes in the DNA created new traits.
 - The environment of the island caused certain changes in the DNA of the lizards.
 - The lizards wanted to become different in size, so helpful new traits slowly appeared in the population.
- How are traits in lizards inherited by their young?
 - When a parent lizard learns to catch certain insects, its young can inherit the ability to catch those insects.
 - When a parent lizard gets stronger claws through repeated use in catching prey, its young can inherit the stronger claw trait.
 - When a parent lizard is born with an extra claw on each limb, its offspring can inherit the extra claw.
 - When a parent lizard's claws are weak because the available prey is easy to catch, its young can inherit the weakened claws.
- 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

- Lizard A
 - Lizard B
 - Lizard C
 - Lizard D
- What is the best way to describe the evolutionary changes that happen in the lizard population over time?
 - The traits of each lizard in the population change slowly.
 - Lizards with certain traits reproduce and become more common.
 - Behaviors learned by certain lizards are passed on to their offspring and become more common.
 - Mutations happen in the lizard population to meet the needs of the lizards as the environment changes.

10. 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.