POINT LOMA NAZARENE UNIVERSITY

Comparison of Massed Versus Distributed Use of Natural Selection Concept Cartoons in a Secondary Biology Curriculum

Thesis submitted in partial satisfaction

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by

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The thesis of Matthew J. Nasont is approved, and it is acceptable in quality and form for publication:

Chair

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Dedication

This thesis is dedicated to my parents, Joseph and Catherine Nasont. The work that follows is as much a reflection of their encouragement and support, as it is a work of passion on my part. Their unwavering faith in my abilities has been one of the singular driving forces in not only my academic pursuits, but in my life.

Thank you mom and dad. I love you.

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Acknowledgments

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Abstract

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Evolution, by means of natural selection, is a core concept central to understanding biology. A hurdle to effective natural selection instruction is the wide range of alternative conceptions held by students that help them make sense of the world in which they live; including those regarding evolution. Teachers can use formative assessment tools, such as concept cartoons, to identify student conceptions and facilitate conceptual development and progression to scientific conceptions. This study looks at the timing of concept cartoon practice to evaluate if spacing the interventions over a longer time period resulted in differential learning and/or retention compared to massing the intervention within the evolution unity of study. The results showed that both distributing, as well as massing the intervention, resulted in learning and retention. A control group, who did not receive the images and possible answer choices, did not display significant learning. These results indicate the efficacy and versatility of natural selection concept cartoons as a formative assessment tool for use in a secondary biology classroom.

Introduction

Evolution, by means of natural selection, is a core concept central to understanding biological science (Dobzhansky, 1973; Jensen & Finley, 1996; BOSE, 2012). The scientific conception of natural selection requires students to understand, connect, and apply complex principles such as molecular and population genetics, differential survival and reproduction, principles of ecology, and competition. A hurdle to effective instruction is the wide range of alternative conceptions held by students in efforts to understand and make sense of evolution. Student-held alternative conceptions in this field include need-based change (Bishop & Anderson, 1990; Demastes, Good, & Peebles, 1999; Nehm & Schonfeld, 2008; Furtak, 2012), Lamarckian views (Bishop & Anderson, 1990; Demastes, et al., 1999; Nehm & Schonfeld, 2008), failure to separate change in the individual versus the whole species or population (Bishop & Anderson, 1990; Jensen & Finley, 1996; Demastes, et al., 1999; Nehm & Schonfeld, 2008), variation as the result of environmental change (Bishop & Anderson, 1990, Demastes, et al., 1999; Nehm & Schonfeld, 2008; Furtak, 2012), and an inadequate or incorrect understanding of the role random molecular processes play in the origin of variation (Furtak, 2012). A recent study found that only 7% of high school students were able to provide the correct explanation of the origin of variation (Ibid). It is for this reason that this thesis study will focus on how best to assess student conceptions regarding evolution.

Teachers must elicit student conceptions so as to facilitate student conceptual development and progression to scientific conceptions (Furtak, 2012). Formative assessments, such as concept cartoons, can be used to identify existing student conceptions (Keogh & Naylor, 1999). Of particular interest to this study presented here, is the timing of concept cartoons in an attempt to create long term knowledge. Cartoons can be presented all at once, thereby massing their exposure within a particular unit of study over 10 successive class periods (Massed practice), or the cartoons could be distributed over 10 weeks in order to revisit the concepts over a longer duration of time (Distributed practice). Differences in retention and learning using Distributed and Massed practice of formative assessment tools have been studied within a variety of fields (Donovan & Radosevich, 1999). There is, however a dearth of Massed versus Distributed practice research in science education. The focus of this study was to compare Distributed and Massed practice in the retention of natural selection content.

Literature review

Theoretical perspective

A NeoPiagetian perspective of learning states that students reorganize prior knowledge in order to incorporate new information, thus resulting in cognitive change. To accommodate this cognitive restructuring, a classroom should serve as the stage on which students are allowed to articulate their ideas, engage in discussion, support their ideas with experimentation, and to evaluate the students' abilities to interact with conceptions of others (Julyan & Duckworth, 2005). It is important that the classroom environment allow students to explore their own ideas in order for them to create a more complete understanding of how the natural world operates. It is essential that the student interpret and construct their own personal understanding of the content in order to reinforce their learning (Piaget, 1964).

The emphasis in progressive classrooms is to evaluate students' current understandings in order to facilitate their progression to more complete and scientific conceptions. Students enter the classroom having their lifetime of experiences with the natural world, and as such, they have their own ideas about how the world works. It is upon these ideas that they construct new knowledge (Harrison & Treagust 1999, Hammer, 2000, Julyan & Duckworth, 2005). Students' prior conceptions tend to not be scientifically complete, but they are seldom entirely useless as there usually exists some useful aspect or portion of their understanding that a teacher can build upon (Hammer, 2000; Smith, diSessa, & Roschelle,1993). It would be useful for teachers to focus instruction, inquiry, discussion, and their line of questioning in a manner that follows, and is commensurate with, not only how the student processes information, but one that also takes into account the current level of students' understanding (Hammer, 2000, Labinowicz, 1980, Smith et al., 1993).

Natural selection alternative conceptions

High school students possess conceptions that they use to attempt to explain the natural world. Frequently, these student-held beliefs fail to correlate with scientific conceptions. There is a great deal of literature that has documented student alternative conceptions in physics (Brown & Hammer, 2008; Brown & Schwartz, 2009; Hammer, 2000), and biology including natural selection (Bishop & Anderson, 1990; Demastes, et al., 1999; Anderson et al., 2002; Evans & Anderson, 2013; Furtak, 2012), cellular respiration and photosynthesis (Bell, 1985; Wood-Robinson, 1991; Canal, 1999 as referenced in Brown & Schwartz, 2009).

Biology students often have naive views of natural selection (Bishop & Anderson, 1990). If a student holds a deficient understanding of the random molecular nature of the origin of variation and its influence on survival, developing expert conceptions of natural selection and evolution can become difficult. Alternative conceptions about natural selection include, but are not limited to, associations of need and/or want with the origin of new traits, environmental changes bringing about new phenotypes in a population (Demastes, et al., 1999; Bishop & Anderson, 1990; Opfer et. al, 2012), the formation of, and heritability of acquired characteristics, and incomplete understanding of the random molecular nature of mutation and its overall impact on the formation of novel phenotypes (Bishop & Anderson, 1990). It is therefore of great import that educators are able to effectively assess these conceptions in order to scaffold instruction that creates long term retention.

Concept cartoons as a formative assessment tool

Following a NeoPiagetian constructivist perspective on learning, formative assessment tools are aimed at helping the teacher identify student conceptions with the goal of scaffolding future interventions and instruction so as to facilitate student cognitive restructuring (Furtak, 2012). Furtak delineates two types of formative assessments; ‘interactive’, in which the teacher watches and observes student interaction and pays attention to student ideas and thinking. The second assessment is a more formal planned assessment, which provides information about students’ learning through the use of quizzes and tests. These types have the same outcome of allowing teachers to check in or understand students’ ideas and learning. Both assessments demonstrate the need for teachers to recognize not only correct student ideas, but also the various range of ideas that lie between scientific and naive conceptions. One formative assessment instrument that tries to identify student’s conceptions, are concept cartoons (Keogh & Naylor, 1999; Kabapinar, 2009).

Concept cartoons pose scientific questions in a non-threatening context that reduces possible stress typically associated with more formal types of assessments (Keogh & Naylor, 1999). During concept cartoon administration, questions are presented to students about a particular phenomenon and show dialogue between characters as possible answer choices. The choices include the correct scientific conception, as well as common research-identified alternative conceptions. Concept cartoons have been identified as being useful tools at eliciting and remedying alternative conceptions, helping students understand scientific ideas, lowering affective filters of normally shy or reserved students, and minimizing classroom management problems during whole class activities (Keogh & Naylor, 1999; Kabapinar, 2009). Recent work at Point Loma Nazarene University in San Diego has resulted in the production of many cartoons aimed at a variety of biological concepts such as natural selection, evolution, photosynthesis, cellular respiration, and cell biology (http://www.pointloma.edu/experience/academics/schools-departments/department-biology/faculty-staff/dianne-anderson-phd/concept-cartoons-0). Of particular focus for this study are those concept cartoons that require students to articulate their conceptions regarding natural selection.

Distributed and Massed practice

Distributed practice involves spacing a practice or intervention over a given length of time. Massed practice calls for little to no rest during the practice. For the purposes of this experiment, Massed practice will be exposure to a concept cartoon over ten successive class periods, whereas Distributed practice will be exposure to a cartoon once a week for ten weeks. It is generally accepted throughout the literature that students perform better at Distributed tasks compared to Massed (Donovan & Radosevich, 1999). There are large discrepancies about this idea however. The definitions of Massed and Distributed practice vary from study to study. Additionally, the types of tasks practiced during the interventions fluctuate with the age of the participants and the domain of the study. Further complicating this field of research is the variation found within the complexity of the tasks or practices themselves.

This field of research is by no means sparse. Comparisons of retention and learning using Distributed and Massed practice have been studied within a variety of fields such as motor skills within sports medicine (Murray & Udermann, 2003; Donovan & Radosevich, 1999), vocabulary retention (Reynolds & Glaser, 1964; Seabrook, Brown, & Solity, 2005), secondary language vocabulary retention (Bloom & Shuell, 1981; Haq & Kodak, 2015), and mathematics (Rohrer & Taylor, 2006). The focus of the following study will be to compare Distributed and Massed practice in the retention of natural selection content. Due to the lack of Massed versus Distributed practice research in science education, and consequently the standardized practices that go along with such a collection of work, this study will operate with tasks and methods that differ from the above mentioned fields of study.

In addition to reformulating these tasks and methods, the definitional qualities of these methods must be reconsidered specifically within the context of science education. Massed practice within other fields describes interventions in which the individuals practice tasks with no "rest" between trials (Donovan & Radosevich, 1999; Bloom & Shuell, 1981; Rohrer & Taylor, 2006; Haq & Kodak, 2015; Murray & Udermann, 2003). Within the domain of sports medicine, "rest" indicates little, to no rest between trials (Donovan & Radosevich, 1999). There is a difference, however, in regards to the time spent on task. One study used a single six minute trial as their Massed practice (Haq & Kodak, 2015) while another used a single 30 minutes trial (Bloom & Shuell, 1981).

Distributed practice within other fields describes instruction in which rest is given between tasks. Definitions throughout the literature define this practice to different degrees. Donovan and Radosevich (1999) identify Distributed practice as providing rest intervals of a few minutes within a single practice session. This contrasts Bloom and Shuell (1981) that simply define Distributed practice simply as allowing rest periods of 24 hours or longer. Further still, Rohrer and Taylor (2006) identify Distributed (or spaced) practice as being dividing practice among multiple sessions throughout one or two weeks.

Due to the discrepancies concerning definitions and methods behind distributed and massed practice, this study will use the following definitions: massed practice will constitute the utilization of formative assessment tools aimed at assessing student conceptions regarding natural selection during the natural selection unit of the course (10 successive class meetings). This class meets roughly two to three times per week for 80 minutes per day. In each of these classes, the students will be exposed to natural selection concept cartoons. In contrast to the 10 successive class meetings within the massed group, distributed practice will involve the distribution of the same natural selection formative assessment tools over the course of the instructional semester such that the content at that time might involve other areas of the general biology curriculum (10 weeks; one per week).

Research question

This research will seek to answer the question: Is there a difference in learning and retention of natural selection conceptions following distributed or massed practice of natural selection concept cartoons?

Methodology

Study site and participants

This study was conducted with 10 classes of ninth grade Biology students (n =270) at the researcher's school of employment. The school site is a suburban private faith-based secondary school in the greater Los Angeles area. Student demographics are 65.1% of students self-identifying as Hispanic/Latino, 14.4% as Caucasian, and the remaining 20.5% of students self-identified as Filipino, multi-racial, Asian/Pacific Islander, and African-American. Approximately 15% of student would receive free or reduced lunch in a public school.

Due to the large sample size, it was impossible for the author to teach all 10 classes of Biology as well as administer the three CINS (Conceptual Inventory of Natural Selection; Anderson & Evans, 2013, see Appendix A) assessments for each class. Teachers participating in this research all possessed a strong biology background, but were varied in their teaching experience and understanding of the influence that alternative conceptions have on student learning. Four teachers agreed to participate in this research. Their treatment groups, teaching experience, and knowledge of alternative conceptions are given in Table 1; pseudonyms have been used for all but the author. Treatment groups were assigned to volunteer teachers so as to limit the number of different protocols any teacher would have to follow. Additionally, the number of classes available for each teacher was limited by their respective teaching assignments.

Table 1
Distribution of treatment groups for each participating teacher. "Dist. Control" is the control group; distributed is added to indicate this groups cartoon timeframe.

Teacher	**Number of sections in each treatment**			**Years**	**Knowledge of**
	Dist. Control	Distributed	Massed	**teaching**	**alt. conceptions**
Travis	1	3		5	Somewhat
Ashley	1			1	None
Marie			4	14	None
Matthew	1			6	Strong

Research design

This research used a mixed methods design to incorporate both quantitative and qualitative data. Quantitative data was obtained from the use of the high school/college version of the CINS. Each treatment group took the CINS three times. A pretest (questions 1-10) was administered prior to the start of the natural selection unit to establish pre-existing student conceptions. Two post-tests (questions 11-20) were administered; one immediately following concept cartoon treatment to assess learning, and the other, six months later to assess retention of natural selection concepts. CINS questions have been created to evaluate student conceptions regarding natural selection in the following areas: biotic potential, stable populations, limited resources, limited survival, variation, origin of variation, variation inherited, differential survival, and change in population/origin of species. Answer choices on the concept cartoons present students with scientific conceptions and research-identified alternative conceptions for the various subtopics. Pre and post-tests align with these ten conceptions (Table 2). Analysis of resulting quantitative data allowed for assessment of student learning and retention of these ten natural selection conceptions.

Table 2

CINS/Concept cartoon alignment

Concept name	**Concept description**	**CINS questions**	**Concept cartoon**
Biotic potential	All species have such great potential fertility that their population size would increase exponentially if all individuals that are born would again reproduce successfully	1, 11	BP #1
Stable populations	Except for minor annual fluctuations and occasional major fluctuations, populations normally display stability	2, 12	SP #1
Limited resources	Natural resources are limited. In a stable environment, they remain relatively constant	3, 13	LR #1
Limited survival	Since more individuals are produced than can be supported by the available resources, but population size remains stable, it means that there must be a fierce struggle for existence among the individuals of a population, resulting in the survival of only a part, often a very small part, of the progeny of each generation	4, 14	LS #1
Variation	No two individuals are exactly the same; rather, every population shows enormous variability	5, 15	V #1

Origin of variation	New variation appears randomly through mutation and sexual reproduction	6, 16	OV #1
Variation inherited	Much of this variation is heritable	7, 17	VI #1
Differential survival	Survival in the struggle for existence is not random, but depends in part on the hereditary constitution of the surviving individuals. This unequal survival constitutes a process of natural selection	8, 18	DS #1
Change in population	Over the generations this process of natural selection will lead to a continuing gradual change of populations,	9, 19	CP #1
Origin of species	This change can ultimately generate new species	10, 20	OS #1

Qualitative data was gathered from six student interviews: two student volunteers from each of the three treatment groups described below. Each participant was interviewed twice; once in the early fall before exposure to concept cartoons, and once again six months after the treatment. Interview tasks have been designed to elicit student conceptions of natural selection (see Appendix B for interview tasks). Interviews provided insight into student conceptual change that is difficult to be captured using quantitative methods alone. Interviews were video recorded on the researcher's personal laptop for transcription purposes. The researcher received IRB approval for use of personal laptop in this study.

