Development and field testing of a concept cartoon intervention to improve students' understandings of the role of genetics in natural selection as a mechanism of evolution

A thesis submitted in partial satisfaction of the

requirements for the degree of

Master of Science

in Biology

by

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2021

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[illegible]

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Chair

Point Loma Nazarene University 2021

Dedication

I dedicate this thesis to my children.

I love you always, and I'm so proud of you.

May nature's endless beauty and complexity inspire you in your pursuit of learning!

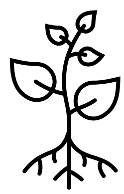


Table of Contents

List of Figures

List of Tables

ABSTRACT

Evolution by natural selection is foundational in biology, yet decades of science education research have shown that common alternative conceptions often persist after college biology instruction. Some of these alternative conceptions are based on deeply ingrained ideas that conflict with the accepted scientific understandings of the role of genetics in natural selection. Effective teaching interventions are needed to address this concern. This study examines whether a concept cartoon intervention improves students' understandings about the role of genetics in natural selection, as measured by concept inventory (CI) questions. Using a mixed methods approach, 88 students at a private Christian university participated in either concept cartoon activities or short answer activities (control), and their improvement was assessed using normalized learning gain scores on pre-test/post-test CI questions. Qualitative results indicated that concept cartoons successfully elicited correct conceptions from students and showed that concept cartoon activities were perceived as helpful in both majors' and nonmajors' biology courses. Answer choices for concept cartoons also matched students' written explanations. Quantitative results showed that concept cartoons were more effective than the control activity at improving nonmajors students' CI scores, and that students who engaged in concept cartoon activities chose the most common distractors less often than control students. Overall, these results support the use of concept cartoons as a useful learning activity in college biology courses to address common alternative conceptions regarding the role of genetics in natural selection, particularly in nonmajors' courses.

1 | INTRODUCTION

Evolution is foundational in biology. It is important for understanding everything from microbiology, cells, and genetics to populations, ecology, and conservation. People make decisions based on their understanding of evolution that affect diverse global concerns such as bacterial antibiotic resistance, agricultural practices, and species extinction patterns, among others. Yet research suggests that evolution is commonly misunderstood among the general population, as well as among college biology students (Alters & Nelson, 2002; Chinsamy & Plaganyi, 2008; Gregory, 2009).

Three decades of research on alternative conceptions related to natural selection show that as few as 10% of surveyed individuals have a functional understanding (Gregory, 2009). Many students in college biology courses retain alternative conceptions that pre-date instruction and are resistant to change after instruction (Anderson, Fisher, & Norman, 2002; Sinatra, Brem, & Evans, 2008; Gregory, 2009). Even when alternative conceptions are specifically addressed in class, research has shown that 50% to 70% of college students may retain at least one (Bishop & Anderson, 1990; Nehm & Reilly, 2005). For this reason, it is necessary to field test novel approaches to address alternative conceptions in the classroom.

Several common alternative conceptions involve the role of genetics, random mutation, and inheritance in natural selection (Berkeley, Understanding Evolution section*,* 2002). These alternative conceptions follow intuitive ideas that conflict with scientific understanding about existing variation in populations, the origin of variation, how variation is inherited, and the concept of differential survival (Gregory, 2009).

The confusion over the role of genetics in natural selection may result from a lack of instructional emphasis on the connection between them. After all, when Darwin first conceived of natural selection, there was no modern knowledge of genetics available. To this day, the two subjects are often taught in separate courses or in separate units within a course (Mead, Hejmadi, & Hurst, 2017). The relationship of these topics may not be fully communicated to students, and they may not make the necessary connections on their own in a meaningful way. When combined with deeply ingrained intuitive ideas, this separation of topics could create a convenient environment for alternative conceptions to perpetuate. The consequences may follow students into their careers as professionals, affecting public interest by preventing understanding of situations such as the development of antibiotic resistant bacteria from an evolutionary perspective.

Previous research acknowledges the need for an instructional connection between genetics and natural selection. For example, it appears that students retain alternative conceptions about the origin of variation in evolution after taking a genetics course (Smith & Knight, 2012), and teaching genetics prior to evolution appears to improve student understandings of evolution (Mead, Hejmadi, & Hurst, 2017). These results suggest that the two components may require unity for accurate understanding. Furthermore, as students may not actively make connections without a specific intervention, it has been argued that evolution instructors should specifically discuss genetics while teaching natural selection (Kalinowski, Leonard, & Andrews, 2010).

The purpose of this study was to field test a teaching intervention to determine whether concept cartoons on the topic of genetics in natural selection are helpful for improving students' conceptions as measured by correct answers to concept inventory questions and qualitative responses.

2 | THEORETICAL BACKGROUND

2.1 | Constructivism in education

For students to build more accurate conceptions about natural selection, it is necessary to consider existing ideas that students bring from previous experiences. According to constructivist learning theory, new knowledge must be incorporated with pre-existing information for learning to occur (Julyan & Duckworth, 2005). Students come to the classroom with preconceived thoughts about how processes work which influence their understanding of new concepts. These previous ideas may not be inherently wrong or invalid, but they may not work within the new context without some reorganizing or refinement (Maskiewicz & Lineback, 2013). For this reason, constructivism seeks not to confront and replace misconceptions, but instead to highlight what is useful about those conceptions, identify in which contexts they work, and recraft them to accommodate more expert ideas. Constructivist learning theory might be utilized for evolutionary biology by discussing when existing conceptions are appropriate in the context of evolution and when they are not. This means that students must be able to articulate and challenge their own ideas before making connections between the new concept and their experiences.

2.2 | Alternative conceptions

Previous conceptions that differ from what is accepted in science education are known as alternative conceptions. Many studies show that alternative conceptions about natural selection are based on intuitive beliefs formed during childhood both in and outside the classroom (Gregory, 2009). From the constructivist perspective, it is important to view these conceptions as serious ideas that can be reformed, and not as replaceable or inherently problematic or interfering (Maskiewicz & Lineback, 2013). According to Smith, diSessa, and Rochelle (1993), viewing student ideas as misconceptions is not only throwing out a useful starting point, but also throwing out the contributions of learners as they build knowledge.

Science education research has shown that alternative conceptions are based on common intuitive beliefs about the world, they are resistant to change, and they often parallel the historical development on an understanding of a topic (Anderson, Fisher, & Norman, 2002). Previous research has emphasized the importance of explicitly addressing alternative conceptions in the classroom setting (Anderson et al, 2002; Bahar, 2003; Chinsamy & Plaganyi, 2008; Taber, 2001). Students greatly benefit from activities that address student confusion through gently confronting contradicting ideas, according to research by D'mello, Lehman, Pekrun, and Graesse (2014).

2.3 | Alternative conceptions related to genetics and natural selection

While learning about natural selection as a mechanism of evolution in biology, students often hold alternative conceptions pertaining to the existence of variation, the origin of variation, random mutation, inheritance, and other topics in genetics (Gregory, 2009). According to sources such as UC Berkeley's Understanding Evolution website and Gregory's compendium (2009), common notions include "Natural selection causes genetic variation," among others shown in Table 1, which was constructed for this study.

Table 1. Alternative conceptions related to the role of genetics in Natural Selection

Target Conception	Alternative Conceptions
The appearance of variation is due to random changes in DNA.	Natural selection is random. Environments cause specific genetic changes to arise.
Certain traits do not appear because they would help an organism to survive.	Mutations arise in response to need. New traits arise in individual lifetimes.
Mutation in individuals is the ultimate source of genetic variation; natural selection works on variation, allowing adaptation of a population to take place.	Natural selection creates genetic variation.
Mutations can be neutral, positive, or negative irrespective of whether they are dominant or recessive.	Mutations are always bad, or always good. Dominant alleles are stronger.
Natural selection can affect prevalence of certain alleles, with alleles in individuals more likely to survive and reproduce becoming more common.	Mutations arise in all members of a population at once. Natural selection makes organisms perfect.
Natural selection requires the existence of variation for nature to act upon. While members of a species may look all the same, they actually have differences that are important in terms of survival or reproduction.	All members of the same species are the same on in the inside, or on a cellular level. Variation has no impact on survival or reproduction.
Mutations that occur in germ line cells can be passed on to offspring. In contrast, somatic mutations that arise during an individual's lifetime are not passed on to offspring.	All mutations can be passed to offspring. Mutations are not passed on and do not affect offspring.

2.4 | Use of concept cartoons as an instructional intervention

Most science educators agree that active learning models improve student learning as compared to conventional types of lecture-based instruction (Armbruster, Patel, Johnson, &

Weiss, 2009; Riedl, Yeung, & Burke, 2021). Active learning occurs when students work on problems together and contribute their own ideas, such as during discussion. Research has shown that such interventions can double the achievement of learning outcomes (Hake, 1998; Knight & Wood, 2005).

Concept cartoons combine active learning with a visual aid to promote constructive discussion by students. They allow students to discover their own confusion regarding difficult concepts in science (Keogh & Naylor, 1999). Introduced for teaching physics at the high school level in 1998 by Keogh and Naylor, concept cartoons have since been widespread and successfully implemented in other subjects and education levels (Naylor & Keogh, 2013). The first concept cartoons for biology (and evolution in particular) were created in 2002 by Anderson and Fisher. The collection is freely available and continues to grow in number and scope (Anderson, 2021). Although most of these concept cartoons were designed for middle school or high school use, the concepts are difficult enough for, and applicable to, college students.

Concept cartoons are typically single-panel images that depict a concept or situation, with text that asks a question, and a correct response amidst several wrong statements based on research on alternative conceptions (Figure 1). In the classroom setting, students must discuss the rationale behind the responses and agree on a correct answer. The resulting discussion comprises arguments and generation of ideas that may help students self-identify and evaluate their own conceptions, as well as draw upon the ideas of peers. This work acknowledges the constructivist perspective on learning because it helps the students identify their own conceptions and sculpt more expert ideas by integrating old knowledge with new knowledge, and by applying concepts in an active way to novel situations, while also determining when old intuitive ideas work and when they don't work as well. It also aids the teacher in doing formative assessments by providing important feedback and direction for further instruction (Chin & Teou, 2009).

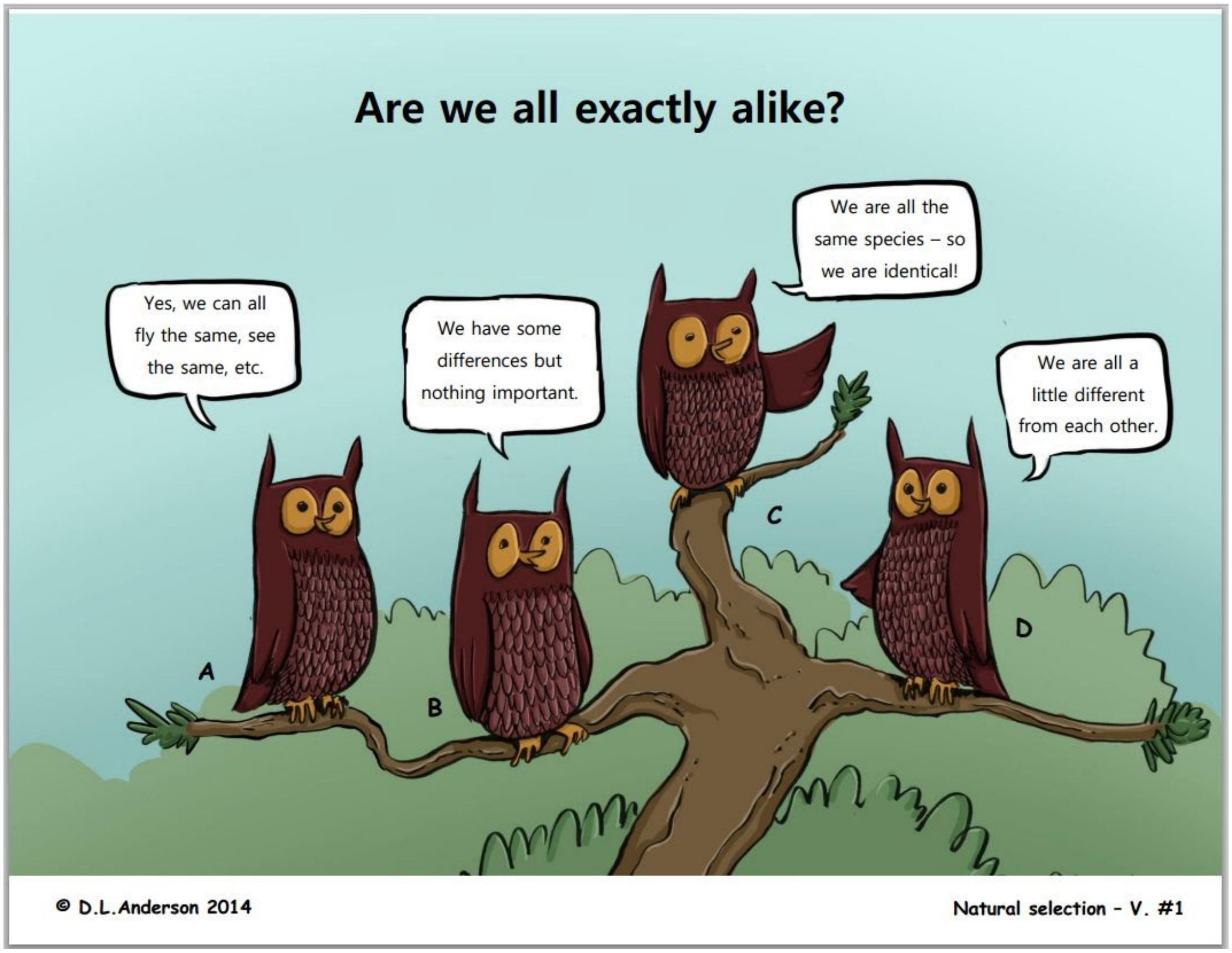


Figure 1. Example of a concept cartoon. This cartoon was created by D.L. Anderson (2014).