Student interviews have been coded according to a modified bidimensional coding scheme (Hogan and Fisherkeller, 1996; see Appendix E). This scheme identified two important aspects about students' conceptions. First, this scheme allowed the researcher to compare how well a student's ideas compare to scientific conceptions, in addition to the range of intermediate or developing conceptions. Second, a bidimensional coding provided insight into how elaborately students can explain their reasoning.

This research largely used the quantitative data obtained from the CINS to evaluate the differences in learning and retention following a Distributed or Massed practice of concept cartoons. The qualitative interviews were used to supplement the quantitative data. Interview transcripts provided supplemental data regarding the progression, if any, of student conceptions toward those of an expert.

Concept cartoons

Concept cartoons were obtained with permission from Dr. Dianne Anderson at http://www.pointloma.edu/experience/academics/schools-departments/department-biology/faculty-staff/dianne-anderson-phd/concept-cartoons/natural-selection. Questions from CINS were aligned with concept cartoons (table 2). Only the cartoons to be used in the study are included in the table below (see appendix C). The CINS pre-test involved questions 1-10 whereas the post-test included questions 11-20 (see appendix A).

Treatment groups

To best compare effectiveness of Massed and Distributed practice, this research used three treatment groups: Distributed, Distributed Control, and Massed. The Distributed group was exposed to concept cartoons over the course of 10 successive weeks (classes meet two to three a week) throughout the Fall 2015 semester of study (see Appendix C for the concept cartoons to be utilized). This group was composed of three classes of about 30 students each (n=71). Some of these cartoons were presented on days where evolution and natural selection were covered within normal instruction.

The Distributed Control group's timing was the same as the Distributed group. Their concept cartoons, however, had a different format than the other concept cartoons (see Appendix D1 for the exemplar Distributed/Massed student response form and appendix D2 for exemplar

Distributed Control student response form). The Distributed Control group consisted of three classes of about 30 students each (n=76). These students did not see the cartoons, nor were they be given possible answer choices to choose from. They simply saw the question for evaluation. In this way, student conceptions were not be influenced by the images or possible answer choices. This group's data provided insight into the usefulness of concept cartoons in eliciting student conceptions. Should this group's data parallel the experimental results, then perhaps the cartoon images are not required for the formative assessment to capture student conceptions.

The Massed practice group was exposed to concept cartoons during the evolution unit of study over the course of 10 successive class meetings (classes meet 2-3 times a week). This treatment group included the remaining four biology classes with approximately 30 students each (n=123).

All three groups followed the same format when it came to exposure with these treatments. Students were divided into their small lab groups. Each student received a student response sheet (Appendix D) that had the cartoon, questions, and answers to choose from. Additionally, the cartoon or question was projected on the screen in the front of the room. Students were given two to three minutes to answer the question and indicate their reasoning on the student response sheet. Then, for three to four minutes, the small lab groups discussed their answers among themselves and indicated any alterations to their previous answers with appropriate explanations. Finally, the whole class discussed the results. The total exposure to each individual concept cartoon or question took 10-15 minutes. This design limited the total time spent on these concept cartoon tasks to 120 minutes per treatment group.

Methodology consideration

There was one major note worth mention about the timing of this study. The school site operated on a class schedule that consisted of rotating blocks. The seven class periods were rotated through a normal school day consisting of four, 80 minute blocks per day. For instance, if Monday's schedule was periods 1, 2, 3, & 4, then Tuesday's schedule was periods 5, 6, 7, & 1, and so on. This is worth mentioning because, although concept cartoons were distributed according to consistent pacing relative to the respective treatment groups, the number of days between each group's exposure varied. To meliorate this potential issue, the amount of time on task was strictly monitored so as to limit uneven exposure to concept cartoons.

Data Analysis

Quantitative data and statistical analyses

CINS pretest was administered to all three treatment groups at start of term, prior to concept cartoon exposure. Single factor ANOVA comparison of mean pretest scores showed no significant difference prior to treatment, $F(2, 297) = 1.62$, $p = 0.20$. Post-test A was administered upon completion of concept cartoon treatments in order to assess learning. Post-test B was given 6 months after post-test A to assess retention. Tables 4 and 5 show the mean CINS scores, standard deviation, and t-test results for all treatment groups.

Assessing learning

Paired, two-tailed t-tests were run to measure significance of student learning of natural selection conceptions following treatment. Results show significant improvement in scores following distributed and massed treatments, but not in the distributed control group, whereas unpaired t-test data show significant learning following the massed treatment (Table 3). The effect sizes for the two significant values were calculated to be $r = 0.15$ for the Massed group and $r = 0.13$ for the distributed group.

Assessing retention

Two-tailed t-tests were run to assess retention with the idea that student scores may improve or decline six months after treatment. If no significant change in scores occurred from post-test A to B, we are assuming the students retained the conceptual knowledge as a result of concept cartoon exposure.

Paired t-test results from the distributed and distributed control groups showed neither significant improvement, nor decline in student scores, and therefore illustrate student retention of conceptions after six months (table 4). Significant change in scores was observed in paired two tailed t-test results for the massed treatment group. This significant result, again, saw a small effect size of $r = 0.16$.

Table 3
Mean scores and results of paired two-tail t-tests assessing student learning within each treatment group.

Treatment	Pretest			Post-test A				
	M	SD	n	M	SD	n	t	df
Dist. Control	3.90	1.58	76	3.95	1.68	76	0.17	75
Distributed	3.70	1.54	71	4.15	1.51	71	1.94*	70
Massed	4.17	1.65	120	4.70	1.71	123	2.48**	119

*p<.05

**p<.01

Table 4
Mean scores and results of two-tail t-tests assessing student retention within each treatment group

Treatment	Post-test A			Post-test B				
	M	SD	n	M	SD	n	t	df
Dist. Control	3.95	1.68	76	3.83	1.58	76	0.58	75
Distributed	4.15	1.51	71	4.08	1.54	71	0.32	70
Massed	4.70	1.71	123	5.20	1.58	118	2.38*	117

*p<.05

Assessing learning and retention of each natural selection conception

Average scores for each question within each of the three tests were plotted on a radar graphs (Figures 1-3). The three lines represent each of the CINS assessments. Each line extending from the center represents the Y-axis upon which the average scores have been plotted allowing for relative comparison. Each question represented a different conception about natural selection. For example, the biotic potential of organisms is represented on the CINS with questions 1 and 11 (BP 1,11). See Appendix A for a full breakdown of the 10 natural selection conceptions covered in the CINS. By analyzing mean scores from each question, a more in-depth representation of student conceptions was identified.

All groups improved most notably with conceptions regarding *variation* and the *inheritance of variation*. Among all three treatment groups, these two conceptions showed the most learning and retention. All three treatment groups showed much lower *biotic potential* scores in post-tests A and B than the pretest.

The distributed control group showed learning followed by a dip in scores on post-test B in *stable population*, *limited resources*, and *origin of variation* conceptions (Figure 1). Conceptions about *limited survival*, *differential survival*, and the *origin of species* all saw much lower scores in both post-tests compared to pretest scores. No change was observed in *change in population* conceptions.

The distributed treatment group displayed learning in *limited resource*, *limited survival*, *origin of variation*, and *change in population* conceptions after the intervention, but lower scores on post-test B when compared to post-test A (Figure 2). Student scores dropped from pretest to post-test A in *origin of species, biotic potential*, and s*table population* conceptions. No change was seen in *differential survival* conceptions.

The massed treatment groups had the most dramatic changes in scores (Figure 3). Learning and retention were shown in, not only *variation* and the *inheritance of variation*, but also in *origin of variation* conceptions. What's more, student scores regarding *limited survival* and *differential survival* not only showed learning, but also had higher scores on post-test B compared to post-test A. No change was seen in *origin of species* conceptions. No learning was noted in *change in population* and *limited resource* conceptions. Student scores on *biotic potential* and *stable population* conceptions were much lower in post-test A than in their pretest, but they showed improvement of scores on post-test B.

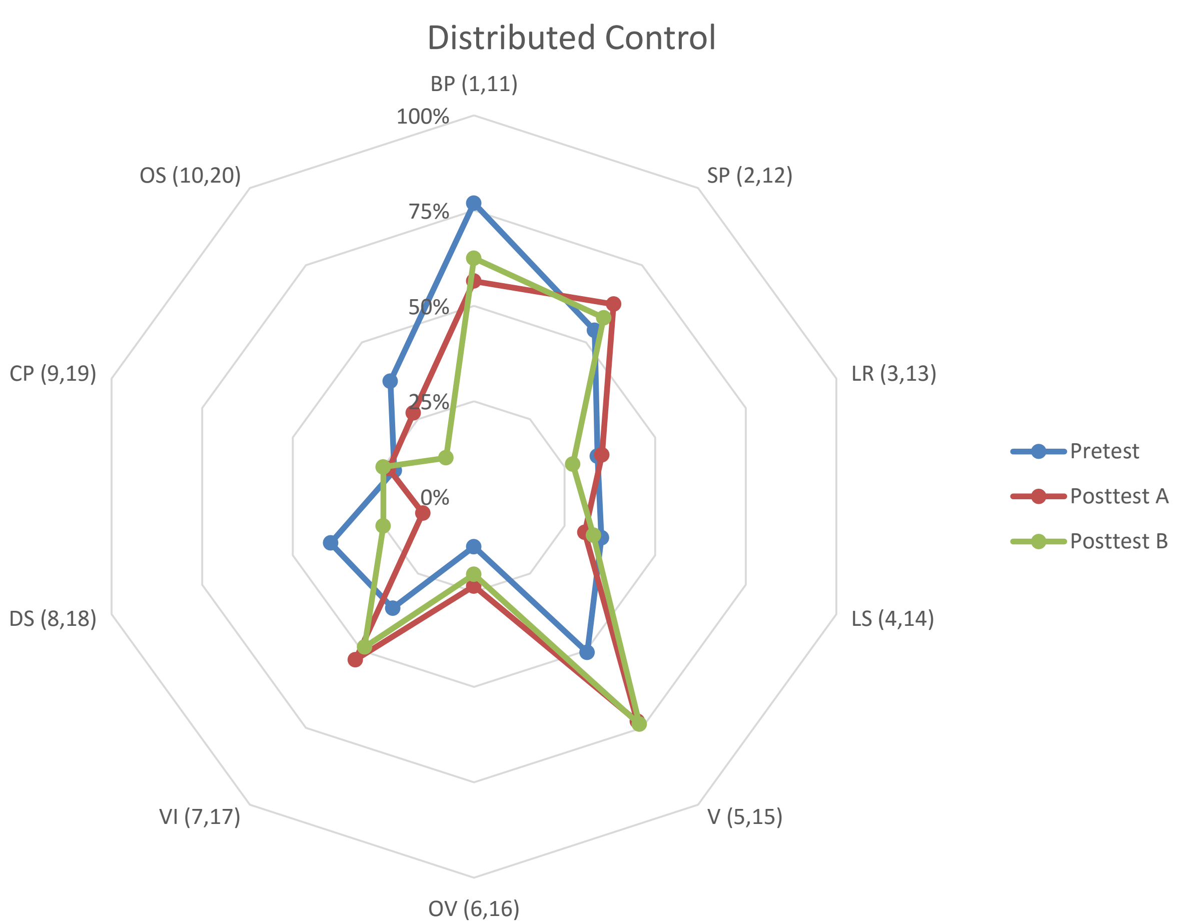

Figure 1. *Radar graph showing mean scores for each natural selection conception for each assessment for the distributed control treatment group. See appendix F for percentages used to create figures. BP = biotic potential, SP = stable populations, LR = limited resources, V = variation, OV = origin of variation, VI = variation inherited, DS = differential survival , CP = change in populations, OS = origin of species.*

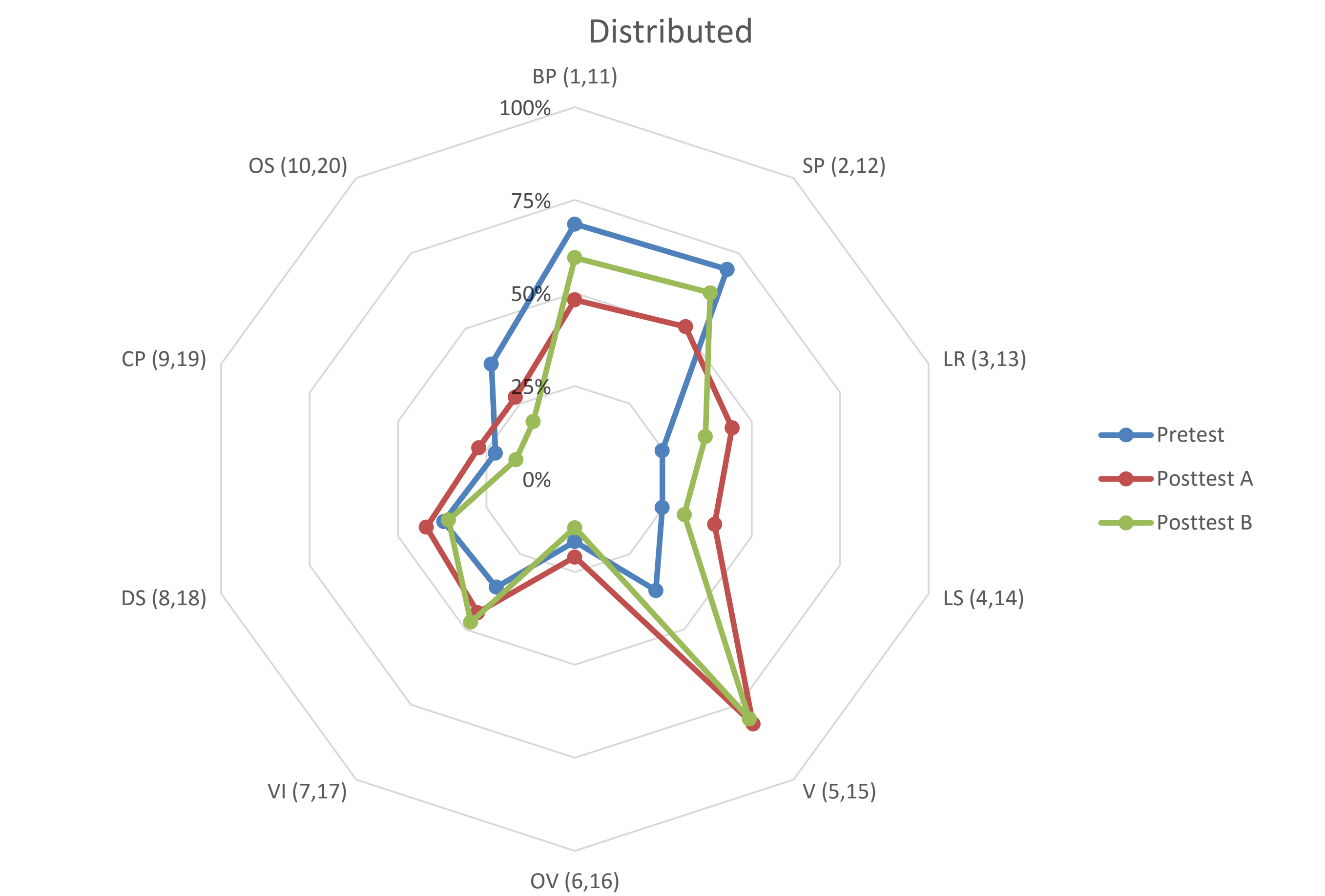

Figure 2. *Radar graph showing mean scores for each natural selection conception for each assessment for the distributed treatment group. See appendix F for percentages used to create figures. . BP = biotic potential, SP = stable populations, LR = limited resources, V = variation, OV = origin of variation, VI = variation inherited, DS = differential survival , CP = change in populations, OS = origin of species.*

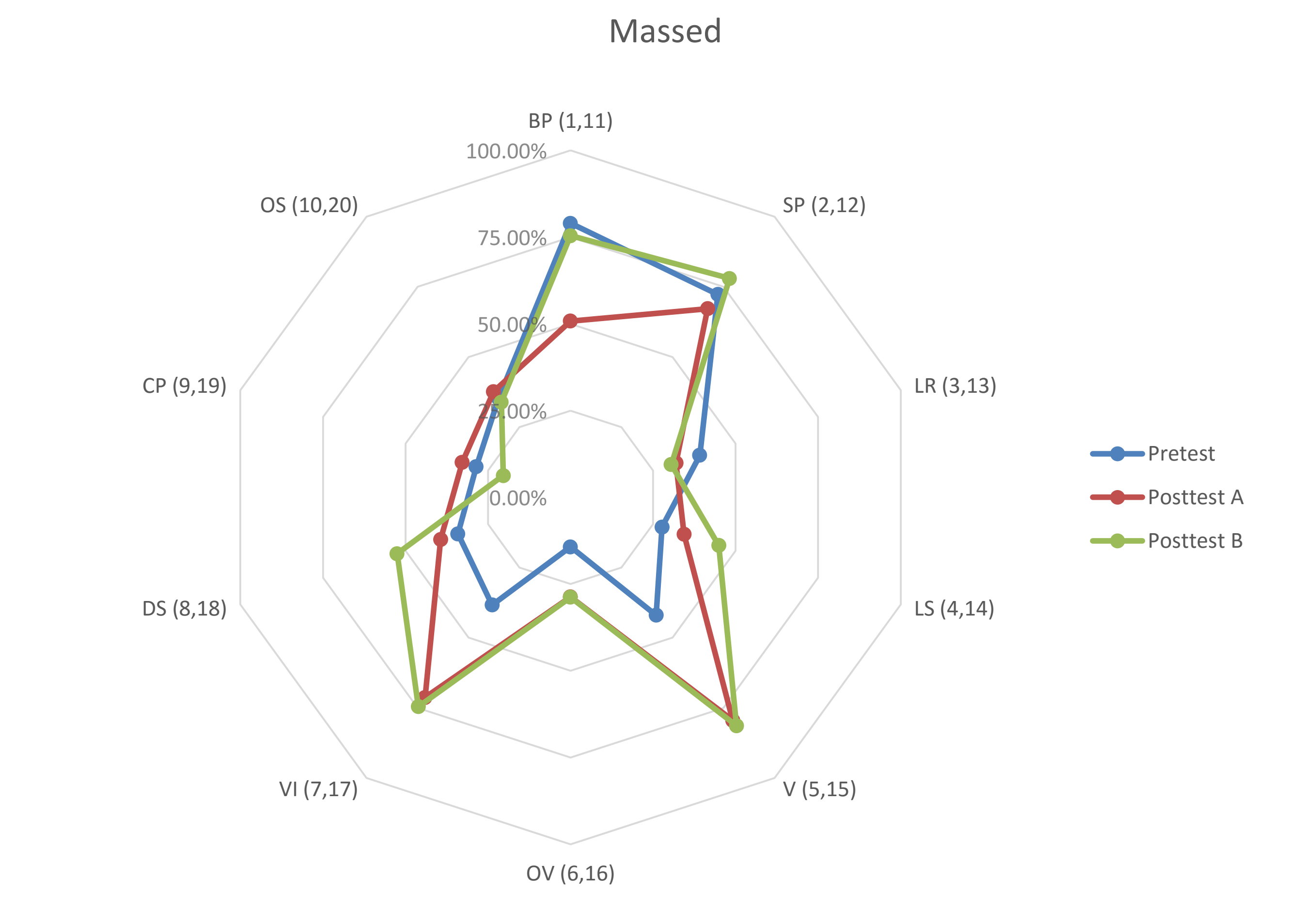

Figure 3. *Radar graph showing mean scores for each natural selection conception for each assessment for the massed treatment group. See appendix F for percentages used to create figures. . BP = biotic potential, SP = stable populations, LR = limited resources, V = variation, OV = origin of variation, VI = variation inherited, DS = differential survival , CP = change in populations, OS = origin of species.*

Qualitative data analysis

Two students from each treatment group were each interviewed twice; once prior to treatment, and 6 months after treatment to assess retention. They are identified by their treatment group and first initial. For example: Student 1 is in the Distributed Control treatment group and her first name begins with G; her interview code is DCG. Their coded interviews and remaining participant interview codes can be seen in table 5. In the table, green represents an improvement in each student's conception, red represents a regression, and yellow indicates no change.

Interviews were analyzed using a bidimensional coding scheme (see Appendix E) modified from Hogan and Fisherkeller (1996). This coding scheme allows the interviewer to evaluate both the student's conceptions as well as gauging how well a student is able to explain his or her ideas. Interview protocols (Appendix B) allowed the interviewer to capture a range of the ten conceptions (Table 2) found in the CINS. Due to the scope of the conceptions, and limited time available during interviews, only the following natural selection conceptions were analyzed from interviews: variation, origin of variation, variation inherited, differential survival, and change in populations.

The interview protocol offered some insight in to each student's conceptual change. Each student showed progression in at least one conception. While every student improved in at least one conception, no definitive pattern is evident based on the small sample size presented here. Five, out of six, students showed improvement in origin in variation conceptions. Three students improved on conceptions regarding variation inherited and differential survival. Two improved on change in populations, and only one student improved on variation.

Student 2, within the distributed control group, saw improvement in more conceptions than any of the other interview participants, but the other participant from this group only improved in one conception. As members of the distributed group, students 3 and 4 showed conceptual improvement in three and two conceptions respectively. Finally, student 5 improved in three conceptions, and student 6, also a member of the massed group, only improved in one conception. These results don't show any obvious relationship between treatments and/or conceptual improvements.

Table 5

Participant interview codes and coded participant conceptions for pre and post treatment interviews for five natural selection conceptions. Yellow indicates no progression toward an expert conception. Green indicates progression toward an expert conception. Red indicates a regression in conceptions away from expert. N/O indicates conceptions that were not observed during interview.

Participant	Treatment group	Interview code	Variation		Origin of Variation		Variation inherited		Differential survival		Change in populations	
			pre	post	pre	post	pre	post	pre	post	pre	post
Student 1	Dist. Control	DCG	C	C	D	B	C	N/O	B	N/O	D	D
Student 2	Dist. Control	DCJ	C	B	F	C	N/O	B	C	B	D	B
Student 3	Distributed	DV	D	F	D	D	F	D	D	C	D	C
Student 4	Distributed	DJ	N/O	C	F	C	D	C	N/O	D	E	N/O
Student 5	Massed	MA	C	N/O	F	B	F	B	D	C	E	E
Student 6	Massed	ME	B	B	D	C	N/O	N/O	D	D	N/O	E

Note: Brief explanation of conception codes: A – Expert/scientific conception, B – compatible/elaborate conception, C – Compatible/sketchy conception, D – Compatible/incompatible conception, E – Incompatible, F – Nonexistent/No evidence of conception. For a full explanation of coding scheme, see Appendix E

Distributed Control treatment group

DCG's pre-treatment interview showed compatible/sketchy conceptions regarding variation inherited as well as a compatible/incompatible understanding of change in populations. When completing the card sort task, she was asked:

Interviewer: Why are gene, variation, and adaptation together?

Participant: Variation is because not every human is going to have brown hair and green eyes, it's going to be different like you have brown hair and blue eyes. It's a variation between traits that each human has, for example. Not everyone's going to have the same thing. Adaptation is because over time the organisms that better adapt to their surroundings are going to survive, so every time each organism is going to have, for example, thicker fur. They're going to get passed down through the genes, thicker fur.

Her response about humans having different hair or eye color illustrates her understanding that variation exists within a population. Her explanation doesn't fully meet the expert conception however, because she fails to explicitly state that no two humans are genetically unique. In addition, she mentions that some traits, like thicker fur (referencing the image from Appendix B, task 1, image 3) are genetic and passed from parent to offspring. This establishes a working knowledge of the inheritance of variation. Her explanation of adaptation fails to meet the scientific conception however, when she states that individual organisms, not populations, adapt to their environment. This is along the lines of inheriting acquired traits and implies a need/want based explanation of adaptation. For this reason, her conception of change in populations is compatible/incompatible.

Later in the interview, during task 1, DCG was shown the picture of a population of guppies. When asked how they were different, she responded:

Participant:	Some of them have different colors on their skin ... I don't know what it's called.
Interviewer:	How do you think that happens?
Participant:	Well, it's genetic, isn't it? It's a genetic variation?

These statements, while compatible that variation has a genetic basis, she is unable to elaborate and her statements don’t seem confident, and are thus sketchy.

DCG’s second interview illustrated retention of learned conceptions in origin of variation, as well as a better ability to explain vertical gene transfer in relation to inheritance of variation. During the card sort portion of her interview, she was asked:

Interviewer:	Okay. Where does the variation come from?

Participant: Genetics and their DNA. It's because the genes are from parents, and I've explained this before. Each parent has different genes and DNA, and when they come together, they switch off DNA and they create the offspring. Each of them has a dominant or recessive allele and they pass it on to their child and whatever is dominant or recessive. They etch those off in child (sic). That didn't make sense. I'm sorry.

Interviewer: You're doing good. Why did you put "gene" and "mutation" together?

Participant: "Gene" and "mutation" are together because mutations can happen within a gene. Before, it's not supposed to be like that... "Gene" and "mutation" are together because mutations can happen within a gene and sometimes something goes wrong when the DNA is crossing and that can lead in a dysfunction within it.

Interviewer: Within what?

Participant: Within the DNA.

New Speaker: Mutations are bad?

Participant: Not always.

Interviewer: Can you explain?

Participant: A lot of the times, mutations can be seen as bad, but sometimes they're not harmful like they don't really affect it. Isn't there a mutation where your eyes can be two different colors? Right? But that doesn't really affect the person besides the fact that they physically look like they have 2 different color eyes. It never really harms them in any way.

She easily identifies DNA as the source of variation after the initial question. She then elaborates on the unique combination of DNA that each parent provides during fertilization. In addition to these, she identifies that mutations can also change the sequence of DNA to make new traits that may or may not be harmful. Her conceptions regarding the origin of variation show an increase from her initial level of Compatible/incompatible to Compatible/elaborate.

The second interview participant from the Distributed Control group, DCJ, showed an improvement in the following conceptions from the pre to post-treatment interviews: variation and differential survival (compatible/sketchy to compatible/elaborate), origin of variation (compatible/incompatible to compatible/sketchy), and change in populations (compatible/sketchy to compatible/elaborate).

During task 1 of his pre-treatment interview, DCJ was shown a picture of a population of herbivores in snowy grassland. He was discussing the presence of thicker fur when he was asked:

Interviewer:	How do you think they got thick fur?
Participant:	Through their ancestors living in such cold weather they had to over generations and generations. They had thicker fur, so the non-thick fur ones that would be more cold and would die, so then the ones with thick fur would keep reproducing and then there would be more with thick fur.

These statements illustrate his understanding of differential survival and change in populations. His statements about differential survival accurately reflect the higher fecundity that would go along with thicker fur in colder climates if it offered a selected advantage over individuals with thinner fur. He also correctly states that this would change the amount of individuals with thick or thin fur over time. However, while he clearly implies a long period of time by saying over generations, he doesn’t fully explain the amount of time needed for such change to occur, nor does he elaborate on the changing of the relative frequencies of thick to thin fur over that time.

Conceptions regarding variation and the origin of variation were identified shortly following the previous statements above. The participant was asked how the thick fur individuals developed thick fur in the first place. He responded:

Participant:	It's because, I guess, not every animal is exactly the same. All of us have different genes.
Interviewer:	How does that relate to fur?

Participant: It's because like, say me and you, because some people grow hair longer, or grow it faster, because anybody can grow their hair out long, but some people can grow it out faster.

Interviewer: How does that relate to genes?

Participant: It's because that can be a trait given to you by the last generation.

Interviewer: Okay, so how did the previous generation get thicker fur?

Participant: I don't know.

He establishes in his first response that not every animal is the same, and that there is a genetic basis for this variation. He then goes on to say that these genes can be given to the next generation as from parent to offspring. DCJ falls short in being able to identify the source for the trait as being either from mutation or from the result of sexual reproduction, and in general he lacks confidence in his understanding of the relationship between genetic variation and population genetics.

During the second interview, DCJ clearly shows his understanding of differential survival, variation, and the inheritance of variation. While discussing the tropical fish in picture 1 of task 1, he was alluding to differential survival when the interviewer posed this question:

Interviewer: You said that some will die and some will survive. What makes the survivors able to survive?

Participant: They have different traits from the ones that didn't survive. Maybe through a mutation or something.

Interviewer: Can you explain that?

Participant: Yeah. Maybe a mutation in the genes or something. Maybe when their parents or somewhere down the line got a trait that was different than the other fish, and that trait let that fish survive better. Say, it can swim faster than the other fish. Maybe it can get there before the other ones. The other ones die and that one survives and makes offspring, so there's more that are faster.

Firstly he states that some fish can survive because they have different traits and implies that this variation allows for their survival and the source of this variation comes from genetic variation. This shows his compatible/elaborate understanding of variation and the origin of variation. Next he identifies that the offspring could inherit the mutation from their parents and that this variation can directly influence the survival of the offspring which can lead to a change in the population. This response further demonstrates a compatible/elaborate conception of the inheritance of variation, differential survival and change in populations. DCJ further addressed these five conceptions, to the same degree of comprehension, in the remainder of the interview.

It is also noteworthy that nowhere in DCJ's pre-treatment interview did he mention the inheritance of variation, nor was he able to identify an origin of variation, but that in his second interview he correctly identifies the connection between, not only the inheritance of variation, but also its genetic basis, as well as its impact on survival and evolution of populations.

Distributed treatment group

Both Distributed participants displayed compatible/incompatible, incompatible, or nonexistent conceptions for the five natural science concepts. During DV's pre-treatment interview, she consistently used need/want or weather-based changes to explain the emergence of traits or adaptations.

> Interviewer: What does it mean to adapt to their environment? You can use this as an example if you like.
>
> Participant: Just adapting to their environment is something changes and they need to survive, and it's over the years, they develop a different trait or lose a trait to help them survive against some environmental factor, such as the cold.