Using concept cartoons helps students internally discriminate amongst conflicting ideas and identify flaws in each conflicting argument by practicing scientific thinking. They are a stimulating and motivational way for students to engage in scientific learning because they seamlessly lead students to ponder questions that enhance understanding. It may come as no surprise then that concept cartoons have been found to be effective at improving conceptions when used as a teaching method, and are generally viewed positively by teachers and students (Dunlop, 2014; Kabapinar, 2005; Keough & Naylor, 1999).

There have been several studies showing the effectiveness of concept cartoons for various purposes in science education. In addition to helping identify alternative conceptions, concept cartoons have been found to help students improve accurate conceptions regarding specific topics in science like photosynthesis (Ekici, Ekici, and Aydin, 2007) and shadow formation (Stephenson & Warwick, 2002), as well as ecosystem ecology (Aslan, Engin, Kurmanbekova, Kayalar, Kayalar, & Karagoz, Engin, 2021). Research on concept cartoons for natural selection, in particular, have shown that concept cartoons are effective in the high school setting (Nasont, 2016) when used all at once or spread out over a period of time. At the middle school level, however, they have been shown to be slightly less effective at improving scores even though students find them interesting (Gross, 2011). Research is needed at the college level to determine the usefulness of cartoons as a teaching intervention for college students to improve their understanding of the role of genetics in natural selection.

2.5 | Use of conceptual inventories to assess student understanding

A common way to evaluate the effectiveness of teaching interventions is to assess student learning gains using a concept inventory. Concept inventories (CIs) are assessments used to test students' understanding of concepts within a subject, not by asking for students to respond with simple definitions, but rather by applying their understanding to specific contexts. In order to facilitate formative assessment in large classes, many CIs use multiple-choice items that include one correct conception and typically three conflicting or inconsistent answers about the subject. The inconsistent answers are based on interviews with students to discover common alternative conceptions (Anderson, Fisher, & Norman, 2002; Smith et al, 2017). The concept inventories created in teaching and education research are used to assess understanding as well as to identify common alternative conceptions, providing a tool that can be used across schools, across cohorts, and across single class terms. Teachers can use them as a diagnostic to adjust curriculum depending on the types of alternative conceptions students bring with them to class. One of the most common uses for a CI is to employ them at both the beginning and end of a course to assess student learning, as well as across cohorts to evaluate teaching methods that may change from year to year (Furrow & Hsu, 2019).

Of the concept inventories available in the biology education research literature related to genetics and natural selection, there is the Conceptual Inventory of Natural Selection (CINS) (Anderson et al, 2002; Evans & Anderson, 2013), the Biological Concept Instrument (BCI) (Queloz, Klymkowsky, Stern, Hafen, & Kohler, 2017), the Evolutionary Development Concept Inventory (EvoDevoCI) (Perez, Hiatt, Davis, Trujillo, French, Terry, & Price, 2013), and the Genetics Concept Assessment (GCA) (Smith, Wood, Knight, & Ebert-May, 2017). There is no concept inventory that specifically addresses genetics as it relates to evolution by natural selection, but it appears in specific questions in all of the inventories mentioned. A concept inventory composed of questions regarding the role of genetics in natural selection is needed to assess potential teaching strategies on this topic. Such a concept inventory could be used to measure the effectiveness of targeted concept cartoons as a classroom intervention for improving student understanding of the role of genetics in natural selection.

2.6 | Research Question

Does a concept cartoon intervention, as compared to a short answer intervention, that addresses concepts surrounding the connection between genetic mutation and evolution by natural selection lead to enhanced understanding and application of accurate conceptions among college biology students (both majors and non-majors), as measured by correct answers to concept inventory questions?

3 | RESEARCH METHOD

3.1 | Research context and design

This study used a mixed method approach so that the effectiveness of a practical classroom intervention could be tested experimentally while also providing valuable insight into the learning process. The quantitative portion allowed for measurement of the gains in individual student performance through the use of concept inventory questions both pre- and post- instruction, while the qualitative portion examined the progression of students' thought processes and reasoning skills both individually and as a group through online written explanations and online discussions boards. This allowed for assessment of the usefulness of the intervention using a standard scale, as well as exploration of the ways in which learning occurred.

3.2 | Study site and participants

Participants included 88 undergraduate students from science majors' and non-majors' biology courses at a small Christian teaching university in southern California. The science majors' course was a second semester ecology and evolution class taught by an experienced, full-time faculty member. The nonmajors' course was taught by an experienced adjunct, and included units on genetics, ecology, and evolution. Neither faculty member was affiliated with the study. The pre- and post- assessments, video lessons, concept cartoons, and short answer questions were part of normal class activities for all students. These activities were completed through a link found within the students' regular online platform. The activities for the majors' course were completed in person, while the activities for the nonmajors' course were completed online asynchronously. Table 2 shows an outline of the study sites (online or in-person) and participants.

The nonmajors class was divided equally into two different treatment groups by last name, alphabetically. Nineteen students (A-L) were placed into the short answer group and the intervention included online videos, short answer questions, and discussion activities. The remaining 19 students (M-Z) were placed into the concept cartoon group, and the intervention included online videos, concept cartoons, and discussion activities.

The majors students self-selected into three lab sections at the time of class registration long before the study took place. There were 29 students in two lab sections that were assigned to the concept cartoon group (18 students in the morning lab section, 11 students in the evening lab section), and 21 students in a third lab section assigned to the short answer group (afternoon lab section). Students worked with either randomly assigned lab partners or on an online discussion board. The study followed the university IRB requirements.

Table 2. Study Sites and Participants

Study site	Course title	# of participants	Intervention
Online	Human Biology & Bioethics (Nonmajors)	38	19 – Concept Cartoons 19 – Short Answer Questions
PLNU	Ecological & Evolutionary Systems (Majors)	50	29 – Concept Cartoons 21 – Short Answer Questions

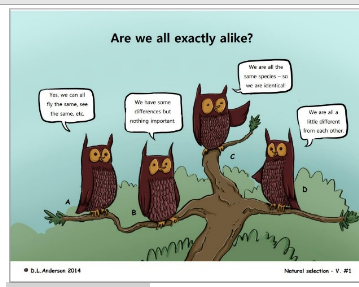
3.3 | Teaching intervention and data collection

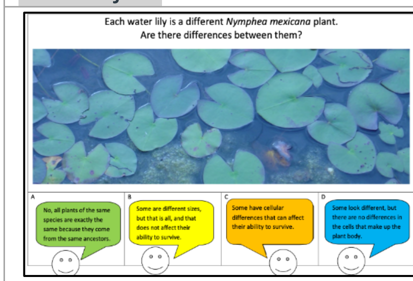
Pre-Test and Post-Test. At the beginning of the semester, all students answered a set of 12 questions regarding the role of genetics in evolution by natural selection (Appendix A). These 12 questions were selected for this study from the following four well-known concept inventories: the CINS, the GCA, the BCI, and the EvoDevoCI. Questions were chosen for their relevance to the role of genetic processes in natural selection. There were three Origin of Variation questions, three Natural Selection questions, three Variation Inherited questions, one Variation Exists question, and two Nonspecific genetic processes questions (Appendix A). Extra credit was given to students for correct answers to incentivize them to do their best. At the end of the semester, the same 12 questions from the pre-test were embedded in the students' final exams.

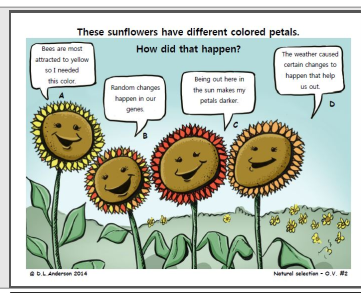
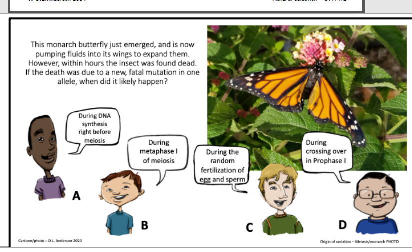
Creation of Concept Cartoons. This study used two concept cartoons that were developed and field-tested by Anderson in 2014 (Table 3). Due to a lack of concept cartoons directly pertaining to the role of random genetic processes in evolution by natural selection, an additional six concept cartoons were created for this study to address the existence of variation, how mutation happens, how mutation is inherited, and how mutation contributes to differential survival (Table 3). These six concept cartoons corresponded with the concepts and scenarios from the four concept inventories (Appendix A) and were based on interviews conducted in a pilot study.

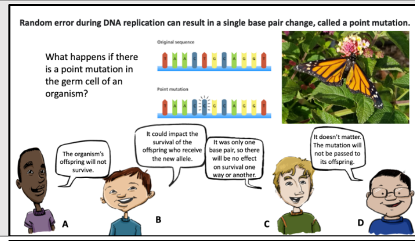
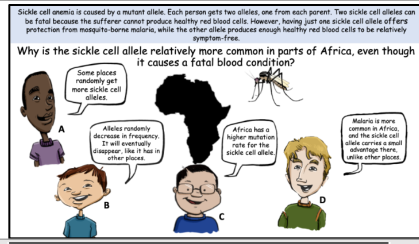
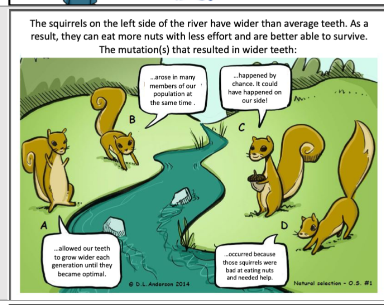
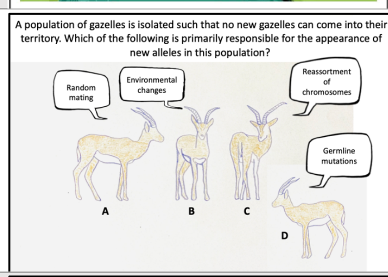
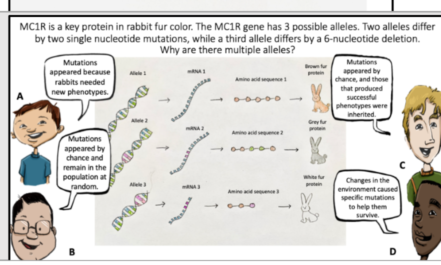
Interventions. All students experienced two teaching interventions during the semester, which were separated by at least two weeks. The teaching interventions coincided with units that contained relevant concepts. Students either worked at home (nonmajors) or in the lab with their lab partners (majors) using computers. Activities each took approximately 30 minutes. In each intervention, students watched a video before completing the activities. In the first intervention, the video was called Origin of Genetic Variation (Pamment, 2019). In the second intervention, videos were created specifically for this project. After watching the videos, the short answer students were given two series of short answer questions (8 total) and an activity evaluation question, while the concept cartoon students were shown two series of concept cartoons (8 total), and one activity evaluation question (Table 3). The first intervention contained five questions, while the second intervention contained four questions. Both control and intervention groups watched the same video content, participated in discussion on the same topics, and spent equal time on task. The only intended difference was whether students had short answer questions or concept cartoons as the "problem" students addressed in their activity time. All students submitted their initial answers individually online. Short answer students were instructed to provide a short answer and a supporting explanation for each question. Concept cartoon students were instructed to provide a letter choice answer and a supporting explanation of their answer choice for each cartoon. After submitting their initial responses, students were then asked to discuss their answers with their partners or with the entire group and come to a consensus. Afterward, each student was invited to explain how and why their answers had changed in a follow-up question online. In the second intervention, students watched a video explanation after they had provided their answers.

Table 3. Intervention Activities

<table>
<tr><th>Short answer groups</th><th>Concept cartoon groups</th><th>New cartoon</th><th>Intervention 1 or 2</th></tr>
<tr><td rowspan="2">What kinds of differences exist between individuals of the same species?</td><td>

Nonmajors</td><td>No</td><td>1</td></tr>
<tr><td>

Majors</td><td>Yes</td><td>1</td></tr>
<tr><td>Where do differences between individuals first come from?</td><td>
</td><td>No</td><td>1</td></tr>
<tr><td>If you are born with a new mutation, when did this mutation likely occur?</td><td>
</td><td>Yes</td><td>1</td></tr>
</table>

What will happen if there is a mutation in the germ cell of an organism?		Yes	1
Why do different variations accumulate in different locations?		Yes	1
Describe why one population of squirrels might have longer teeth than another population.		Yes	2
If a population of gazelles is isolated so that no new gazelles can enter their territory, how does the population get new alleles?		Yes	2
Explain how rabbits came to have multiple alleles for fur color in various populations.		Yes	2
In what way were these short answer questions helpful to you when learning about evolution?	In what way were these concept cartoons helpful to you when learning about evolution?	Yes	2

3.4 | Data analysis

Average scores on the pre-test were compared using a two-sample *t*-test to make sure there was no difference between treatment groups at the beginning of the study. Average percentages of correct conceptions were calculated regarding students' answers to the concept cartoon and short answer activities. Students' written responses (such as student explanations for their answer choices and online discussion) were evaluated qualitatively to ensure that responses matched their answer choices, and to determine how the activities contributed to student learning.