She implied that the need to develop a certain trait to survive and also to survive changes in the climate. Later, she used similar logic when answering a question about the emergence of poisons in a population.

Interviewer: Now how do they get those traits? Growing faster or the poisons, how do those traits come to exist?

Participant: They came to exist by developing them over time, over periods of time, in their genes. Their genes changed and it's able for them to develop this certain trait to help them survive better than others.

Again, she used an explanation based around the need for change in populations. When further asked how organisms can develop traits that help them survive, she mentions mutations, but is unable to connect them to new variations.

Interviewer: How would they develop that trait that would help them survive over the years?

Participant: By different species and maybe mutation or something?

Interviewer: What's mutation?

Participant: It's something that just happens, I guess. If two species mate or something, something can happen and that can get them a mutation or something happened to that original species, I guess.

In this example, she clearly does not understand what mutations are, or how they relate to the origin of new variation. This type of response can be noted multiple times in the transcript.

When prompted later to identify what genes are and where they are located, DV replied:

Participant: I don't really know where the gene is located, I mean, it's like inside the ... Is it located like inside them, I guess? Because you get your gene from your parents and that gene can help you survive and not.

Interviewer: How do we get genes from our parents?

Participant: I don't know. You get half of them from our ... We get them from our parents because they made us. I don't know.

The only information DV is able to correctly identify is that genes are inherited from one's parents. She is unable to elaborate on anything else relating to the inheritance of traits or how sexual reproduction can result in variation.

During the second interview, DV still struggles with change in populations and identifying an origin to variation, but she is more able to elaborate her conceptions when asked about why a population of guppies may have variation in color.

Interviewer: How do they get different fins?

Participant: I guess they could have developed them over time. It just, to help them survive better in that way.

Interviewer: So where does the different colored fins come from, like how does a fish get colored fins?

Participant: Well they got it like from mutations help them develop or adapt into their environment that they're currently living in.

As in her first interview, DV used need-based changes to describe why the fish may have different fins as opposed to random variations. For these reponses she has identified that the fish have variation, and that mutations are involved in this somehow. Her responses though are still based on the environment and need-based changes. When she talks about mutations helping them adapt, it's in the context of an environment in which they are already located.

The second interview participant from the Distributed treatment group (DV) fared better discussing the origin of variation (nonexistent conceptions to compatible/sketchy) from her pre to post treatment interviews. She also went from not being able to address variation within a population in the pre-treatment interview, to compatible/sketchy conceptions in her post-treatment interview. She showed no improvement in conceptions concerning the inheritance of variation. Her score was compatible/incompatible for both interviews.

During the card sort, DV placed the mutation card with the adaptation, population of rabbits, and individual rabbit cards. When asked by the interviewer to clarify her understanding of what mutations are, she responded:

Participant: Something different in the species or ...

Interviewer: What would that something be? Where would we find mutations?

Participant: I think mostly in appearances or ... I can't say.

While it is clear that she associates the term mutations with phenotypic differences, her response fails to identify mutations as being changes in the DNA. Later in the interview, she manipulated the gene card. This time when asked to clarify her understanding of the term, she was able to talk a little about in inheritance of traits.

Interviewer: Could you define gene, please?

Participant: It's the stuff in our body that makes us look the way we are. It's what we get from our parents, kind of shows how we act…

Interviewer: What is that stuff?

Participant: I don't know the word.

She shows here that there is some connection between genes and the transfer of traits from parent to offspring, but is unable to elaborate as to the nature of this interaction. Later in the interview she started talking about the guppy image from task 1. She was talking about how two fish had different tails when she was asked:

Interviewer: Okay, all right. How do you think that those different colored fins happened?

Participant: Again genes.

Once more she mentions genes, but she does not elaborate on the origin of the variation, nor the influence that variation has on the fitness of the fish.

In her post-treatment interview, DJ was able to discuss the genetic basis of variation within a population, as well as how those variations can be inherited. During the card sort, she placed variation with population of rabbits, and was asked:

Interviewer: Okay. You put variation with population of rabbits. Can you explain that?

Participant: I put variation population of rabbits because within a population of rabbits there is variation. Different rabbits don't look alike. Say, one of their tails is fuzzier than the other ones. Or one's brown and one's white.

Interviewer: What would cause those variations?

Participant: Their DNA.

Interviewer: Okay. How could one be brown and one be white if their DNA is different? What would make those differences to begin with?

Participant: Whatever they inherited from their own family members and just before that and before that. The proteins that their DNA produces. Yeah.

In her first answer, she clearly states that there is variation within a population. Nowhere in her first interview dis she make a clear statement about variation in populations so clear. She then is also able to correlate the genetic origin of that variation and give the example of fuzzy tails. Finally, she is able to discuss the heritability of the trait through a couple generations. The only thing she is missing is that mutations are the ultimate source of this variation. In this one exchange, DJ showed an improvement in three conceptions (variation, origin of variation, and variation inherited) from nonexistent or incompatible, to compatible/sketchy.

Massed treatment group

The two Massed treatment interview participants showed an improvement in origin of variation (from nonexistent to compatible/elaborate with MA and from compatible/incompatible/sketchy with ME). MA improved on inheritance of variation from nonexistent to compatible/elaborate while ME was unable to show any understanding of the conception during either interview. Neither participant showed improvement on change in population conceptions; both MA and ME remained at incompatible.

MA's pre-treatment interview made clear that she didn't understand origin of variations. During the card sort, for example, she was discussing a population of rabbits and how they can become faster if they want to when she was asked:

Interviewer: How can a rabbit become faster because it wants to?

participant: I guess because they can just start running and then they get used to that. They start running faster and faster for their own survival and then they just happen to become stronger. Like us humans, we work out to get stronger; it can happen to the same with the rabbit.

This response illustrates acquisition of traits through use or disuse which is incompatible with the genetic basis for the origin of variation. Later in the card sort task, she was looking at the gene card when she was asked:

Interviewer: Where do we find genes?

participant: In our parents.

Interviewer: Where?

participant: I don't know.

She is unable to make the connection that genes found in the DNA are the basis for heritable traits. Combined with her ideas on the acquisition of traits, these comments about heritability of genes point toward an incompatible or nonexistent conception of the origin and inheritance of variation.

MA demonstrates an incompatible conception about change in populations when she is discussing adaptation during the card sort.

Participant: [Adaptation], I guess it would go with the individual rabbit because they have to adapt to the surroundings because as they keep moving from one area to another, they start to realize that not everything is the same, so they have to prepare themselves for what can happen between them and nature.

Interviewer: How would they prepare themselves?

participant: They can get used to the weather. If it's a cold area, they can try to find shelter that keeps them a bit warmer than what they're used to. As time goes by, they start getting used to it and then they don't have to be in that same shelter anymore because they're already used to the cold.

Her statements here show that animals can change because of a realization that they need to, and that this continues as time goes by. This conception doesn’t address the possibility of mutations creating new, possibly beneficial mutations in a population that can influence fitness over a long enough period of time.

In her second interview, MA made improvements in her conceptions of the origin and inheritance of variation to compatible elaborate. In following exchange, MA makes clear the connections between the origins and inheritance of variation.

Interviewer: What makes one fish have a different color tail than another fish?

Participant:	I guess with a parent or mutation because you don't really know what happened because mutations just randomly happen. We can't really explain it as well enough. We just know that it could just happen anytime.
Interviewer:	Will this fish, if it has a baby fish, will that baby fish have the same tail?
Participant:	Well, it depends on the other parent. The other parent has an all red tail and that's a dominant trait then the offspring would probably have the red tail.
Interviewer:	Okay, so how would the mutation make a different colored tail in their babies.
Participant:	When the genes combine something could just switch and it won't click right and then something could happen.
Interviewer:	When you say something would switch, what do you mean?
Participant:	You know how there's AG and CT? When they all line up to their pairings, if something switches, like they go to the wrong letter I guess, something would happen.

Firstly, she identifies that variation, such as color, can be the result of random gene mutations. Later in the exchange she discusses how the DNA nucleotides can be altered during a mutation to generate that variation in the first place. She also correctly speaks to how these new variants combine during sexual reproduction and lead to the inheritance of the variation. Her response here also identifies that the DNA for both parents still need to combine to generate the genome of the offspring regardless of the mutation in one of the parents. This indicates that she has a working knowledge of the contributions to variation provided, not only by mutation, but also by independent assortment and fertilization. It is worth noting that these previous statements provide evidence of extra-intervention learning that cannot be attributed to the cartoon exposure alone.

MA maintained an incompatible conception about change in populations during her second interview. When providing an example of tortoises evolving from turtles, she maintains that organisms change in response to being introduced to a new environment.

Interviewer: What is an adaptation?

Participant: I want to say you're just a different type of turtle, like a tortoise. They don't really go in the water as much so they have to adapt to the ground rather than the water.

Interviewer: What features would a tortoise have that would be considered adaptations to living on land?

Participant: I guess their claws on their feet. They're stronger so they can walk on the ground easier. The rubble on the ground wouldn't slow them down as much as a regular turtle. Since they go in the water too their feet are kind of smoother I guess.

Interviewer: They have different feet. That allows them to walk on land.

Participant: Yeah.

Interviewer: How did they get those feet to begin with?

Participant: I guess if you go back to their family tree. As they start to adapt to different places that they had to move to, overtime their feet would adjust to the ground and then further along the way their feet became the way it is as it is now.

Again, her final statement in this exchange illustrates that she sees change in populations as being the result of adapting to places they ‘had to move to’. This is incompatible with the scientific conceptions which require mutations to generate new variations that allow for dispersal to new habitats like land as in the case of tortoises.

ME’s interviews didn’t show much learning or retention compared to the previous five participants. She maintained a compatible/elaborate conception about variation. Only origin of variation conceptions showed improvement from compatible/incompatible to compatible/sketchy. Her conceptions about differential survival remained compatible/incompatible.

When shown the guppy photo from task 1, ME identified the photo as representing variation within a species.

Participant: I think this one's variation within a species.

Interviewer: How are they different?

Participant: They're different in their colors. Like a few of them have different colors on their fins, like their tails.

She is able to clearly recognize that there exists variation of tail color within the population of guppies.

When discussing why two different species of tree may have different heights, she was asked:

Interviewer: What made that one tree taller?

Participant: I think over time it was just the things that it absorbed. It wanted to get taller. It didn't want to but it was able to get taller because of the resources it had around it like water and the sun. Yeah.

She attributes height to be solely the result of the materials a plant is able to acquire. While access to nutrient is contributory to plant height, she fails to identify that genetic differences would also account for differences in height.

During the card sort, when asked if she could define mutation and describe the role mutations have in variation, she replied:

Participant: I think mutation has to do with like reproduction and like the way the ... I know what it is, it's just hard to explain.

This time she is unable to identify mutation as the ultimate source of new variation.

When presented with the photo of tropical plants in task 1, ME decided to discuss the competition in the system.

Participant: [This is] competition because in the environment you can see that there's different types of plants and they may be fighting for sunlight or space or good habitat so they could grow and produce more.

Interviewer: How would they get that good habitat or space?

Participant: By using other species to grow. I don't know, different things around them to help them grow. Like water, they could absorb the water so they could grow. Yeah.

Interviewer: Okay. What else would they compete for?

Participant: They'd compete for light, space.

Interviewer: What is it about a plant that would make one plant better at getting light?

Participant: The place where they're positioned, like the place where they're located. Say there's like a giant tree above one of the plants and one of the plants is covered in shade and the other one is covered in the sun. It just depends on the location.

She recognizes that the plants in a tropical system need to compete for resources like light or space, but her responses lack confidence, as well as, any mention of the survival being a consequence of the genetic makeup of those individuals. Her responses indicate that she know not all individuals can or will survive, but the lack of elaboration make this response compatible/incompatible.

During her post-treatment interview, ME maintained her understanding of variation. When she was presented the guppy photo again, she recognized the variation within the population.

Participant: I think this one has variation within species because there's, I believe it's the same type of fish but they're different colors so they vary. I think it's also survival, yes.

Also, her conceptions of differential survival remained compatible/incompatible from her pre to post treatment interview. When shown the herd of herbivores in task 1, she identified it as an example of competition.

Interviewer: Why is it competition?

Participant: Competition because there are maybe predators around and they compete to stay alive and they also compete for mates and space and food and yeah.

Interviewer: Okay, so what allows them to compete for space and mates and food and staying away from predators? What allows these organisms to do that, to compete? You can pick any one of those parts and talk about that if you'd like.

Participant: Well they compete for ...

Interviewer: How about this, let me rephrase it. What would allow this animal to out compete this animal?

Participant: Maybe they're going for the same partner to mate.

Interviewer: All right.

Participant: So what they want to do is that they want to impress the one that they're fighting for. They could physically fight each other.

Interviewer: So what would allow one of them to win?

Participant: I think if it majorly hurts the other one or if it gets more food than the other one.

When asked why it is an example of competition, ME alludes to the differential survival of some members of the herd as ‘they compete to stay alive’. When she was further prompted to account for why some members would be more likely to survive over others, she is unable to identify their fitness as having a genetic foundation.

The only conception in which ME demonstrated learning and retention was with regard to the origin of variation. When asked directly about the source of variation found in the population of guppies, ME answered:

participant: When they reproduce there's different like combinations of DNA between the fish when they reproduce. So some of them come out different.

Here she is able to correctly identify sexual reproduction as a source of variation found in a population. She does not, however include mutations in her response.

Data analysis summary

Quantitative data presented shows no statistical difference in learning and retention between massed and distributed exposure with natural selection concept cartoons. Both groups displayed learning and retention, while the control group did not. Further analysis of the CINS questions showed that, with the exception that all groups showed improvements in *variation* and the *inheritance of variation* conceptions, any other broad generalizations about conceptual change are not present. The interviews transcripts, although representative of conceptual change in six students, falls short in providing enough evidence to draw broad conclusions about differences between groups. All students who participated in the interviews improved, but not in large enough numbers to make claims about one groups' development over the other two. If anything, the interviews provide evidence of learning that occurred outside of the concept cartoon intervention.

Discussion

This study sought to identify any difference in learning and retention of natural selection conceptions following massed or distributed exposure to concept cartoons. Both the massed and distributed treatment groups showed significant learning of natural selection conceptions, as demonstrated by their improved scores from pre-test to post-test A data points. The distributed control group scores, however, did not indicate learning of natural selection conceptions. The distributed and distributed control groups displayed no significant change in post-test B scores compared to post-test A, indicating retention of material. The massed treatment group presented significant change in their post-test B scores. Further statistical analysis revealed that this change corresponded to a significant improvement in CINS scores after the six-month period. It is important to reiterate that this improvement in scores cannot be attributed to the concept cartoon intervention. This learning could have come from variation in teachers and teaching styles inherent to this type of research.

Of the three treatment groups, what differentiated the control group from the other two, was that their cartoon exposure was limited to the questions presented, and not the color images or the possible answer choices. It's possible that the images and possible answer choices provide a starting point for further discussions within their small groups. If a student does not have to rely solely on their own knowledge to generate an answer, but rather they can build on images and possible answers presented to them, they may be more willing to participate in these activities which are aimed to allow students to examine, discuss, and evaluate their ideas. It is worth mention that the three teachers who taught the control group courses noted that it was interesting to see students generate their own answer choices in the absence of the possible answers given to the other two groups. These volunteer teachers had expected to see higher scores from this group due to the generation of answers by students, requiring higher levels of participation and learning. Evidence found in data analysis suggests that, contrary to the assumptions of these teachers, information was learned better with the use of concept cartoons images and answers.