Concept cartoon answers were scored by correct letter choices, on the condition that the short-answer explanation also contained the correct target conceptions. Meanwhile, control students' answers were scored by giving full points for statements that accurately answered the question and used correct conceptions. Half-points were given for answers that included both correct conceptions and wrong conceptions. Students were marked incorrect when their answers clearly showed inaccurate conceptions relating to the target conceptions, or when the response did not answer the question. Students scored one point for each correct conception for each cartoon or short answer question. Notable and informative correct and alternative conceptions were highlighted. Qualitative responses about the perceived usefulness of cartoons were categorized by topic.

Student's gain scores were analyzed using a two-sample *t*-test to determine if one treatment group had significantly greater improvement than the other. The effect size, Cohen's *d*, between the gain scores was calculated [(mean2 – mean1)/SD(pooled)]. Students' normalized gain scores were calculated for each group to control for the difference in pre-test scores [(post – pre)/(100 – pre)] (Hake, 1998).

Radar graphs were created to show how students in each group improved on each question on the post-test depending on the treatment group. Pie charts were made to show which incorrect answers were chosen in both the pre- and post- test by both majors and nonmajors.

4 | RESULTS

4.1 | Qualitative Intervention Results

In the intervention groups for both majors and nonmajors, the majority of students answered the concept cartoons correctly (Table 4; Appendix B) and their supporting explanations included correct conceptions associated (Appendix B). Student answer choices matched their written explanations 99.5% of the time. The concept cartoon activities resulted in more correct conceptions (and fewer incorrect conceptions) in their written explanations when compared with the short answer activities (Table 4). However, there were notable alternative conceptions expressed, or chosen, in both the concept cartoon and the short answer groups (Table 5; Appendix B). Student explanations and answer choices are shown in detail in Appendix B. The most frequent alternative conceptions were centered on organisms "needing" to change. For example, one majors concept cartoon student said that "the weather caused certain changes to happen as with the different seasons and the flowers needed to adapt and change to these new changes."

Table 4. Overall correct written answers produced by students per activity

Group	Intervention 1	Intervention 2
Majors control	63.9%	67.2%
Majors cartoon	80.0%	94.1%
Nonmajors control	63.1%	61.0%
Nonmajors cartoon	62.0%	88.6%

Table 5. Examples of intervention responses expressing alternative conceptions

Short answer (control)	Concept cartoon
"[Members of the same species] may look different due to slight differences in their environment, but they are all the same on a cellular level."	*"Mutation is inherited by chance and it's random not by needs or means of a species to inherit the perfect phenotype."*
"New alleles come from mutations that occur during random mating (meiosis)."	*"The cause of such alleles is random and thus there are places that have a bigger chance of it occurring because of factors in the environment or gene pools in the regions."*

Perceived Benefit of Concept Cartoons. The qualitative data shows that all 48 students who interacted with the cartoons and provided comments (29 majors and 19 nonmajors) generally liked the cartoons as shown by their positive responses in Appendix C. Both nonmajors and majors provided insights as to how they were helpful. Remarkably, there were no negative responses about the cartoons even though some of the images could have been perceived by college students as being made for younger students. Several students in both the majors' class and the nonmajors' class were enthusiastic about liking the cartoons. All students were able to give a concrete reason for how they perceived concept cartoons to be helpful.

Nonmajors students said that concept cartoon activities helped them to learn evolution by providing an application for their knowledge using real scenarios (3 students), by providing a visual aid (10 students), by simulating exam questions (3 students), and by critically examining incorrect answers (4 students). Biology majors said that concept cartoons help them solidify their understanding by making concepts simpler to understand (6 students), by helping them critically examine alternative conceptions (10 students), by providing real-life examples of concepts (6 students), by providing more detail, complexity, or perspective to concepts (6 students), by reviewing what they have already learned (3 students), and by simulating a multiple-choice test (1 student). Interestingly, many majors reported that concept cartoons provided more detail, complexity, or perspective to concepts, while none of the nonmajors reported this feedback (Appendix C).

4.2 | Pre-test/post-test concept inventory scores

Overall, nonmajors scored an average of 72.95% on their post-test while majors scored 72.50%. Nonmajors outperformed majors on highest score, with 15.8% of the 38 nonmajors in either group scoring 100%, compared to only 4.00% of the 50 majors in either group scoring 100%. Two-thirds of the top scores overall came from students in the concept cartoon group. When looking at just the concept cartoon groups, the nonmajors' post-test average score was 82.3% correct, while the majors' post-test average score was 76.6% (Figure 2). When looking at just the control groups, the majors' post-test average score was 68% while the nonmajors post-test average score was 65% (Figure 2). The pre-test/post-test concept inventory scores show that nonmajors cartoon students improved more than short answer students overall (53.4% improvement compared to 26.1%), while majors cartoon students improved similarly to majors short answer students (12.1% compared to 11.6%) (Figure 2).

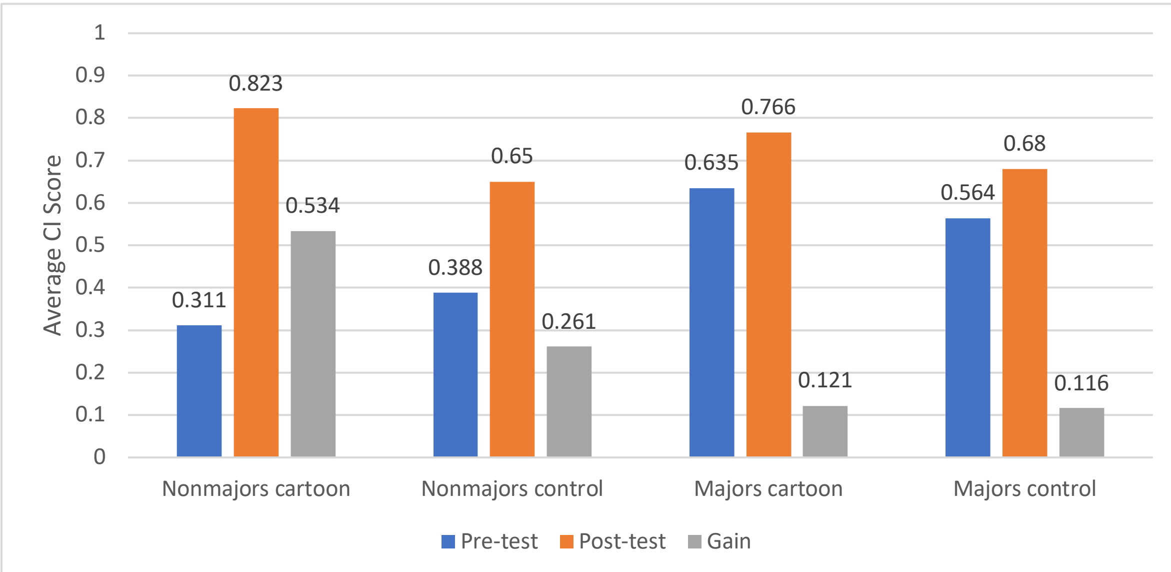


Figure 2. Average CI Scores for Pre-Test, Post-Test, and Gain. Nonmajors cartoon students improved on the Concept Inventory questions much more than short answer students (53.4% improvement compared to 26.1%), but there was not a large difference between majors' treatment groups (12.1% compared to 11.6%).

Nonmajors. A two-sample *t*-test showed that there was no significant difference between the nonmajors cartoon and short answer groups on their pre-test, with an average of 30.7% correct (SD=16.1) for the cartoon group and 38.8% correct (SD=19.7) for the short answer group, $t(36)=1.36$, $p=0.180$. The pre-test scores showed a normal distribution with zero students scoring full points. After two teaching interventions, the cartoon group scored an average of 82.1% correct (SD=15.8) on the post-test, compared to the short answer group with an average of 65.1% correct (SD=24.1) (Figure 3). The gain score between the pre-test and post-test scores showed that the cartoon group improved by an average of 52.6% (SD=24.4) of the possible gain, while the short answer group had a gain score of an average of 26.1% (SD=25.1) (Figure 3).

A two-sample *t*-test showed that the difference between the cartoon group's improvement and the short answer group's improvement was significant, *t*(36)=-3.2663729, *p* <0.002, and the effect size for this (Cohen's *d*) was 1.06, which is very large (Figure 3). The average normalized learning gain (Hake's *g*) for the cartoon group was 0.72 (SD=0.28), while the average normalized gain score for the control group was 0.32 (SD=0.62), (Figure 3). Also, 85% of nonmajors in the short answer group improved on the post-test (n=19), while 100% of nonmajors in the cartoon group improved on the post-test (n=19) (Figure 4).

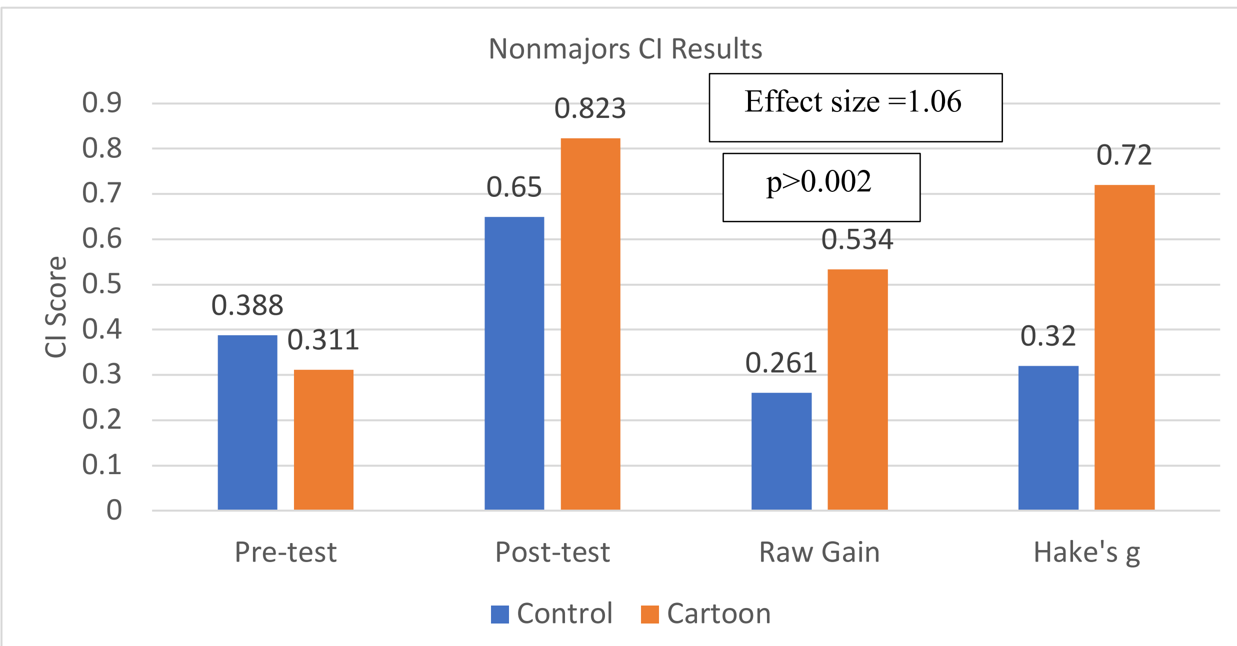


Figure 3. Nonmajors results. After two teaching interventions, the cartoon group scored an average of 82.1% correct (SD=15.8) on the post-test, compared to 65.1% correct (SD=24.1) by the short answer group. The gain score between the post-test and pre-test scores showed that the cartoon group improved by an average of 52.6% (SD=24.4) of the possible gain, while the short answer group had a gain score of an average of 26.1% (SD=25.1). A two-sample *t*-test showed that the difference between the cartoon group's improvement and the short answer group's improvement was significant, t(36)=-3.2663729, p <0.002. The effect size for this (Cohen's *d*) was 1.06. The average normalized learning gain (Hake's *g*) for the cartoon group was 0.72 (SD=.28), while the average normalized gain score for the control group was 0.32 (SD=.62).

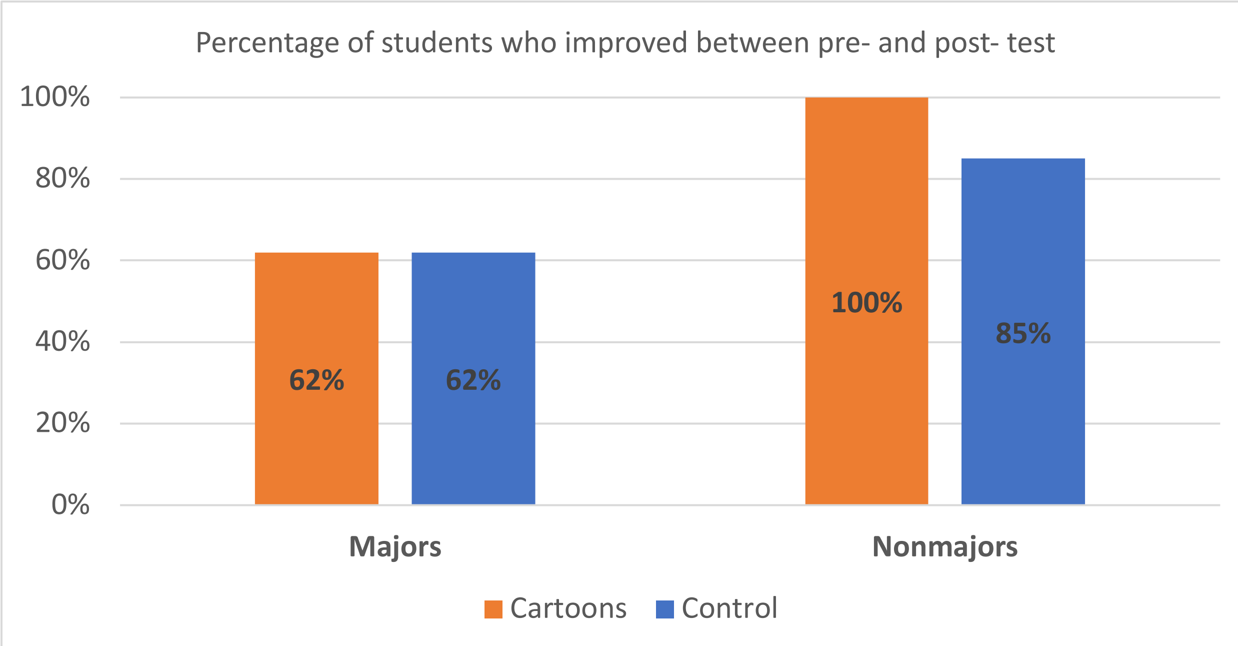


Figure 4. Percentage of students who improved between pre- and post- test. Results showed that 62% of majors in the short answer group improved on the post-test (n=21), and 62% of majors in the cartoon group improved on the post-test (n=29). Meanwhile, 85% of Nonmajors in the short answer group improved on the post-test (n=19), and 100% of nonmajors in the cartoon group improved on the post-test (n=19).

Majors. A two-sample *t*-test showed that there was no significant difference between the majors cartoon and short answer groups on their pre-test, with means of 56.5% (SD=23.2) in the short answer group, and 64.5% (SD=23.2) in the cartoon group, $t(43)=-1.213$, $p=0.232$ (Figure 5). The students' pre-test scores showed a normal distribution, with three students scoring full points in the cartoon group, and one student scoring full points in the short answer group. After two teaching interventions, the cartoon group scored an average of 76.6% (SD=17.6) on the post-test, compared to 68.0% (SD=17.6) by the short answer group (Figure 5). The gain score by the cartoon group averaged 12.1%, while the gain score for the short answer group averaged 11.6% (Figure 5). A two-sample *t*-test showed that this was not a significant difference, $t(43)=-0.0726$, $p=0.47$. After removing the students who scored full points on their pre- and post- tests from the *t*-test, there was still not a significant difference between the two groups, with averages of 14.8% improvement for the cartoon group, and 11.6% improvement for the short answer group, *t*(42)=-0.465, p=0.322. The average normalized learning gain (Hake's *g*) for the cartoon group was 0.067 (SD=0.762), while the average normalized learning gain for the control group was -0.19 (SD=1.75) (Figure 5). Finally, 62% of majors in the short answer group improved on the post-test (n=21), and 62% of majors in the cartoon group improved on the post-test (n=29) (Figure 4).

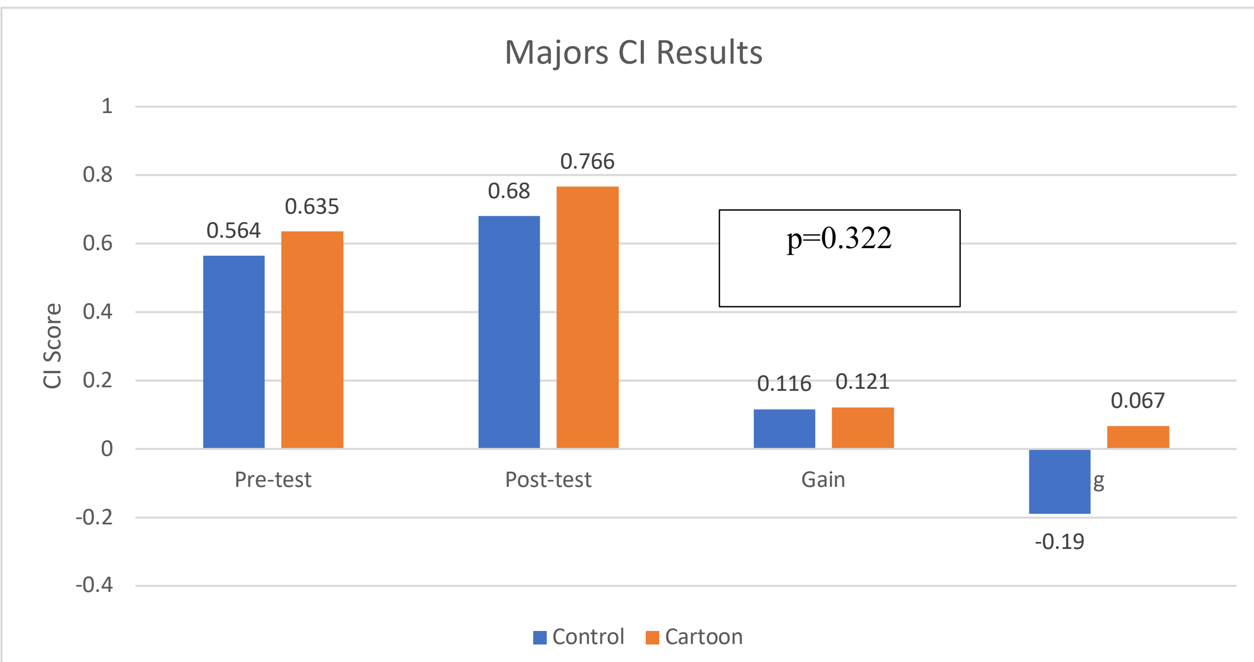


Figure 5. Majors Results. After two teaching interventions, the cartoon group scored an average of 76.6% (SD=17.6) on the post-test, compared to 68.0% (SD=17.6) by the short answer group. The gain score by the cartoon group averaged 12.1%, while the gain score for the short answer group averaged 11.6%. A two-sample *t*-test showed that this was not a significant difference, *t*(43)=-0.0726, p=0.47. The average normalized learning gain (Hake's *g*) for the cartoon group was 0.067 (SD=0.762), while the average normalized learning gain for the control group was -0.19 (SD=1.75).

4.3 | Improvement on specific concept inventory questions

For both the majors group and the nonmajors group, the performance of concept cartoon students and short answer students was compared by calculating the average improvement between their pre-test scores and their post-test scores for each individual concept inventory question using a radar graph (Figure 6). In the radar graph, the orange line shows the percentage of improvement by the short answer students for each question, and the blue line shows the percentage of improvement by the concept cartoon students.

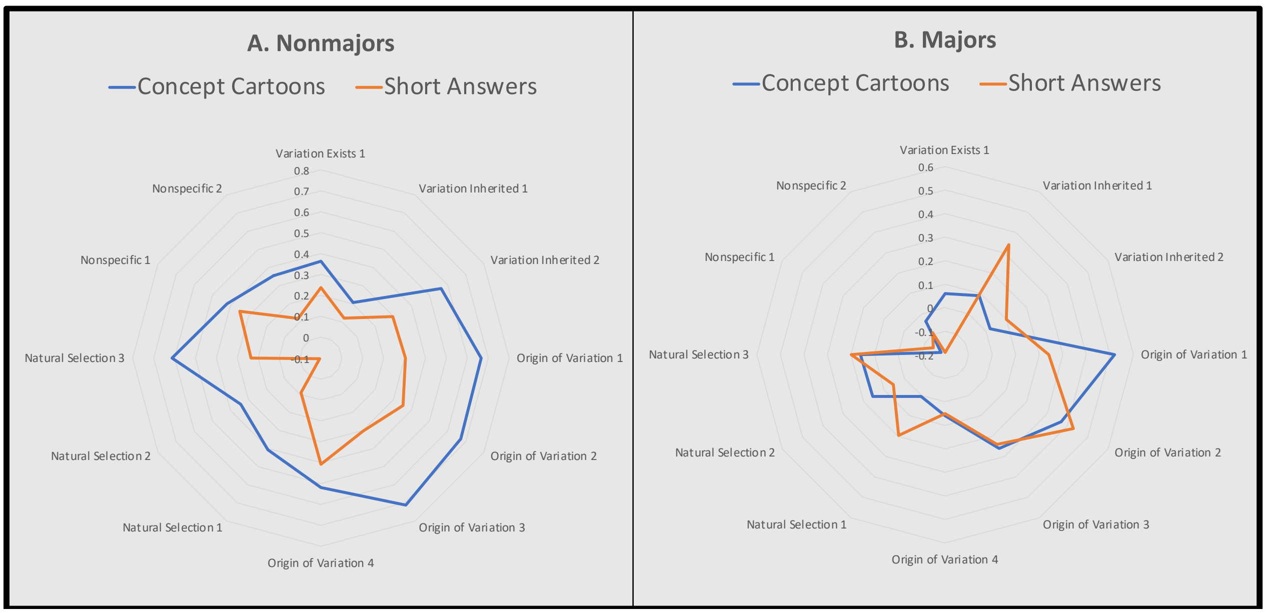


Figure 6. Gain scores for each CI question. Nonmajors concept cartoon students improved more than short answer students on all concept inventory questions. Majors concept cartoon students improved more on some, but less on others, than short answer students.

The nonmajors' radar graph (Figure 6A) shows that concept cartoon students improved more between their pre-test and post-test overall, as well as on every question, compared to short answer students, which is indicated by the blue line being closer to the outer edge than the orange line. The concept cartoon group showed the greatest improvement on Origin of

Variation questions 1, 2, and 3, as well as Variation Inherited question 2 and Natural Selection questions 1, 2, and 3.

The majors' radar graph (Figure 6B) shows that cartoon students improved more between their pre-test and post-test than short answer students on Origin of Variation question 2, Variation Exists question 1, and Natural Selection question 1. However, the short answer students improved more than cartoon students on Variation Inherited question 3, Natural Selection question 9, and Natural Selection question 10.

The most frequently missed pre-test questions for both the majors and nonmajors were the Origin of Variation questions (Appendix B). Students typically chose answers that focused on organisms "needing" new traits, rather than choosing correct answers that described "random genetic processes" as the origin of variation.

One question was particularly interesting: For the pre-test, 31% of majors in the cartoon group and 33% of majors in the short answer group answered question 2 (Origin of Variation 1) correctly (Figure 7). After the interventions, 82% of majors in the cartoon group (n=29) answered the question correctly compared to 57% of majors in the short answer group (n=21). The cartoon group's 51% improvement is more than double the improvement of the short answer group's 24% improvement (Figure 7).

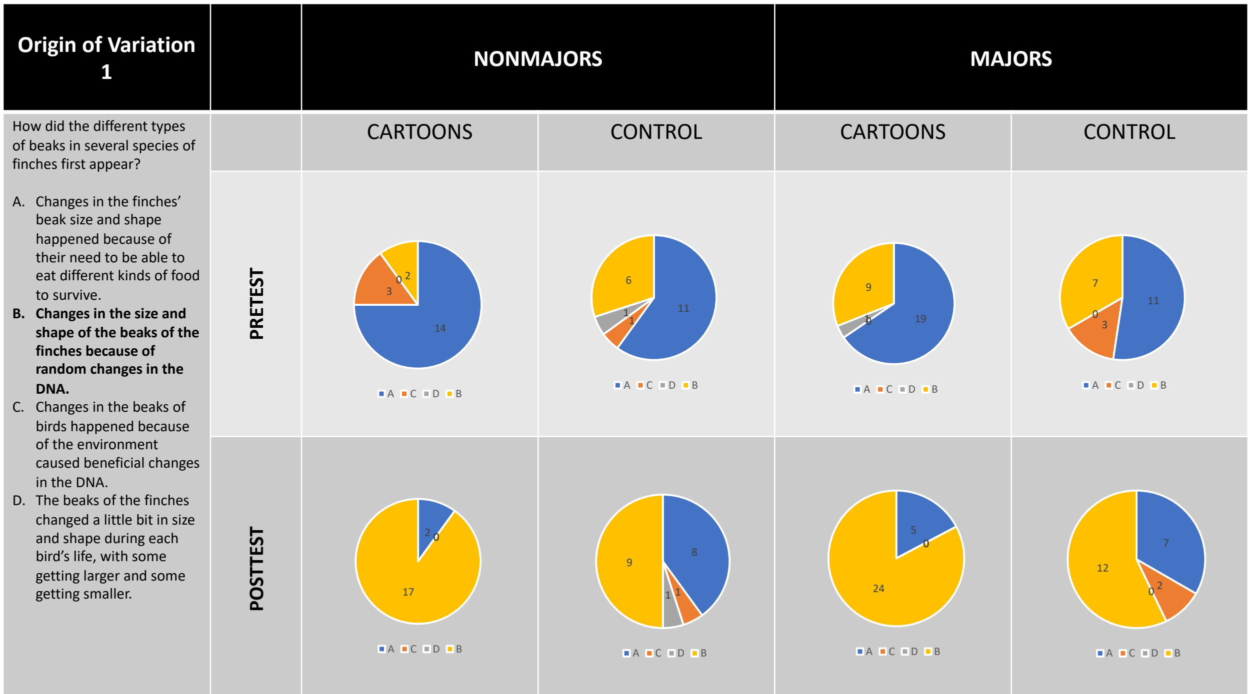


Figure 7. Origin of Variation 1 pie chart. Correct answers to Origin of Variation question 1 increased more for students in the cartoon group for both majors and nonmajors compared to control.