In order to evaluate the items of the cartoons that are most effective for learning, it was important to analyze scores to determine which showed the most change. This was done through a detailed item analysis of CINS scores and provided insight as to which treatment groups experienced the most improvement overall, as well as which conceptions were more commonly learned and retained by students.

The massed group showed large gains in scores on five of the 10 conceptions (limited survival, variation, inheritance of variation, origin of variation, and differential survival). Of those five conceptions, two saw a further increase in mean scores from post-test A to B. Again, this improvement is not attributable to the interventions presented here. The distributed and the distributed control groups showed learning and retention in only two conceptions (variation and inheritance of variation). These two groups also scored higher in their pretest than both post-tests on questions about biotic potential and the origin of species.

Consistent patterns were identified between all three groups demonstrating learning and retention in variation and inheritance of variation. This could be due, in part to emphasis of the teachers and course material. Further research in this area is suggested. All three treatment groups had consistently low scores on questions about limited resources, limited survival, origin of variation, change in populations, and the origin of species.

Limitations

This study had several limitations. Most notably is the variability in course instruction inherent to a research design like the one presented here. The four volunteer teachers, while strong in a biology background, varied in their teaching experience, knowledge of alternative conceptions and their familiarity with concept cartoons as a formative assessment tool. Marie’s classes, which were all from the same treatment group, saw significant increases in learning and retention, as opposed to groups taught by other teachers. This could be due to the treatment or longer teaching experience than that of the other three teachers. Additionally, the author is the only teacher with strong knowledge regarding the role alternative conceptions play in student learning. This previous knowledge could have impacted the ways in which students learned material, however no significant changes were seen in the data.

There were also limitations with the research design and implementation. The distribution of treatments to volunteer teachers was meant to streamline their responsibilities in CINS administrations and cartoon exposures. By spreading out the treatment groups as evenly as possible to the volunteer teachers, any differences in teaching styles may have been meliorated. Furthermore, problems with administration of post-test A for the massed treatment group made paired t-tests an impossibility. In a miscommunication between the researcher and one of the teachers, no identification was provided for the tests, ruling out the option of a comparative test within that group. While significance was still able to be measured, the ideal statistical analysis to answer the research question was unable to be performed, and thus limits the weight of final claims.

In addition to the limits within the specified group, the interviews conducted provided little fine scale information to identify patterns in the responses. This limited the additional information that was hoped to supplement the quantitative data. Designed to be responsive and progressive according to content, the interview questions varied between volunteers as the result of their respective responses to identical interview tasks. While normally effective for gathering this type of information in interviews, the protocol failed to identify the student’s understanding of the 10 conceptions addressed in the CINS. Generalizations about conceptual differences between groups were difficult to make due to the small sample size of interviews in which comparative analysis is not appropriate. Even though this is a limit for the qualitative data analysis, this study relied mainly upon a large sample size for the quantitative data.

Limitations as the result of poor student motivation are assumed within this research. The three CINS administrations did not influence student grades, nor did they receive extra credit or special reward for completing them. One teacher reported an anecdote of a student who, upon receiving their scantron sheet, instantly filled in C for all questions and waited for the CINS administration to be done by putting his head down to nap. This lack of student investment, may indicate a margin of error for the data, and could be researched further in a setting in which student participation is at a higher level or tied to a form of punishment or reward.

Conclusion

Students enter a classroom with a lifetime of experiences interacting with the natural world. These experiences have shaped their conceptions about how that natural world operates and provides them a foundation to make sense of information. This study suggests that concept cartoons are effective formative assessment tools for student learning and retention of natural selection conceptions, regardless of whether they are massed or distributed throughout the unit of study. This learning and retention is built upon student’s conceptions about natural selection as they interact with the concept cartoons. Students are able to discuss ideas with peers, defend perspectives, and question ideas of peers using this formative assessment tool. Use of this tool limits potential fear of being wrong, and instead encourages students to use their conceptual thinking to problem solve within a structured framework. Although this tool minimizes this fear, which is common in a large class setting, it is imperative, that the teacher pay attention to student discussions about the cartoons in order to identify current knowledge and build curriculum appropriately upon it. Students can, and will, under the right circumstances, effectively analyze their conceptions during small group discussions, but the responsibility falls on the teachers to understand what conceptions students are developing in order to design curriculum and modify instruction that facilitates students' conceptual progression towards that of an expert.

While this research identified no significant difference in learning and retention following massed or distributed practice with concept cartoons, modifications to the timing can still be made. Future research could stretch the cartoon exposures over a longer period than presented here. Furthermore, further studies should focus on designing an interview protocol that addresses each of the 10 CINS conceptions. While the CINS is an effective tool for quantitatively measuring student knowledge, an interview protocol is required that will allow future research to detect fine scale conceptual change that may be missed with the CINS alone.

Understanding evolution is crucial to a complete understanding of biology and a student's ability effectively interact with, and solve problems in life science require that they fully understand natural selection, its mechanisms, and consequences. Concept cartoons have been shown to be an effective formative assessment tool that can be utilized by teachers to facilitate the conceptual development of their students. The study presented here has shown the versatility that concept cartoons can have in a secondary classroom. These cartoons can be massed or distributed throughout a unit of study to help progress conceptual development from those of novice to expert.

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Appendix A – Conceptual Inventory of Natural Selection (CINS)

Conceptual Inventory of Natural Selection

2013 High School/College Version

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

List of concepts and answer key

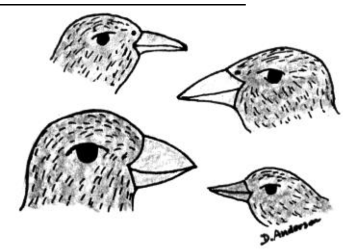
Concept name	Concept description	CINS 2013 version items	Answer key
Biotic potential	All species have such great potential fertility that their population size would increase exponentially if all individuals that are born would again reproduce successfully.	1, 11	C
Stable populations	Except for minor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

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

2013 High School/College Version

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

Introduction to Galapagos finches



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

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

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

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

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

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

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

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

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

5. A population of finches has hundreds of birds of a single species. Which sentence best describes the group of finches?

   a. The finches share all the same traits and are identical to each other.
   b. The finches share all of the most important traits, and the small differences between them do not affect how well they reproduce or how long they live.
   c. The finches are all identical on the inside, but have many differences in appearance.
   d. The finches share all of the most important traits, but also have differences that may affect how well they reproduce or how long they live.

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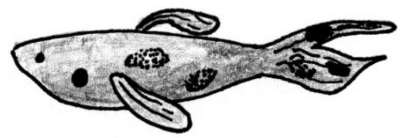
6. How did the different types of beaks first appear in the finches?

   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 the birds happened because the environment caused beneficial changes in the DNA.
   d. The beaks of the finches changed a little bit in size and shape during each bird's life, with some getting larger and some getting smaller.

Introduction to South American guppies



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

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

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

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

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

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

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

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

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

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

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

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

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

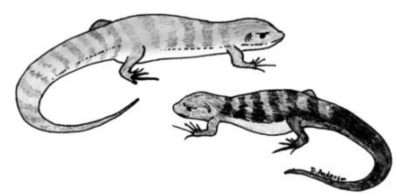
13. Guppies eat a variety of insects and plants. Which statement describes the availability of food for guppies?

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

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

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

Introduction to Canary Island Lizards



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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix B - Interview tasks

Task #1: Interview about instances

Instructions:

I am going to show you several pictures now. Please tell me whether each one is an example of one or more of the terms on this card, then explain your answers. As you think about each picture, please try to do so out loud.

Terms on card:

Competition

Variation within a species

Variation between species

Survival

Photos shown during task #1 (below):

Coral reef fish

Trinidadian guppies

Antelope

Tropical island foliage

Task #2: Card sort

Instructions:

Please define or explain the meaning of the terms on the cards, then arrange them on the table so that the words that are closely related to each other are close together, and those that are unrelated to each other are far apart.

If there are any terms that are unfamiliar to you or have nothing to do with natural selection, put them aside. As you think about each card, please try to do so out loud. After you are done, I may ask you to explain your sorting.

Terms on cards:

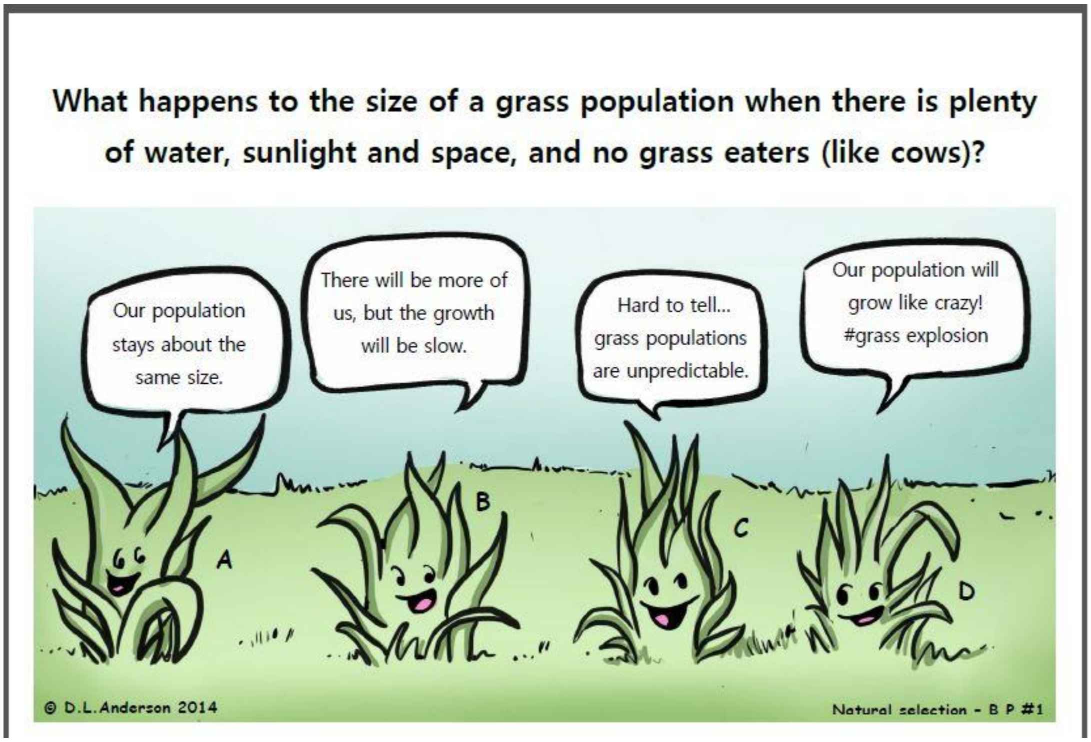
Adaptation
Gene
Individual rabbit
Mutation
Want
Need
Population of rabbits
Random
Survival
Variation

Possible student responses	**Possible follow-up questions**
Competition	*-How can competition result in all of these different kinds of fish?*
Variation within a species	*-How does this variation occur?* *-Where does this variation come from?* *-How does the variation affect the other species?* *-Are these fish all the same species?*
Variation between species	*-How does this variation occur?* *-Are these fish all the same species?* *-Where does this variation come from?*
Survival	*-How does this picture show survival?* *-Is there anything about these organisms that affects their survival? ***if answer mentions variation, then- where does that variation come from?* *-what do you mean by variation?*

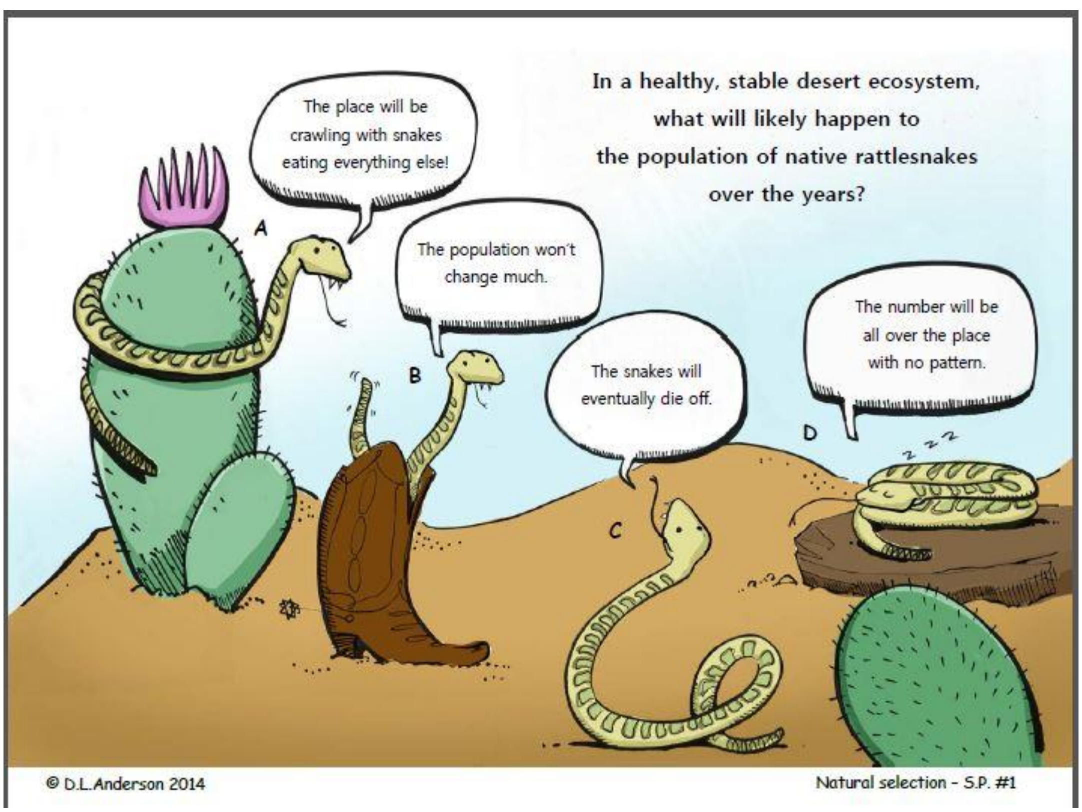
Possible student responses	**Possible follow up questions**
Need or want associated with variation/adaptation/survival/or gene	-*How can an organism's wants/needs affect its evolution?* -*Can organisms want or need things like humans do? If so, can that influence their evolution?* -*Can humans change our traits if we want to or need to?* -*Can organisms adapt when they want to?* -*What does adaptation mean to you?* -*How can need/want influence variation?*
Mutation associated with need/want	-*What role does mutation play in evolution?* -*If I want/need to mutate, can I do it?* -*What does mutation do to a gene pool?*

Appendix C – Concept cartoons

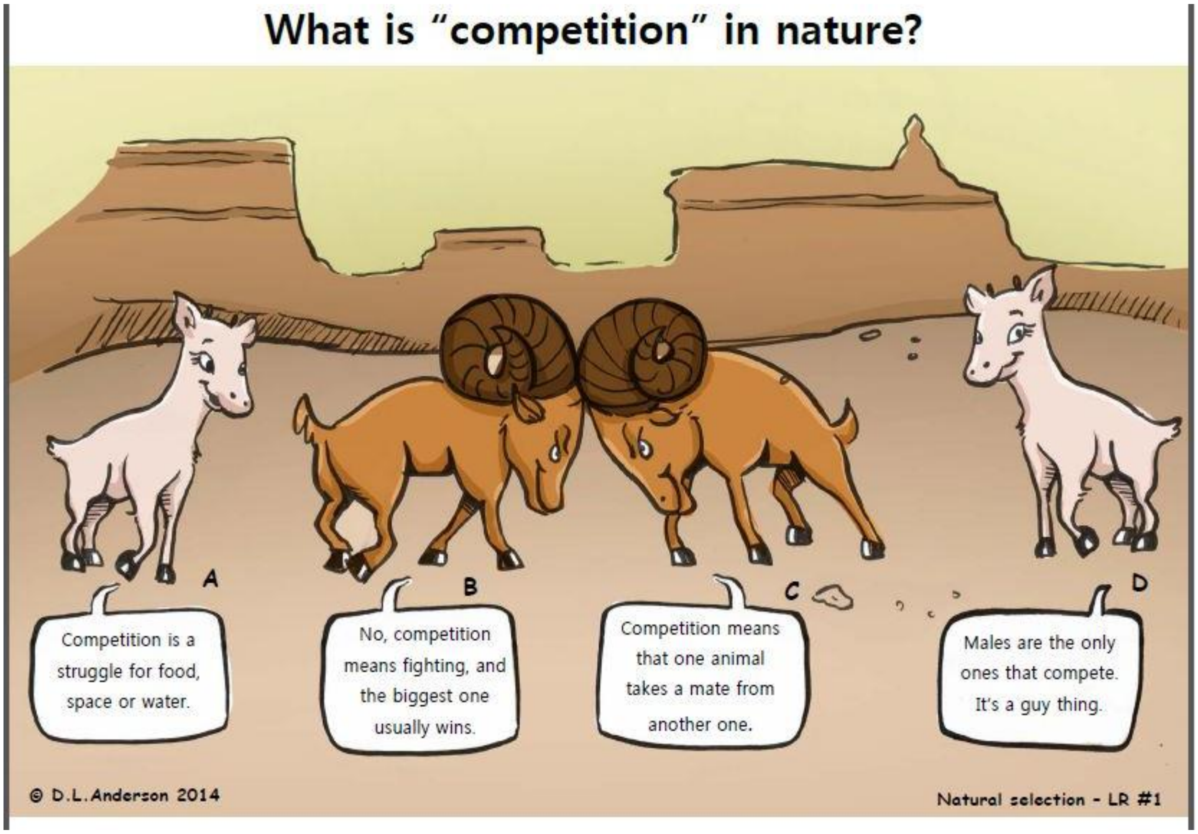
Concept Cartoon #1 – Biotic Potential (BP) #1 – Grass; D



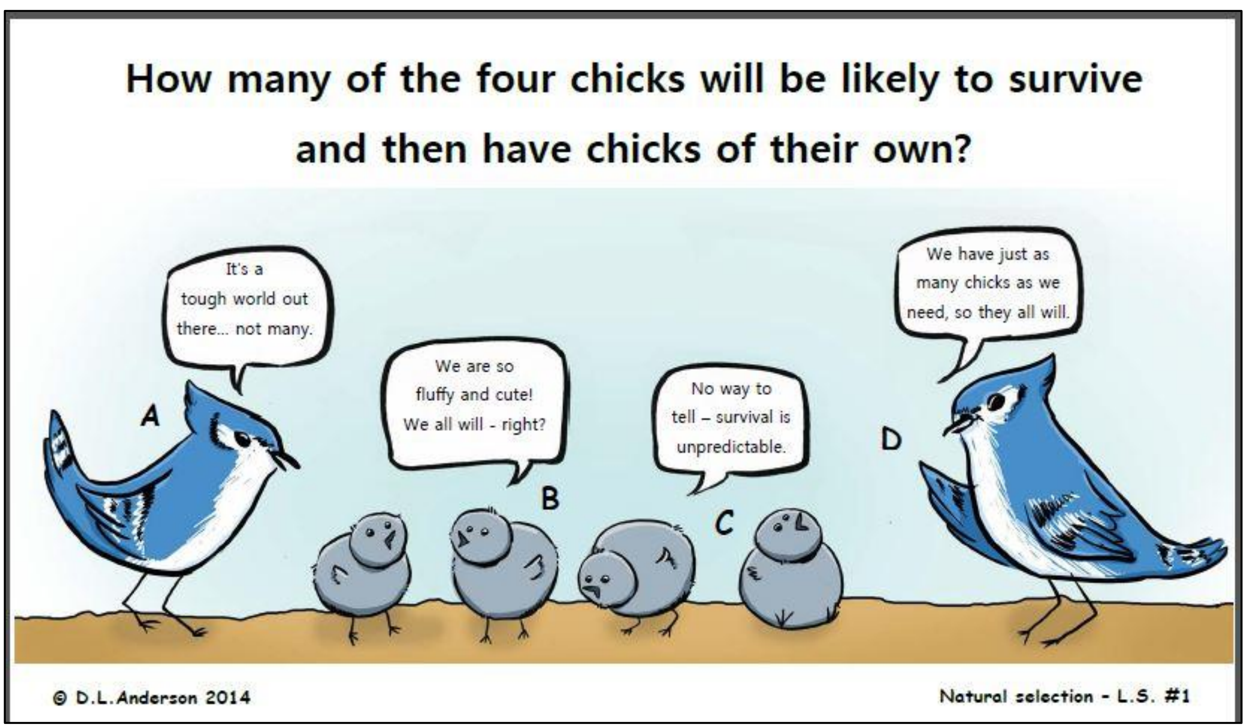
Concept Cartoon #2 - Stable Population (SP) #1 – Snakes; B



Concept cartoon #3 – Limited Resources (LR) #1 - Bighorn Sheep; A



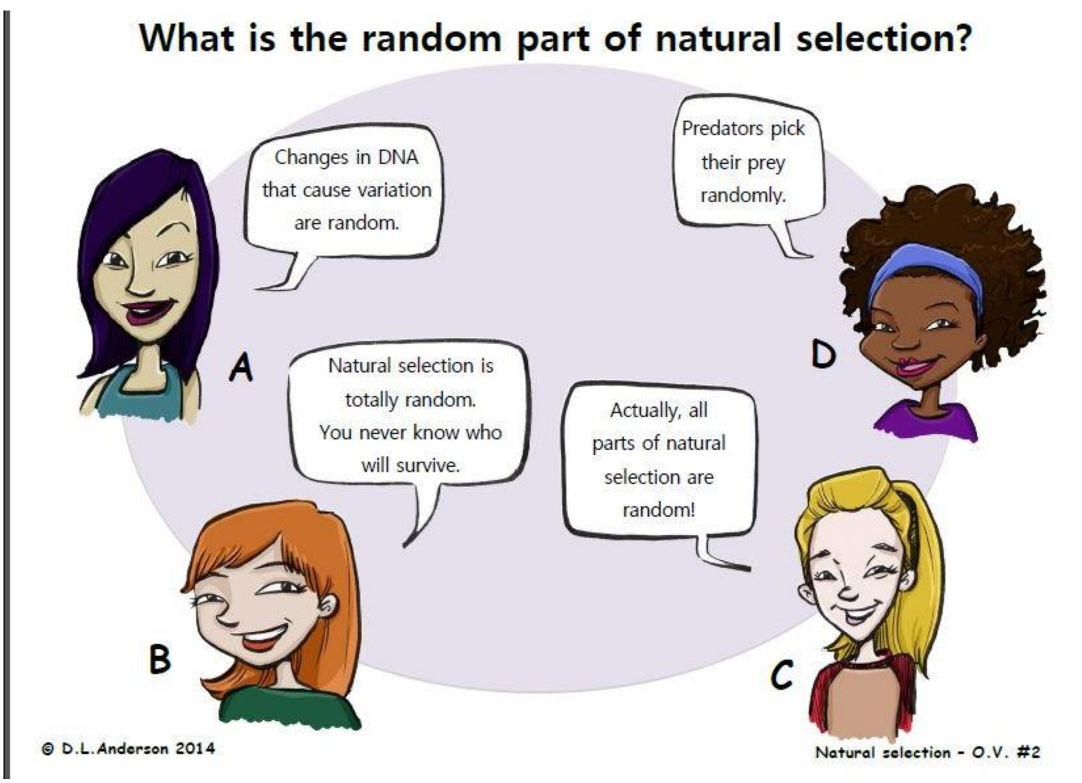
Concept Cartoon #4 – Limited Survival (LS) #1 - Blue Jays; A