Pie chart summary tables for individual CI questions. Pie charts for each CI question in Appendix D reveal that concept cartoons were superior at improving students' conceptions for both majors and nonmajors for certain items (OV1, OV3, VI3). For other items, concept cartoons were only superior for the nonmajors students (OV2, VI2, NS1, NS2, NS3), while majors students did about the same whether they had cartoons or short answers (Appendix D). When cartoons were superior for both majors and nonmajors, the positive effect of the cartoons appears to be larger in most cases for the nonmajors students than for the majors. In fact, the nonmajors' cartoon group performed better (higher percentages of correct answers) than either majors group on several questions on the post-test (VE, OV1, OV2, OV3, NS1, and NS3) (Appendix D).

The pie charts also reveal which distractors were chosen most often, and thereby show that concept cartoons effectively reduced the most common alternative conceptions, particularly compared to the control group. An example of this is seen in the pie chart for Origin of Variation 1, which shows that the most common incorrect answer choice made by majors and nonmajors students on the pre-test was that "changes in the finches' beak size and shape happened because of their need to be able to eat different kinds of food to survive" (Figure 7). After the concept cartoon intervention, this choice was reduced from 74% to 10% in nonmajors (compared with 57% to 42% in control), and from 65% to 17% in majors (compared with 52% to 33% in control) (Figure 7; Appendix D).

Two CI questions were not directly targeted by intervention activities, though the questions are indirectly related; one item shows slightly greater improvement by the nonmajors cartoon students compared to other treatment groups (Nonspecific 1), while the other item showed no obvious superiority of any treatment group (Nonspecific 2) (Appendix A).

5 | DISCUSSION

This study sought to determine whether a concept cartoon intervention could improve student conceptions about the role of genetic mutation in natural selection. This study was designed to determine if a concept cartoon intervention, as compared to a short answer intervention, that addresses concepts surrounding the connection between genetic mutation and evolution by natural selection led to enhanced understanding and application of accurate conceptions among college biology students (both majors and non-majors), as measured by correct answers to concept inventory questions.

This study found that concept cartoons indeed led to greater improvement on concept inventory scores for nonmajors compared to the control group. The gain in CI scores for the cartoon group was much greater than the control group gain, with a significant difference in average scores and a large effect size. For majors, cartoon students improved more than control students overall, but the difference was not significant and the effect size was small. These results indicate that concept cartoon teaching interventions are at least as useful as short answer activities for biology majors, and are more useful than short answer activities for nonmajors. This suggests that concept cartoons may be used to enhance understanding and application of accurate conceptions among college biology students, particularly nonmajors.

In general, concept cartoons were perceived as helpful by both majors and nonmajors students based on survey results. Both majors and nonmajors who participated in concept cartoon activities reported liking the cartoons for several reasons, such as providing a visual aid, making concepts simpler to understand, practicing critical thinking skills by examining incorrect ideas, simulating a multiple-choice exam, applying knowledge to real-life scenarios, providing more detail or complexity to concepts, and reviewing what they had already learned. This feedback suggests that concept cartoons are valued by, and appropriate for college-leveled students, both majors and nonmajors.

Furthermore, qualitative responses indicate that the concept cartoon activities were effective in eliciting correct conceptions from students. Correct cartoon answer choices matched up with correct conceptions in written responses 99.5% of the time. This indicates that students' responses to concept cartoons could reasonably be used as an informal assessment to gauge student conceptions, which may save time in evaluating a large class.

Concept cartoons also led to a higher average of accurate conceptions for both groups compared to short answer activities, suggesting that they may be more effective at promoting understanding.

Finally, pie charts for each treatment group, majors and nonmajors, reveal that students who discussed concept cartoons chose the most common distractors less often than the control group. In particular, concept cartoon students improved the most on CI questions that focused on origin of variation. This indicates that concept cartoons may be more effective than short answer questions at improving student conceptions and could be used as an effective teaching intervention. The concept cartoons used in this study appear to be especially useful for targeting concepts about Origin of Variation in natural selection.

While majors students reported liking concept cartoons and did very well on the concept cartoon activities, they did not perform significantly better than control on their final exam overall, and though there was a difference, the effect size was small. Majors cartoon students improved their normalized learning gain scores on average, while majors control students decreased their scores on average. The majors performed better on certain questions, but not others, when compared to the control group. Notably, the entire majors' class did not perform as well as expected on the post-test compared to the pre-test, with a class average of 72.5%. (For comparison, the nonmajors class average was 73.0%). Biology majors were expected to answer more CI questions correctly than the nonmajors because they were in a class specifically focused on evolution and had taken Cell Biology the previous semester (although the genetics content in that course is limited).

The majors' final exam performance overall may have been influenced by external factors that could have affected these results. Notably, this was a hybrid semester that took place during the middle of the COVID-19 pandemic. Majors students, who typically have heavy science course loads, may have been more overwhelmed in this unusual circumstance than nonmajors students. It is also possible that the majors students believed they would not be tested on concepts from the intervention activities for some reason, and so perhaps they did not study them as well as the nonmajors did.

Previous studies have shown that there is a difference between how majors and nonmajors learn topics in biology (Klymkowsky, 2005; Knight & Smith, 2017), though studies conflict on how they are different. For example, Knight and Smith (2017) showed that majors in genetics courses outperformed nonmajors on identical content assessments, finishing with significantly higher learning gains. However, other studies have shown that nonmajors' courses have produced greater learning gains than majors' courses (Klymkowsky, 2005). This is perhaps because, as Sundberg and colleagues (1994) found, students develop more expert conceptions when fewer details are taught. In these studies, majors and nonmajors ended the semester at similar levels of expertise in biology concepts (Sundberg & Dini, 1993; Sundberg, Li & Dini., 1994), which is corroborated by the present study. When treatment groups were collapsed, the nonmajors students matched the majors students in levels of understanding on the post-test, with much greater learning gain scores.

It should be noted that the control group could also be considered an intervention based on active learning principles. The control students wrote out short answer responses and discussed them with partners and as a group. This may have been equally stimulating from a constructivist standpoint for the majors group, when compared to concept cartoons. For the nonmajors group, however, it appears that having an added visual aid and being able to choose answers from a group of common alternative conceptions was more helpful than a typical active learning exercise. Concept cartoons may be more beneficial for some students than short answer work because they provide students with the chance to consider alternative conceptions, and because they allow students to test out concepts on real examples with a visual aid provided. This conclusion is supported by many nonmajors' qualitative responses about concept cartoons, such as:

> *"I like these concept cartoons because I am a visual learner and being able to see what I am being asked about helps me a lot."*
>
> *"I feel like they were very helpful because they gave us multiple answers to where we could possibly see what worked vs what didn't."*
>
> *"They helped me directly address the other explanations for genetic variation that I have heard from other people and that I could have incorrectly concluded on my own."*

Overall, these results indicate that concept cartoons may be a useful learning activity for college biology instructors to address common alternative conceptions regarding the role of genetics, particularly origin of variation and natural selection, especially for nonmajors. A concept cartoon discussion and consensus activity could be used following a lecture or lab to increase student understanding, improve exam scores, and help instructors gain a sense of what conceptions are held by their students.

5.1 | Notes about majors vs nonmajors

It has been proposed by some that nonmajors students develop more sophisticated conceptions about topics in biology than majors due to receiving a more manageable amount of content and difficulty-level in their courses (Sundberg and Dini, 1993; Sundberg et al., 1994). In the present study, nonmajors cartoon students performed better on their final exams than majors students, using identical exam questions as a measure.

While majors did very well on the cartoon interventions, it did not carry over to their final exams. Perhaps majors students who chose distractors on the final exam, but not on the cartoon intervention, developed confusion from an overwhelmingly detailed amount of knowledge that they had recently acquired. This would support the idea that an overload of course content could prevent majors from sculpting more sophisticated conceptions, or it could mean that in the moment of pressure, such an overload can cause them to revert to old ideas.

It is conspicuous that many majors reported that concept cartoons provide more detail, complexity, or perspective to concepts, while none of the nonmajors reported this type of feedback. This finding could imply that the majors (who were learning specifically evolution) did not have enough concurrent genetics instruction. Perhaps concept cartoons work best as a complement to simultaneous genetics and natural selection instruction and require more emphasis on genetics than the majors learned during their regular coursework.

5.2 | Alternative conceptions persist

In the end, the highest average score on the CI posttest was the nonmajors concept cartoon group, at 82% correct. In comparison, the nonmajors control averaged 65%, and the majors class averaged 72% (again, no significant difference between treatments). These numbers are lower than desired for an end-of-semester assessment. These results appear to add to the large body of existing data showing that alternative conceptions are resistant to teaching interventions. While active learning activities have been associated with fewer alternative conceptions, previous work has shown that after a year of college biology education, 70% of students continued to use at least one alternative conception when explaining evolution (Nehm & Reilly, 2007).

5.3 | Notes about specific cartoons

Gazelles. During the intervention, 100% of the majors students and 84% of the nonmajors students chose the correct answer on the Gazelles concept cartoon. This concept cartoon was worded almost exactly like the corresponding question on the CI post-test, with only the word "gazelles" changed to "buffalos," and the answer choices elaborated from two-word answers to short sentences. While the nonmajors students scored 68% for this question on their post-test (a 57% improvement), the majors only scored 73% (a 5% improvement). This finding is confusing because it shows that while the cartoon was very helpful for the nonmajors, it appears that the accurate conceptions demonstrated by the majors on the intervention did not carry over to their post-test. Every single person in the majors group answered the question correctly in lab, and then only a few students improved on the final exam. This may be because the students worked in pairs on the intervention, but individually on the post-test. It may also have been due to exam stress. Alternatively, it may be due to something that was learned during other class activities between the intervention and the final exam.

Lilies. The first version of this cartoon stated as the correct answer: "C. Some [lilies] have cellular differences such as ability to photosynthesize that can affect their ability to survive."

This wording threw off most students in the morning lab section. 8 students chose B (38%), 5 students chose D (23%), 1 student chose A (5%), and only 7 students chose the correct answer, C (33%). Their explanations were also inaccurate, showing that they reverted to more intuitive alternative conceptions when presented with an unfamiliar situation for the concept of Variation Exists. They said things like:

"I chose D because the composition of what makes the plant stays the same (i.e. the cells that compose them)."

"Option C cannot necessarily be proven based upon the given information, and Option D is correct in saying that they do look different, but they have unique DNA sequences that would change the cells from one plant body to the next. It is evident that some lilies are different sizes, and there could be argument as to why it effects their means of survival."

"I cannot prove option C based on a photo."

After changing the phrasing to "cellular differences," 87% answered correctly, but some students still had trouble. For example, one student said:

"The plants are the same because the composition is the same, the cells are not changing unless there are mutations."

This may indicate that the students (all of whom were majors) struggled to transfer the relevant concept (Variation Exists) to the cellular level, or that they are more inclined to look for specific evidence instead of using their imagination to form hypotheticals. Future work may be done to address this finding. Alternatively, this concept cartoon could be reworked even further to address the students' confusion.

Squirrels. The original squirrels cartoon used in this study appeared to be successful at eliciting student conceptions and improving CI scores. However, after several reviews of the qualitative data, it seems that a lingering question may exist in general regarding how mutations increase within a population, and the common alternative conceptions (such as teleology) that go with it. These ideas could be unpacked by creating a cartoon to point out the timing and location of mutations. For example, it might be helpful to ask students how many times a specific mutation occurs randomly when a population changes over time. Students may be under the impression that mutations occur more in one group due to natural selection, instead of understanding that inheritance occurs differentially due to natural selection.

5.4 | Limitations

Limitations to this study include the specific demographic of a private Christian university and the small sample size of 88 participants. Furthermore, this study took place in the middle of the COVID-19 pandemic, which may have influenced the results.

6 | IMPLICATIONS FOR FUTURE RESEARCH AND PRACTICE

With concept cartoons growing in popularity, this work supports their continued expansion in science education, and for teaching natural selection in particular. These results suggest that a visual active learning approach that has students sort through common alternative conceptions may be successful where other approaches have struggled in helping students apply accurate conceptions about natural selection. More research should be conducted to determine how and why majors and nonmajors differ in their response to concept cartoons. Individual cartoons should be further tested in focus groups to ensure they are appropriate for broader settings and applications. More cartoons should be created for the subject of genetics, and more research should be done to determine the association between understanding genetics and success in applying concepts in natural selection. Future research should replicate this study in other settings to determine if these findings can be generalized to other demographics, and during a post-pandemic semester. Furthermore, refinements could be made to the concept cartoons, and new concept cartoons might be added to address lingering alternative conceptions regarding the role of genetics in natural selection, particularly those regarding Variation Inherited.

ACKNOWLEDGEMENTS

I would like to acknowledge Dianne Anderson, who helped me every step of the way. Also, I would like to acknowledge the faculty and students of PLNU who took part in this project, and my research committee for their valuable input. Finally, I would like to acknowledge my family for humoring my notions and cheering me on.

CONFLICTS OF INTEREST

I declare that there are no conflicts of interest.

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Appendix A. Concept inventory questions used for pre- and post- tests

CI, Topic, Level, Reference	CI items used in the study
Concept Inventory of Natural Selection (CINS), Natural selection, High school/ College, (Evans & Anderson, 2013)	**Variation Exists 1** A population of finches has hundreds of birds in a single species. Which sentence best describes the group of finches? A. The finches all share the same traits and are identical to each other. B. The finches share all the most important traits, and all 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. **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.** **Origin of Variation 1** How did the different types of beaks first appear in the finches? A. Changes in the finches' beak size and shape happened because of their need to be able to eat different kinds of food to survive. **B. Changes in the size and shape of the beaks of the finches because of random changes in the DNA.** C. Changes in the beaks of birds happened because of the environment caused beneficial changes in the DNA. D. D. The beaks of the finches changed a little bit in size and shape during each bird's life, with some getting larger and some getting smaller. **Variation Inherited 1** What kind of variation in the traits of the finches is passed on to their offspring? A. Only behaviors that were learned during the finch's life. B. Only traits that were beneficial during a finch's life. **C. Only traits that were coded for by a finch's DNA.** **D.** D. Only traits that were affected by the environment in a beneficial way during the finch's life. **Origin of Variation 2** Where did the variation in body size of three species of finches probably first come from? A. The finches 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 finches. D. D. The finches wanted to become different in size, so helpful new traits slowly appeared in the population.

Evolutionary Developmental Concept Inventory (EvoDevoCI) Evolutionary and developmental biology, College, (Perez Hiatt, Davis, Trujillo, French, Terry, & Price, 2013)	**Natural Selection 1** Approximately 10,000 years ago a population of crayfish entered a cave. Though initially indistinguishable from crayfish that live on the surface, today the cave crayfish do not develop eyes and have *longer antennae that provide an improved sense of smell*. By manipulating their embryos in the lab, it is possible to produce cave crayfish with eyes. When the cave crayfish with and without eyes are placed into a dark, cave environment, they show no difference in survival and reproductive success. When investigating crayfish genes that play a role in the development of the sensory nervous system, it is discovered that a gene known as *sense1* is active at higher levels in the embryos of cave crayfish than in embryos of surface crayfish. When the level of activity of *sense1* is artificially increased in embryos of surface crayfish they develop without eyes and with long antennae. Of the following hypotheses, which best explains how cave crayfish have lost their eyes? A. In the cave population, the *sense1* gene appeared, causing crayfish to lose their eyes and improve their sense of smell. B. In the cave population, mutations in *sense1* that increased the activity of *sense1* appeared repeatedly and more frequently over time. **C. In the cave population, a mutation that increased the activity of *sense1* became more frequent in cave crayfish over time because it also improved sense of smell.** D. In the cave population, the crayfish lost their eyes over time because they did not use them.
Genetics Concept Assessment, Genetics, College, (Smith, Wood, Knight, & Ebert-May, 2017)	**Origin of Variation 3** An isolated population of prairie dogs has longer than average teeth. As a result, they can eat more grass with less effort and are better able to survive. The mutation(s) that resulted in longer teeth: A. allowed the teeth to grow longer over several generations until they reached an optimal length for eating grass. B. arose in many members of the population at the same time. **C. happened by chance.** D. occurred because the prairie dogs needed to be more efficient at eating grass to survive and reproduce. E. E. would only occur in a prairie dog population that eats grass and would not occur in a population that lives on seeds. **Variation Inherited 2** A young man develops skin cancer that does not spread to any other tissues; the mutation responsible for the cancer arose in a single skin cell. If he and his wife (who does not have skin cancer) have children after the skin cancer diagnosis, which of the following statements is most likely to be true? A. All the man's children will inherit the mutation. B. All the man's children will inherit the mutation if the mutation is dominant. C. Some of the man's children may inherit the mutation depending on which of his chromosomes they inherit. D. **D. None of the man's children will inherit the mutation.** **Nonspecific 1**

<table>
<tr><td></td><td>
The MLH1 gene is located on chromosome 3 in humans and four different alleles have been identified. The maximum number of alleles a single normal individual can have is:

A. 1
B. 2
C. 3
D. 4

Variation Inherited 3

A population of buffalos is isolated such that no new buffalos can come into their territory. Which of the following is primarily responsible for the appearance of new alleles in this population?

A. Reassortment of chromosomes during the process of creating sperm or eggs.
B. Mutations in cells that will become sperm or eggs
C. Changes in the environment that favor some buffalo traits over others.
D. Random mating between the buffalos in the population.
</td></tr>
<tr><td>
Biological Concepts Instrument (BCI),

General Biology,

High school,

(Queloz, Klymkowsky, Stern, Hafen, & Kohler, 2017)
</td><td>
Natural Selection 2

How can a catastrophic global event influence evolutionary change?

A. There are short term effects that disappear over time.
B. Only some species may survive the event.
C. New genes are generated.
D. D. Undesirable versions of the gene are removed. Natural selection produces evolutionary change by…

Natural Selection 3

Natural selection produces evolutionary change by…

A. Reducing the effects of detrimental versions of the gene.
B. Producing genes needed for new environments.
C. Reducing the number of new mutations.
D. D. Changing the frequency of various versions of the genes.

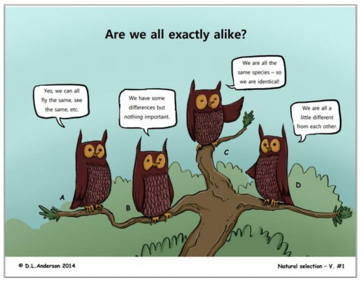
Nonspecific 2

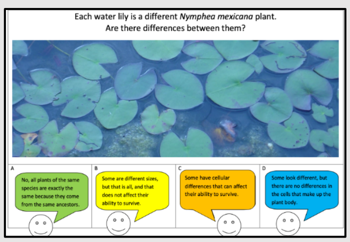
Consider a diploid organism that is homozygous for a particular gene. How might the deletion of this gene from one of the two chromosomes produce a phenotype?

A. If the gene encoded a transcription factor.
B. If the deleted allele were dominant.
C. If one copy of the gene did not produce enough gene product.
D. D. If the gene encodes a multifunctional protein.
</td></tr>
</table>

Appendix B. Quantitative and qualitative responses for concept cartoons

Qualitative response examples were chosen for inclusion in Appendix B if they were well-explained or were typical of the average response for that answer choice.
Correct answers bolded.

<table>
<tr><th>Cartoon</th><th>Nonmajors</th><th>Majors</th></tr>
<tr>
<td>

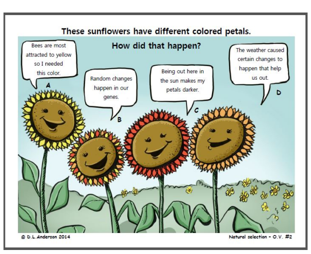
Variation Exists</td>
<td>**80% D**
15% B
5% A
Though they are the same species and share several same characteristics, there will be none that are exactly the same to another.
I totally agree with what you said for number 1. The only way you can be the same is if you have a twin, but even your personalities differ.</td>
<td>Not used with these students</td>
</tr>
<tr>
<td>

Note: The percentages used here are only the evening lab. Replaced with above cartoon because it was complicated for majors students, and it was thought that a simpler version would be better for the nonmajors.

Variation Exists</td>
<td>Not used with these students</td>
<td>**87% C**
6.7% D
6.7% B

I chose this one because the composition of what makes the plant stays the same (i.e. the cells that compose them) however due to mutations and variation of DNA will make them appear different.

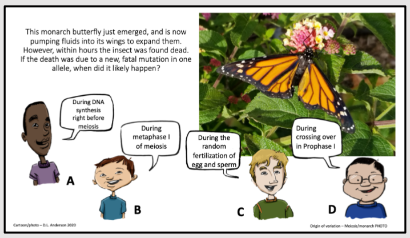
This answer is the best because within individuals of the same species there are small genetic differences known as variations that affect their survival. Even if their common ancestor are the same or their sizes are different it is their cellular level DNA that makes them different.

Not every individual of the same species is exactly the same. Regarding lilies, the fact that some are bigger than others can be credited to each lily's ability to perform photosynthesis effectively. The bigger lilies most likely perform photosynthesis more effectively than the smaller lilies. This is because more effective photosynthesis results in the creation of more glucose molecules for each lily.</td>
</tr>
<tr>
<td>

Origin of Variation</td>
<td>**60% B**
15% A
15% C
10% D
I chose B because the random selection of genes during mitosis allows for changes to happen like the color changes in the pedals.</td>
<td>**85% B**
12% D
3% A
I chose B because the differences in petal color come from genetic mutations, not environmental factors, and they happen randomly as opposed to changing to whatever the plant needs.

D. The weather caused certain changes to happen as with the different seasons</td>
</tr>
</table>

<table>
<tr>
<td></td>
<td>Even though each of the other responses have truths for individual flowers, the majority of variation comes from random changes in genes over time.

I chose A because I’m not fully sure which one it is, but I think their color coming from a function makes sense, since function is related to structure.</td>
<td>and the flowers need to adapt and change to these new changes.</td>
</tr>
<tr>
<td>

Genetic Mutation</td>
<td>50% A
30% D
10% B
10% C

I chose A for 3 because DNA replication is when genetic abnormalities occur.

D. During crossing over in meiosis, there is an exchange of DNA between homologous chromosomes which may have played a part in the development of the fatal mutation.

D. During crossing over in Prophase I. This is when genetic information is shuffled around, so it would be when the new mutation formed.</td>
<td>79% A
15% D
6% B
If death was caused by a new mutation in one allele that was not present previously, then it must have occurred during the DNA replication phase, which would have changed the allele.

A, because DNA replication is where mistakes are most likely to happen to the genome, I think; I wasn't too sure about this question.</td>
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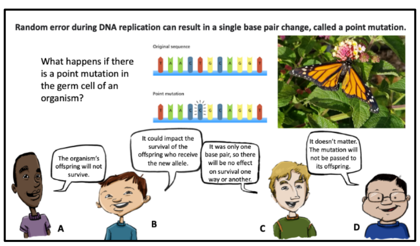
<td>

Variation Inherited/Genetic Mutation</td>
<td>90% B
10% D
I chose B because the mutations are going to get passed on to the offspring, which could potentially affect the physical characteristics of the organism, which could be fatal when the mutations are being passed down to the offspring.

Point mutations can have a range of beneficial, neutral, or negative impacts, so although the offspring could be affected by this change, it's not a guaranteed death sentence.</td>
<td>97% B
3% D
The correct answer is B. Germ cells are egg and sperm cells used to pass on genes from generation to generation. Mutations resulting in new alleles may or may not affect an organism's ability to survive, depending on the type of mutation and the gene function.</td>
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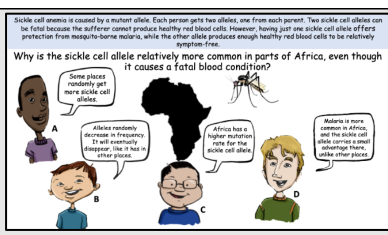
<tr>
<td>

Differential Survival/Natural Selection</td>
<td>80% D
20% C
D. In different parts of Africa, the sickle cell allele is more prominent because malaria is more present in this part of the world, therefore, carriers of this allele have a higher survival advantage and are more likely to reproduce because of their survival.</td>
<td>88% D
3% B
9% C
D. Since the sickle cell allele offers an advantage in Africa, it makes sense that the allele frequency for sickle cell anemia would be higher there. People who have that one sickle cell allele will be at an advantage over others in the population.</td>
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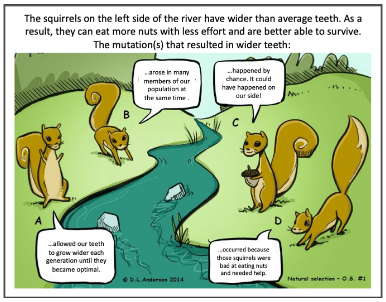

Origin of Variation/Genetic Mutation
</td>
<td>
68% C
21% A
2% B
I believe it is C because genetic mutations occur randomly.

The squirrels on the left side had a mutation that allowed them to have wider teeth which continued to appear generation after generation until most squirrels on left side had wider teeth.
</td>
<td>
89% C
8% B
3% D
We chose "C" because it best fits the definition of natural selection. The mutation for wider teeth likely was a random event. It then enabled the squirrels who had the mutation to better fit their environment, so it was passed down over generations.

Mutations are totally random. Because of this, we can determine that the random mutation occurred first that resulted in wider than average teeth, but became more frequent in the population due to natural selection.
</td>
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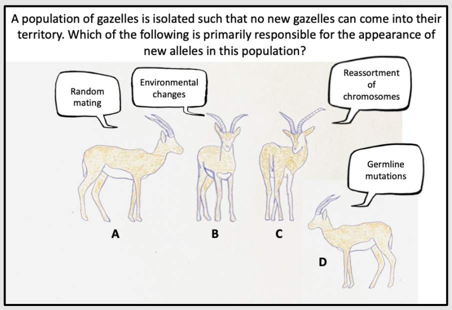
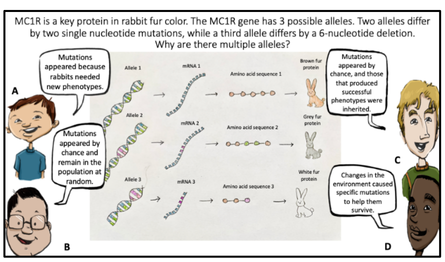


Origin of Variation/Genetic Mutation
</td>
<td>
84% D
11% C
5% B
D. The only source of new alleles.