Concept

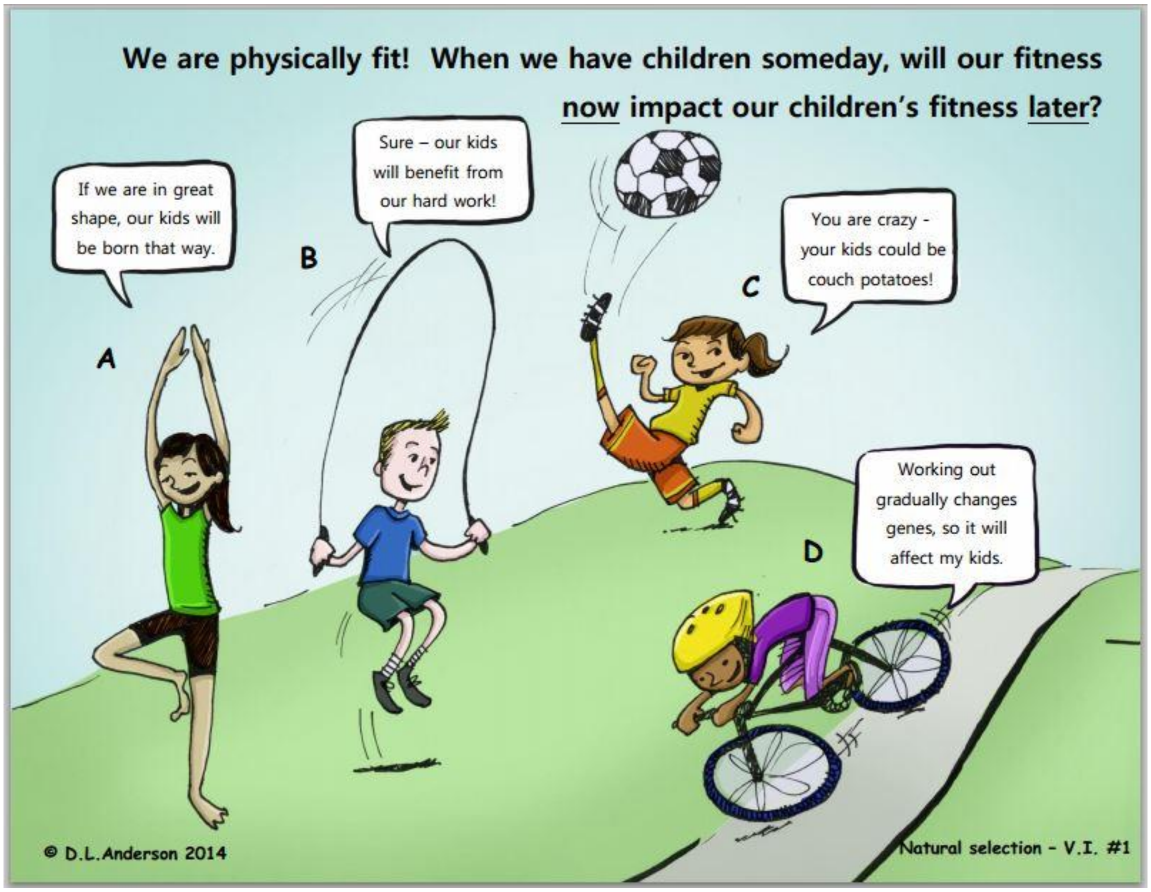
Cartoon #5 – Variation (V) #1 – Owls; D

Concept Cartoon #6 – Origin of Variation (OV) #1 - Random Part; A

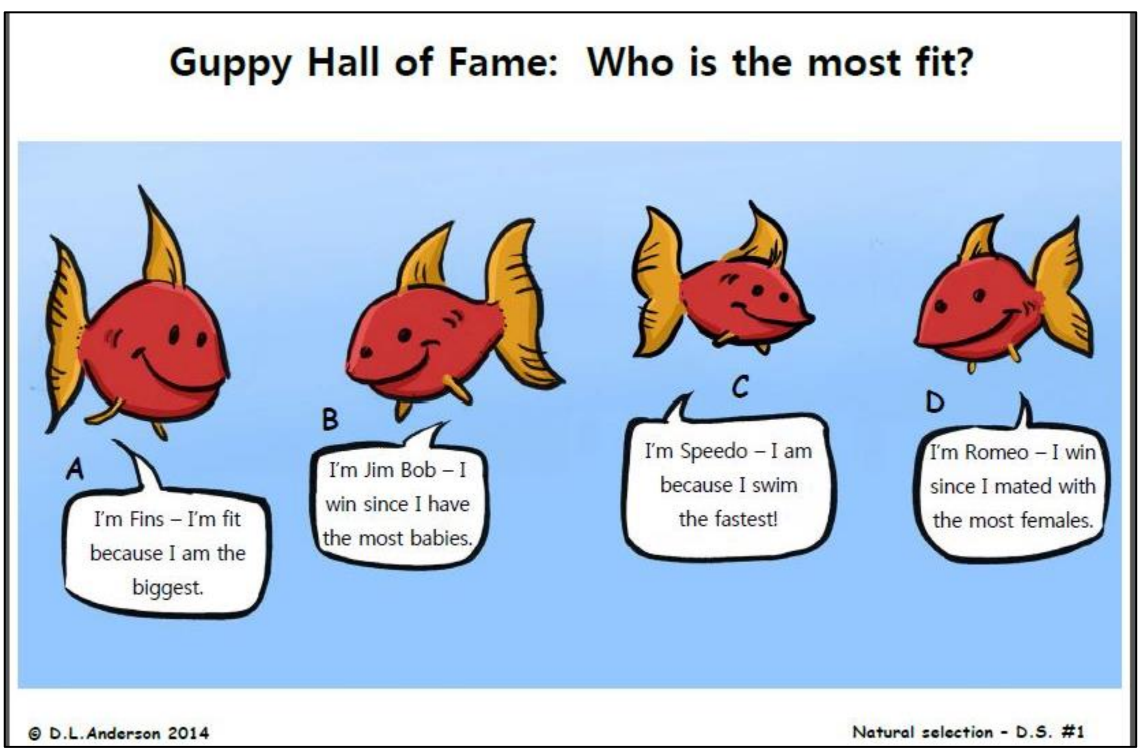


COMPARISON OF MASSED VS DISTRIBUTED

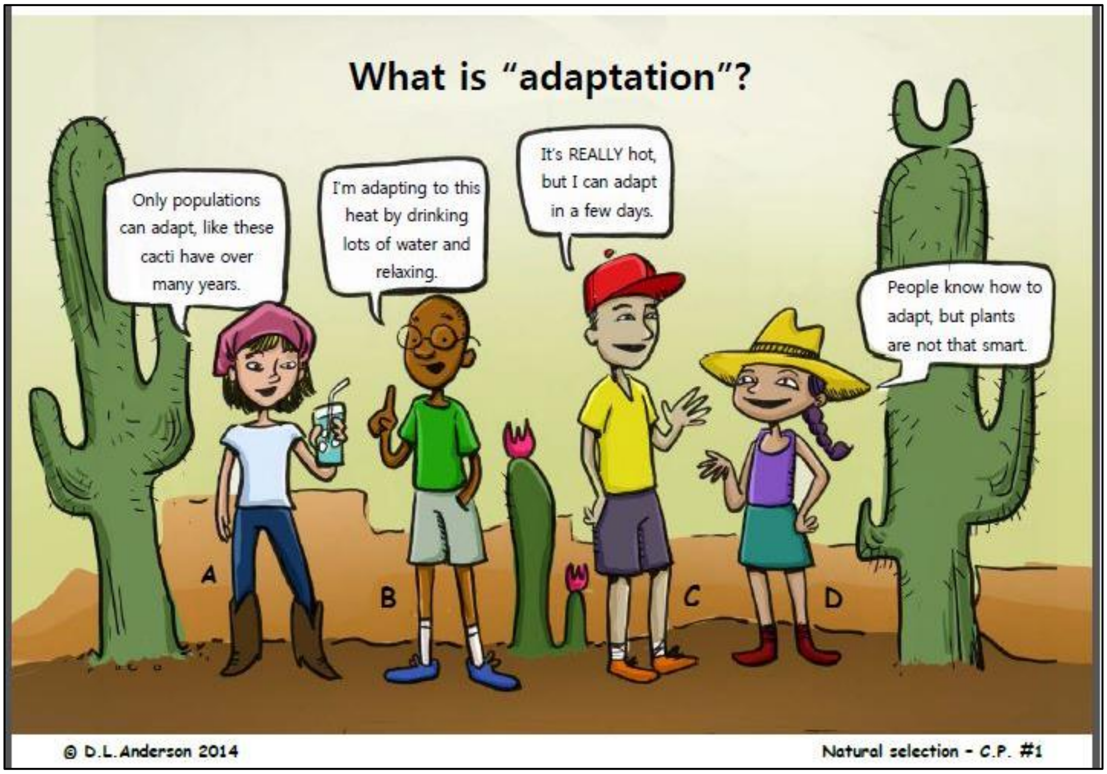
Concept Cartoon #7 – Variation Inherited (VI) #1 – Fitness; C



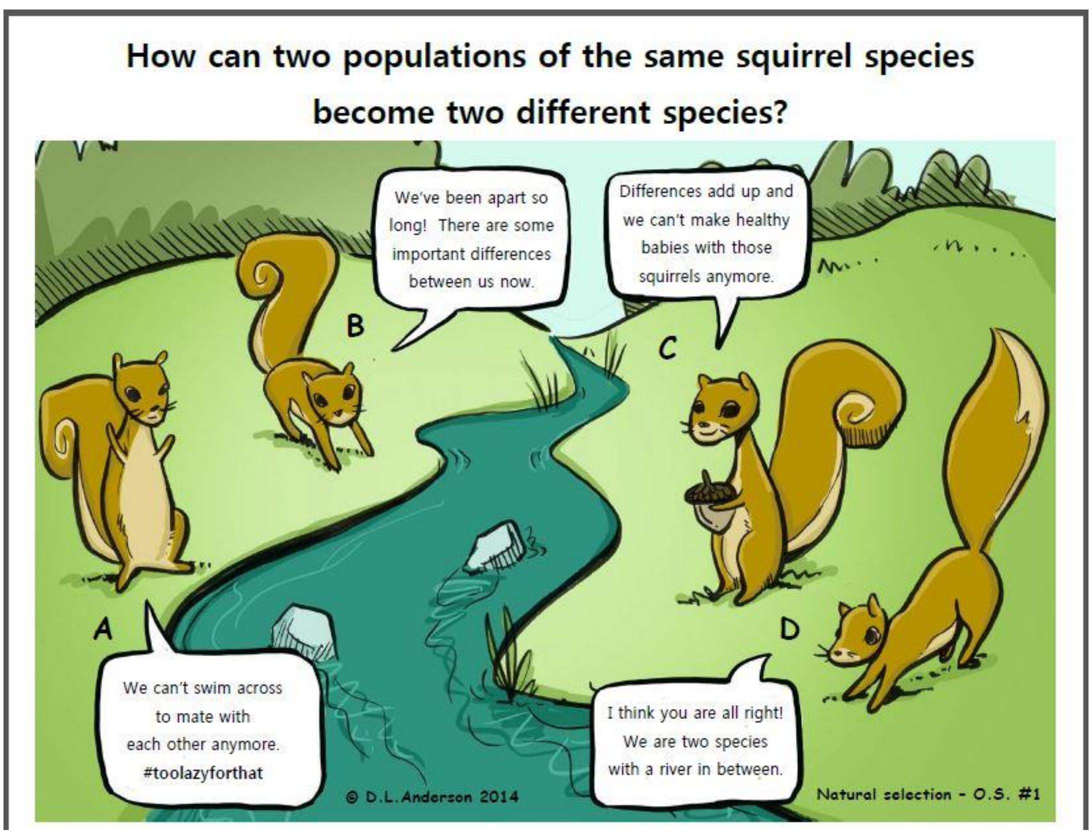
Concept Cartoon #8 – Differential Survival (DS) #1 - Most Fit Guppy; B



Concept Cartoon #9 – Change in Population (CP) #1 – Cacti; A

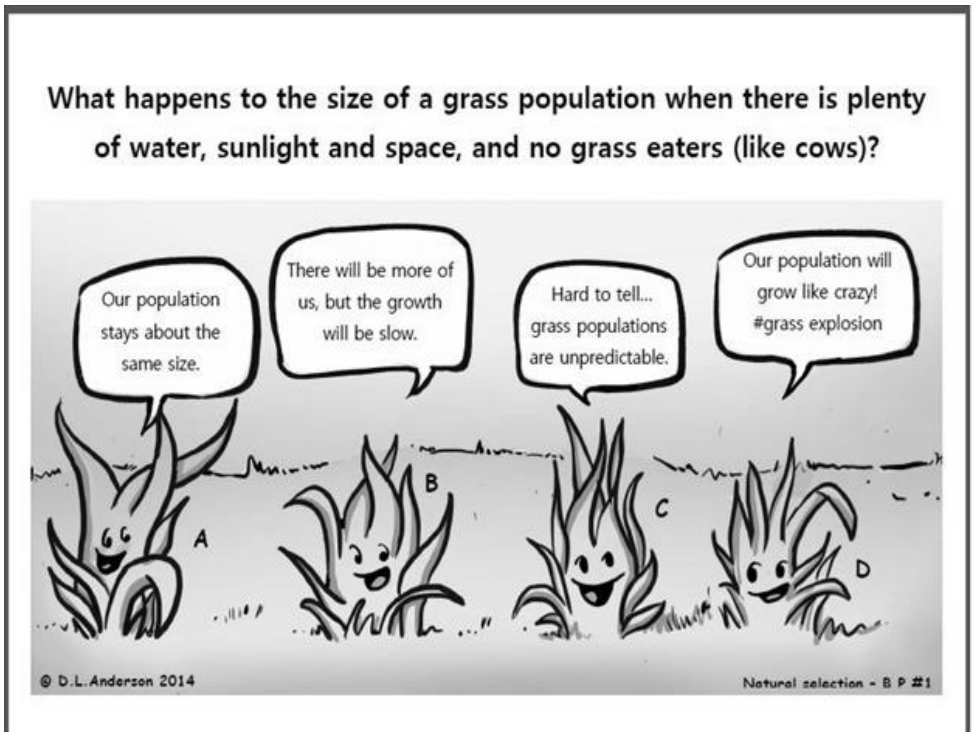


Concept Cartoon #10 – Origin of Species (OS) #1 – Squirrels; D



Appendix D1- Distributed/Massed Student Response form

Instructions: Read the question in the cartoon and choose which answer you think is best.



<u>Part A</u>: Spend 2-3 minutes explaining your answer

Circle which answer you chose? A B C D

Why did you choose that answer?

Why didn't you choose the others?

<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

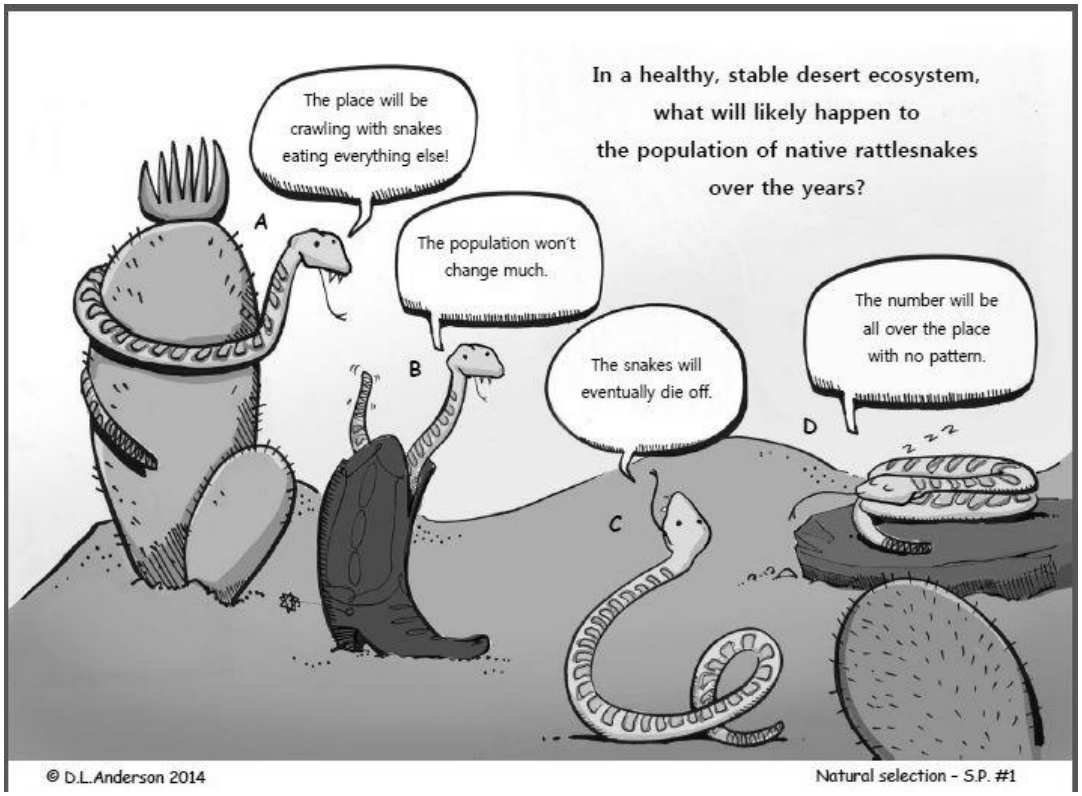
Circle which answer your small group chose? A B C D

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question in the cartoon and choose which answer you think is best.



<u>Part A</u>: Spend 2-3 minutes explaining your answer

Circle which answer you chose? A B C D

Why did you choose that answer?

____

____

Why didn't you choose the others?

____

____

<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Circle which answer your small group chose? A B C D

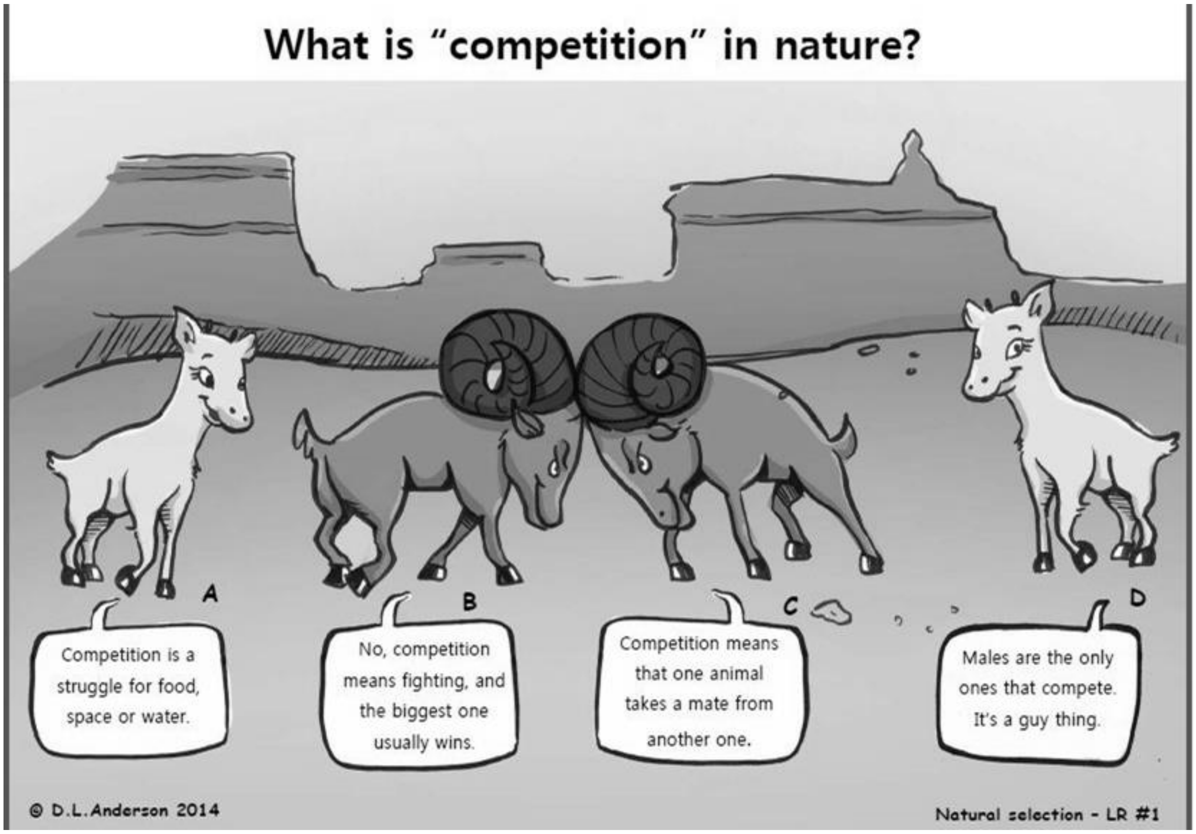
Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

____

____

Instructions: Read the question in the cartoon and choose which answer you think is best.



<u>Part A</u>: Spend 2-3 minutes explaining your answer

Circle which answer you chose? A B C D

Why did you choose that answer?

____

____

Why didn't you choose the others?