D. Germline mutations is responsible for the appearance of new alleles in this population as it can change the gene coded. If there is no new gazelles in an isolated area random mating will not cause new alleles. Environmental changes and reassortment of chromosomes do not cause the appearance of new alleles.
</td>
<td>
100% D
D. We chose germline mutations because the mutations could form when the DNA is being replicated to make the gametic cells.

The best choice is D because it is the only option that could possibly lead to the formation of new alleles by mutation. Random mating and reassortment of chromosomes both deal with a shift in the same alleles, but do not create new ones. Mutations will lead to different sequences that will create new alleles within the population.
</td>
</tr>
<tr>
<td>


Origin of Variation/Variation Inherited/Differential Survival/Natural Selection
</td>
<td>
84% C
11% D
5% B
I chose C because mutations occur by chance and if the phenotype that is inherited works out well for the generation of rabbits it will keep being passed on.

Mutations occur at random. The fur color is a heritable trait, and the fur color that offers the most protection against predators will result in a greater survival rate of that color bunny. This allows for that color fur bunny to reproduce more, passing on the trait for a specific color, resulting in a more successful phenotype in terms of survival.
</td>
<td>
89% D
8% B
3% D
We chose B because mutations are inherited by chance, not by a means of whether or not the mutation creates a successful phenotype.

The best option is C because mutations do occur by chance, narrowing it down to options B and C. C is a better answer because the mutations do not remain in the population at random, but are inherited into the population, making that specific allele prevalent in the population. Those phenotypes that are inherited by the population eventually become favorable in the population, so the mutations that occurred do not remain in the population by random but are there with a specific purpose.
</td>
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</table>

Appendix C. Student reactions to concept cartoons

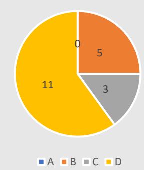
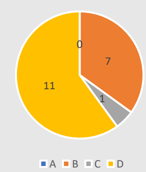
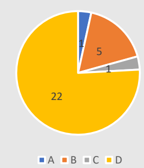
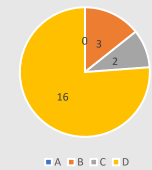
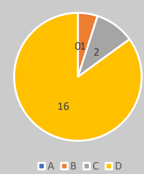
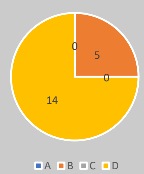
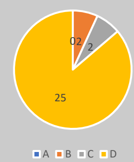
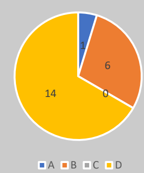
Theme of student responses	**Nonmajors**	**Majors**
1. Concept Cartoons allow students to apply concepts to real examples.	• *They were so helpful for me because they put the concepts we learned into real-world scenarios so I could understand them better.* • *These concept cartoons are helpful when learning about evolution because it brings up examples and allows for the concepts of biology to be applied to real-life situations.* • *They show the difference instances where mutations occur. These questions and cartoons provided examples that made it clear that mutations are random.*	• *Concept cartoons provide an easily accessible and clear example of how evolutionary phenomena occurs.* • *Concepts cartoons help solidify my understanding of concepts in evolution by providing realistic or close to realistic responses or interpretation to evolutionary concepts.* • *Concept cartoons help solidify my understanding of evolutionary concepts because it takes the specific concepts learned and applies them to real-life scenarios. These cartoons helped explain the reasoning for why certain relationships exist at the microevolution level.* • *They give examples to why evolution works with mutations, the environment, and the orgnisms evolving.* • *Concept cartoons help solidify my understanding of concepts in evolution because they provide different situations, examples, or questions with answers from every angle. These questions really make me think and help me understand these different concepts regarding evolution.*
2. Concept Cartoons simplify concepts.	• *It made the concepts of mutations and natural selection easier to grasp. Sometimes a textbook can make the content a bit confusing. Applying the concepts to easy-to-understand cartoons makes content more applicable and understandable.*	• *They break down evolution concepts into simple ideas that provide the foundation for applying them to more complex scenarios.* • *They provided a detailed, yet concise view into many of the different aspects of Evolution, such as how/why allele frequencies can change.* • *the cartoons essentially "dumb things down" which helps me understand it more clearly at a simpler level.* • *They simplify complicated ideas that allow me to process and understand harder concepts in evolution better such as mutations.* • *I find it more helpful to have a visual simplified scenario to begin grading onto these concepts.* • *Yes, they really simplify the ideas so we feel more comfortable going more in-depth in the subject.*
3. Concept Cartoons simulate a multiple choice test.	• *I felt less pressure to get the right answer and focus on my score and was able to really dial into what I was learning. This was actually super helpful.*	• *I really enjoy these questions because it also helps me prepare how to attack a multiple choice test question by utilizing deduction to narrow down the choices to one or two logical answers. Overall, I think that the concept cartoons do improve my understanding of the concepts.*
4. Concept Cartoons provide a visual aid.	• *I like these concept cartoons because I am a visual learner and being able to see what I am being asked about helps me a lot.* • *The concept cartoons are really helpful for visualization. I can understand mutations, alleles, and other concepts through these pictures.* • *For me, cartoons have always been a faster way to learn concepts because I read the speech in my own words and it is helps me visualize and remember better. It also helps me stay more focused on what I am learning because it is more interesting to look at and I do not get bored. It is helpful when learning about evolution because it allows me to see what is going on and think for myself.*	• *I like the visuals that I like the visuals that are provided and the videos provide thorough and helpful explanations as to why the correct is answer correct.* • *I find it more helpful to have a visual simplified scenario to begin grading onto these concepts.*

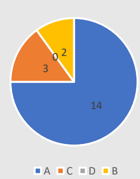
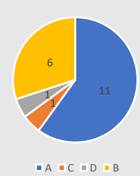
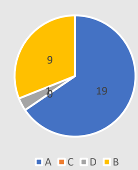
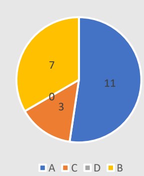
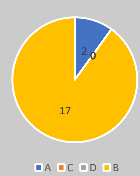
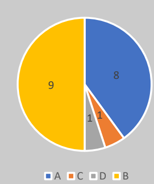
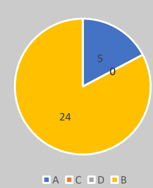
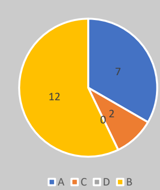
	• *It also allows you to visually see the examples and choose the answer based off of the cartoon.* • *These cartoons helped my learning about evolution because of the visuals.* • *I found these cartoons very helpful because I am a visual learner. Actually seeing the different options as well as a fun colored visual, I got to understand each side a little more as in which ones were a potential answer versus which ones sounded dumb.* • *These cartoons were helpful because they helped give a visual representation of the difference between different possible answers for how evolution could occur and helped me lean about new concepts* • *They illustrate and give a visual on how different genes change and the logistics which contribute to these changes.* • *They helped me visualize.* • *They gave me a visual.*	
5. Concept Cartoons help students critically examine alternative conceptions.	• *They helped me directly address the other explanations for genetic variation that I have heard from other people and that I could have incorrectly concluded on my own so that I now better understand why those opinions are incorrect.* • *They show the different instances where mutations occur and explain the thought process of the different answers. It helps you really think through and make sure the answer you choose has a correct explanation.* • *I feel like they were very helpful because they gave us multiple answers to where we could possibly see what worked vs what didn't, but then she explained why the answer was it.* • *The answers given allowed me to critically think about evolution and go with the answer that seemed the most accurate according to the videos.* • *The concept cartoons helped me to distinguish what the primary reason for mutations in the animals. They gave me a visual and multiple options that enabled me to pick the correct option.*	• *They are helpful because they allow us to apply our knowledge of a subject immediately after learning which helps understand the information better.* • *These concept cartoons help solidify my understanding of concepts in evolution by allowing me to think critically on a problem and come to a conclusion and then see if I was correct. These concept cartoons help solidify my understanding of concepts in evolution by allowing me to think critically on a problem and come to a conclusion and then see if I was correct. If I was not correct these cartoons have me understand why I was wrong and why the answer is correct.* • *They help by explaining why some hypothesis is incorrect, as well as give reasons to why it is the way evolution works with mutations, the environment and the organisms evolving themselves.* • *It was helpful to see the nuance between different incorrect interpretations of biological principles.* • *It is helpful to explain what is wrong with the other answers so I can see where in my thinking I was incorrect if I got the answer wrong.* • *They help you explain in detail why answers are correct or incorrect instead of just giving you the correct one.* • *It is extremely helpful to understand why incorrect responses or reasonings are wrong and rectify that thinking method to the correct interpretation or understanding of concepts in evolution for learning and testing purposes.* • *Allows common misconceptions to be debunked and thoroughly explained. Also provides a great explanation for the correct answers.* • *It is helpful having an explanation why each one of the other perspectives was incorrect.* • *…where some answers are partly true but the wording of the statement is false. It makes me really think about each answer and eliminate all of the false ones.*
6. Concept Cartoons provide more detail, complexity, or perspective to concepts.		• *The concept cartoons delved into some specific topics that we didn't cover in class. Through this activity, I was able to stimulate my natural curiosity on the matter as well as learn new concepts. Learning these new concepts reinforced what I've learned in class by taking a new perspective to similar key points on evolution.* • *Concept cartoons help to solidify my understanding of concepts in evolution by giving multiple perspectives and choosing the one that is correct and then having an*

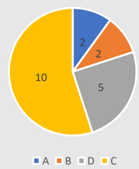
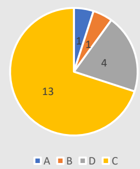
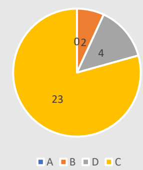
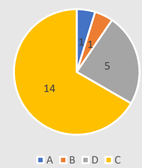
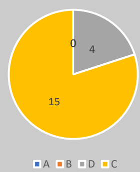
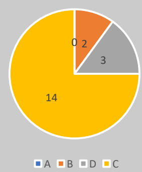
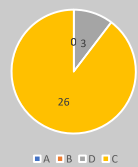
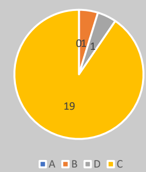
		explanation why each one of the other perspectives was incorrect. • *Concept cartoons force you to think with all sorts of other views on a subject but you have to know your material to truly figure out what's write and wrong and prove why right is right, and why wrong is wrong.* • *They provide different situations, examples, or questions with answers from every angle. Concept cartoons help solidify an understanding of concepts by giving a variety of answers that may be applicable, which makes you think deeper about the answer.* • *Concept cartoon helps solidify my understanding of evolution because it asks tricky questions.* • *I think they help to figure out the details of the content because they provide answer choices that have only slight changes in them.*
7. Concept Cartoons help students review.		• *I like this idea a lot, I think it is a great form of review.* • *Reviewing these topics helped me refresh my memory of what we have already learned.* • *Concept cartoons have helped me review concepts that I've learned in the past, which then allow me to obtain a better understanding of how evolution works in regards to genetics.*

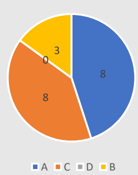
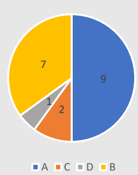
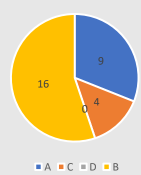
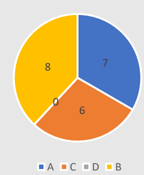
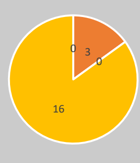
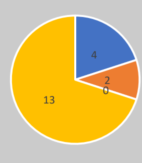
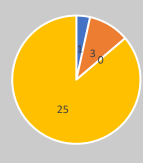
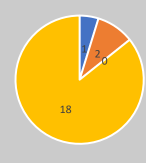
Appendix D. Pie charts for individual CI questions pre- and post- test by intervention group

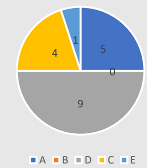
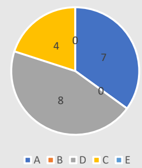
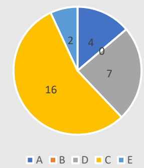
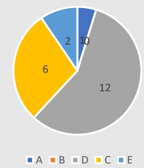
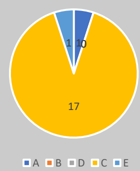
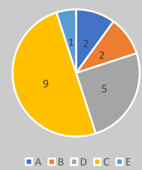
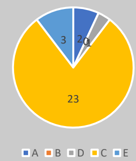
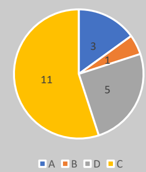
(Correct answers in yellow)

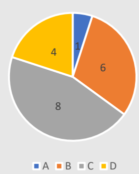
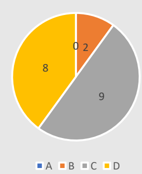
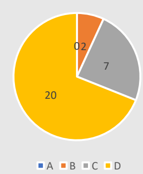
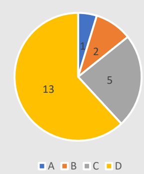
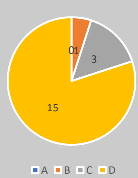
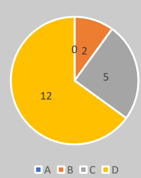
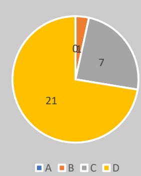
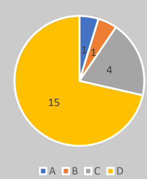
Variation Exists		NONMAJORS		MAJORS	
A population of finches has hundreds of birds in a single species. Which sentence best describes the group of finches? A. The finches all share the same traits and are identical to each other. B. The finches share all the most important traits, and all the small differences 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.**		CARTOONS	CONTROL	CARTOONS	CONTROL
	PRETEST				
	POSTTEST				

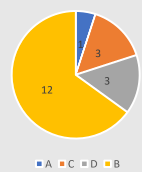
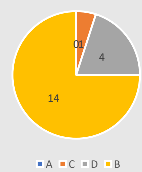
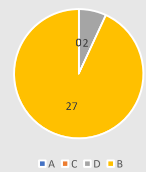
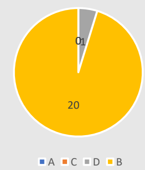
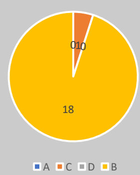
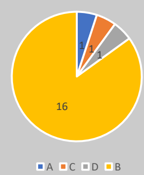
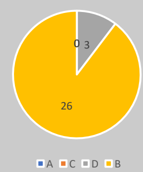
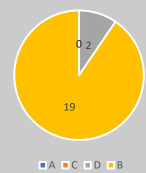
Origin of Variation 1		NONMAJORS		MAJORS	
How did the different types of beaks in several species of finches first appear? A. Changes in the finches' beak size and shape happened because of their need to be able to eat different kinds of food to survive. **B. Changes in the size and shape of the beaks of the finches because of random changes in the DNA.** C. Changes in the beaks of birds happened because of the environment caused beneficial changes in the DNA. D. The beaks of the finches changed a little bit in size and shape during each bird's life, with some getting larger and some getting smaller.		CARTOONS	CONTROL	CARTOONS	CONTROL
	PRETEST				
	POSTTEST				

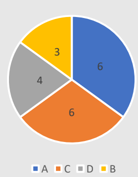
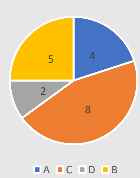
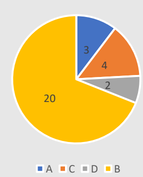
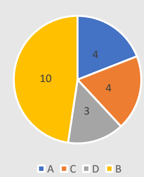
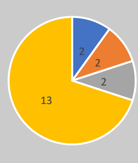
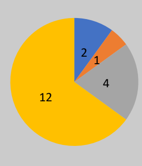
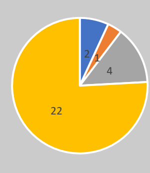
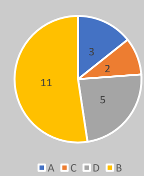
Variation Inherited 1		**NONMAJORS**		**MAJORS**	
		CARTOONS	CONTROL	CARTOONS	CONTROL
What kind of variation in the traits of finches is passed on to their offspring? A. Only behaviors that were learned during the finch's life. B. Only traits that were beneficial during a finch's life. **C. Only traits that were coded for by a finch's DNA.** D. Only traits that were affected by the environment in a beneficial way during the finch's life.	**PRETEST**				
	POSTTEST				

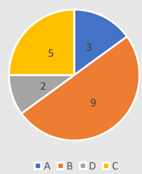
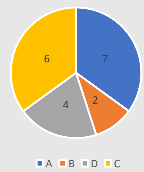
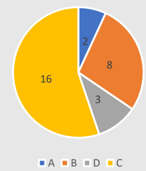
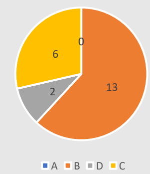
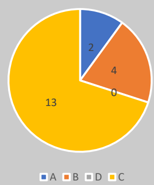
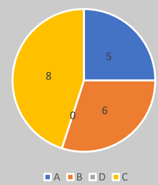
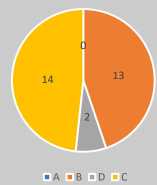
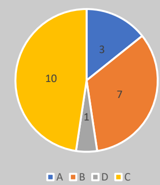
Origin of Variation 2		**NONMAJORS**		**MAJORS**	
		CARTOONS	CONTROL	CARTOONS	CONTROL
Where did the variation in body size of three species of finches probably first come from? A. The finches needed to change in order to survive, so new helpful traits formed. **B. Random changes in the DNA created new traits.** C. The environment of the island caused certain changes in the DNA of the finches. D. The finches wanted to become different in size, so helpful new traits slowly appeared in the population.	**PRETEST**				
	POSTTEST				

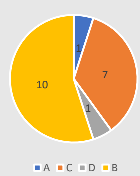
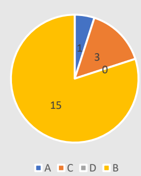
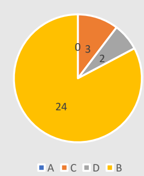
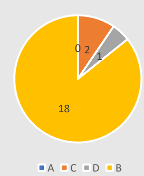
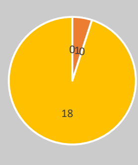
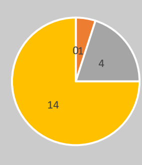
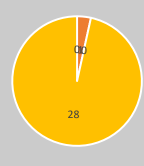
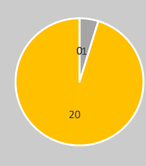
Origin of Variation 3		**NONMAJORS**		**MAJORS**	
		CARTOONS	CONTROL	CARTOONS	CONTROL
An isolated population of prairie dogs has longer than average teeth. As a result, they can eat more grass with less effort and are better able to survive. The mutation(s) that resulted in longer teeth: A. allowed the teeth to grow longer over several generations until they reached an optimal length for eating grass. B. arose in many members of the population at the same time. **C. happened by chance.** D. occurred because the prairie dogs needed to be more efficient at eating grass to survive and reproduce. E. would only occur in a prairie dog population that eats grass and would not occur in a population that lives on seeds.	PRETEST				
	POSTTEST				

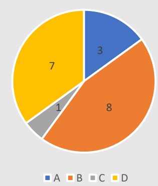
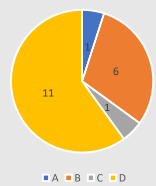
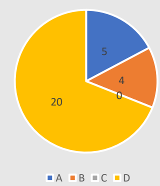
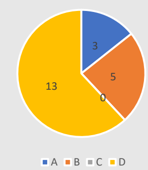
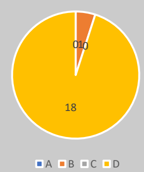
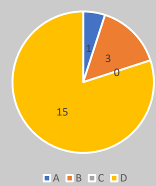
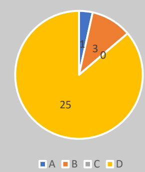
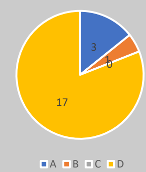
Variation Inherited 2		**NONMAJORS**		**MAJORS**	
		CARTOONS	CONTROL	CARTOONS	CONTROL
A young man develops skin cancer that does not spread to any other tissues; the mutation responsible for the cancer arose in a single skin cell. If he and his wife (who does not have skin cancer) have children after the skin cancer diagnosis, which of the following statements is most likely to be true? A. All the man's children will inherit the mutation. B. All the man's children will inherit the mutation if the mutation is dominant. C. Some of the man's children may inherit the mutation depending on which of his chromosomes they inherit. **D. None of the man's children will inherit the mutation.**	PRETEST				
	POSTTEST				

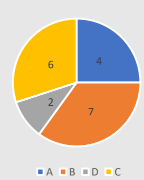
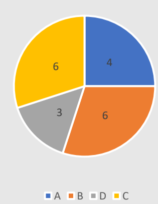
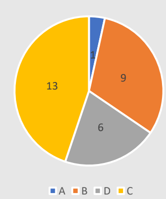
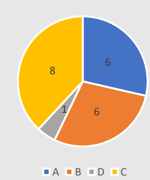
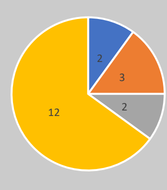
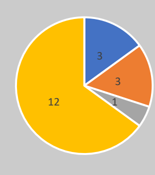
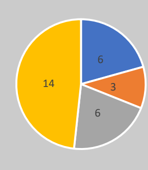
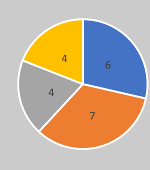
Nonspecific 1		NONMAJORS		MAJORS	
The *MLH1* gene is located on chromosome 3 in humans and four different alleles have been identified. The maximum number of alleles a single normal individual can have is: A. 1 **B. 2** C. 3 D. 4		CARTOONS	CONTROL	CARTOONS	CONTROL
	PRETEST				
	POSTTEST				

Variation Inherited 3		NONMAJORS		MAJORS	
A population of buffalos is isolated such that no new buffalos can come into their territory. Which of the following is primarily responsible for the appearance of new alleles in this population? A. Reassortment of chromosomes during the process of creating sperm or eggs. **B. Mutations in cells that will become sperm or eggs** C. Changes in the environment that favor some buffalo traits over others. D. Random mating between the buffalos in the population.		CARTOONS	CONTROL	CARTOONS	CONTROL
	PRETEST				
	POSTTEST				

Natural Selection 1		NONMAJORS		MAJORS	
Of the following hypotheses, which best explains how cave crayfish have lost their eyes? A. In the cave population, the *sense1* gene appeared, causing crayfish to lose their eyes and improve their sense of smell. B. In the cave population, mutations in sense1 that increased the activity of sense1 appeared repeatedly and more frequently over time. **C. In the cave population, a mutation that increased the activity of *sense1* became more frequent in cave crayfish over time because it also improved sense of smell.** D. In the cave population, the crayfish lost their eyes over time because they did not use them.		CARTOONS	CONTROL	CARTOONS	CONTROL
	PRETEST				
	POSTTEST				

Natural Selection 2		NONMAJORS		MAJORS	
How can a catastrophic global event influence evolutionary change? A. There are short term effects that disappear over time. **B. Only some species may survive the event.** C. New genes are generated. D. Undesirable versions of the gene are removed.		CARTOONS	CONTROL	CARTOONS	CONTROL
	PRETEST				
	POSTTEST				

Natural Selection 3		NONMAJORS		MAJORS	
		CARTOONS	CONTROL	CARTOONS	CONTROL
Natural selection produces evolutionary change by… A. Reducing the effects of detrimental versions of the gene. B. Producing genes needed for new environments. C. Reducing the number of new mutations. **D. Changing the frequency of various versions of the genes.**	PRETEST				
	POSTTEST				

Nonspecific 2		NONMAJORS		MAJORS	
		CARTOONS	CONTROL	CARTOONS	CONTROL
Consider a diploid organism that is homozygous for a particular gene. How might the deletion of this gene from one of the two chromosomes produce a phenotype? A. If the gene encoded a transcription factor. B. If the deleted allele were dominant. **C. If one copy of the gene did not produce enough gene product.** D. If the gene encodes a multifunctional protein.	PRETEST				
	POSTTEST				

Appendix E. IRB-approved consent form

Informed Consent to Participate in Research

Introduction/Purpose I understand that I am being invited to participate in a research study. **Course number/name: ________________** is sponsoring this study at Point Loma Nazarene University. The purpose of this research is to test the effectiveness of teaching strategies in biology education.

Procedures I understand that the proposed length of my participation in this study consists of 5 sessions throughout the semester. During this time, I will watch short media presentations and participate in group discussions regarding relevant concepts in biology. Furthermore, I will provide answers to conceptual inventory questions to demonstrate what I have learned.

Risks There are no more than minimal risks (what one would encounter in daily life) associated with this study.

Benefits My participation in this study will help the researcher understand more about the effectiveness of biology education strategies. In addition, I may benefit as a student from examining concepts in biology, and I may be eligible to receive extra credit for correct answers to conceptual inventory questions.

Voluntary Participation I understand that my participation is voluntary and that I may refuse or withdraw from the study at any time without penalty.

Confidentiality I understand that the data collected for this study and/or any identifying records will remain confidential and kept in a locked file and/or password-protected computer file in the researcher's office. I understand that all data collected will be coded with a number or pseudonym (fake name), that my name will not be used. I further understand that the results of this research project may be made public and information quoted in professional journals and meetings, but information from this study will only be reported as a group, and not individually.

Debriefing I understand that I have the right to have all questions about the study answered in sufficient detail for me to clearly understand the level of my participation as well as the significance of the research. I understand that at the completion of this study, I will have an opportunity to ask and have answered all questions pertaining to my involvement in this study by contacting Marissa Dickison at mdickison111@pointloma.edu after the study is complete, around June 10, 2021**.**

Receipt of informed consent: I acknowledge having received a copy of the consent form. I understand that I may call the investigators involved in the study, or supervising professor, Dr. Dianne Anderson, in order to discuss confidentially any questions about my participation in the study. Also, should I have any concerns about the nature of this study I can also contact the Chair of PLNU's IRB (IRB@pointloma.edu).