____

____

<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Circle which answer your small group chose? A B C D

Did your answer change? YES NO

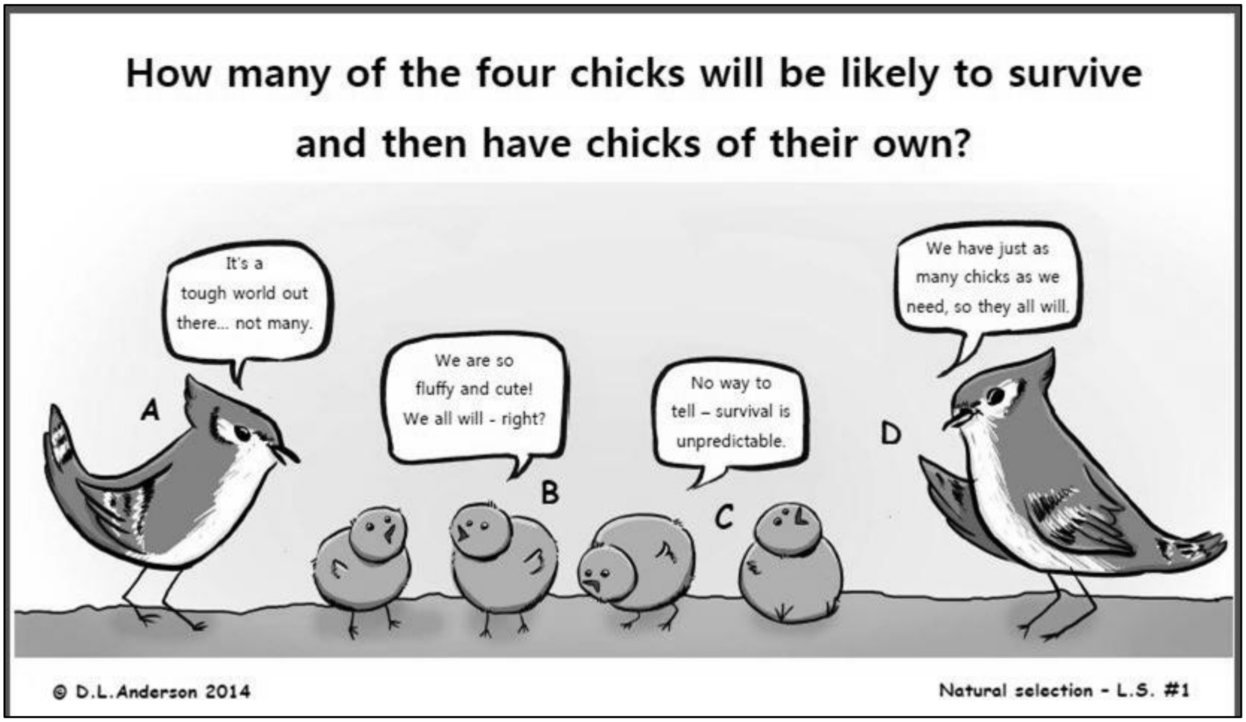
If so, why did your answer change? What argument/evidence helped change your mind?

____

____

COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question in the cartoon and choose which answer you think is best.



<u>Part A</u>: Spend 2-3 minutes explaining your answer

Circle which answer you chose? A B C D

Why did you choose that answer?

____

____

Why didn't you choose the others?

____

____

<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Circle which answer your small group chose? A B C D

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

____

____

COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question in the cartoon and choose which answer you think is best.

<u>Part A</u>: Spend 2-3 minutes explaining your answer
Circle which answer you chose? A B C D

Why did you choose that answer?

____

____

Why didn't you choose the others?

____

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.
Circle which answer your small group chose? A B C D
Did your answer change? YES NO
If so, why did your answer change? What argument/evidence helped change your mind?

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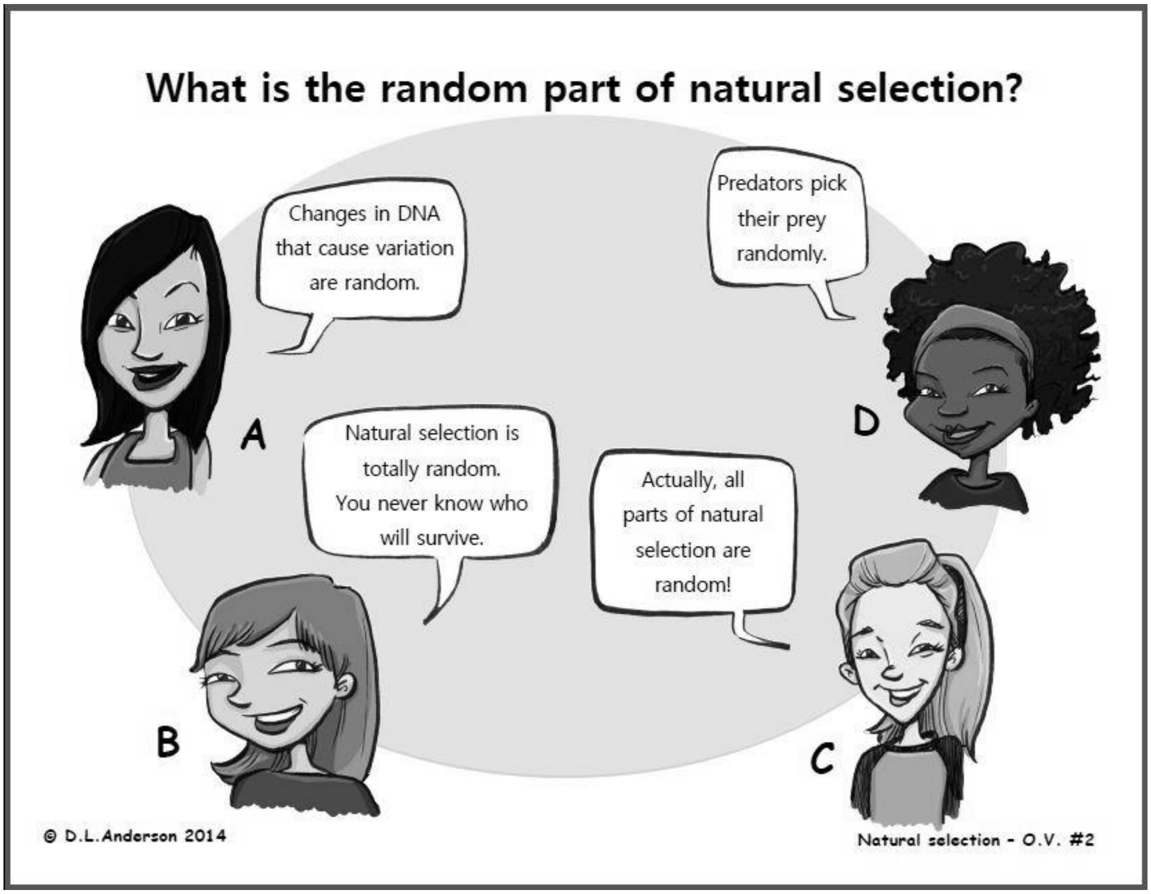
COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question in the cartoon and choose which answer you think is best.



Part A*: *Spend 2-3 minutes explaining your answer

Circle which answer you chose? A B C D

Why did you choose that answer?

____

____

Why didn't you choose the others?

____

____

Part B*: *Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Circle which answer your small group chose? A B C D

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

____

____

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Circle which answer your small group chose? A B C D
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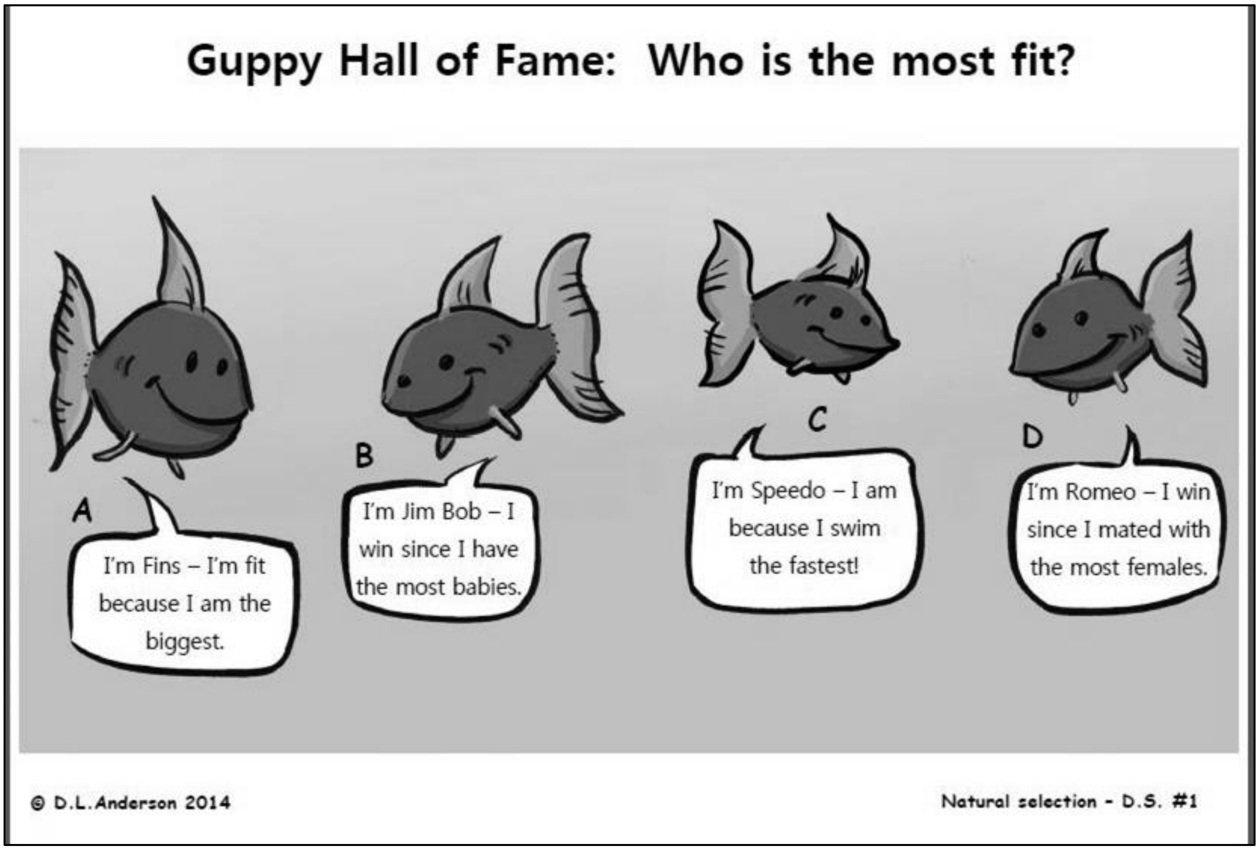

<u>Part A</u>: Spend 2-3 minutes explaining your answer

Circle which answer you chose? A B C D

Why did you choose that answer?

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Why didn't you choose the others?

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Circle which answer your small group chose? A B C D

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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Why did you choose that answer?

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Circle which answer your small group chose? A B C D

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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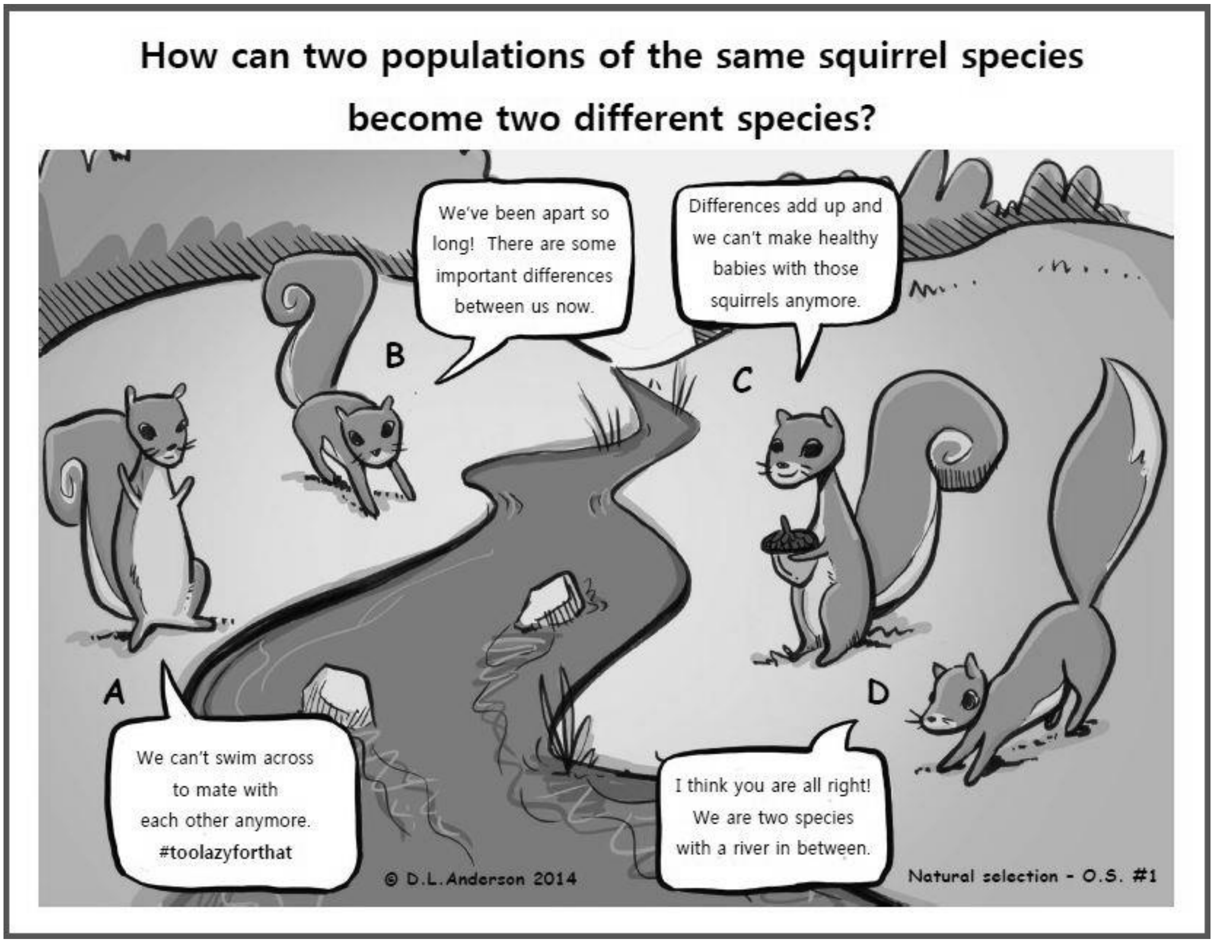
Instructions: Read the question in the cartoon and choose which answer you think is best.



<u>Part A</u>: Spend 2-3 minutes explaining your answer

Circle which answer you chose? A B C D

Why did you choose that answer?

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Why didn't you choose the others?

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Circle which answer your small group chose? A B C D

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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Appendix D2 – Distributed Control Exemplar Student Response form

Instructions: Read the question and write out your answer in the space provided.

What happens to the size of a grass population when there is plenty of water, sunlight, and space, and no grass eaters (like cows)? *B.P. #1*

<u>Part A</u>: Spend 2-3 minutes answering the question.

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question and write out your answer in the space provided.

In a healthy, stable desert ecosystem, what will likely happen to a population of native rattlesnakes over the years? S.P. #1

<u>Part A</u>: Spend 2-3 minutes answering the question.

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question and write out your answer in the space provided.

What is competition in nature?	L.R. #1

<u>Part A</u>: Spend 2-3 minutes answering the question.

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question and write out your answer in the space provided.

A male and a female blue jay have four chicks one spring. How many of the fours will be likely to survive and then have chicks of their own? L.S. #1

Part A: Spend 2-3 minutes answering the question.

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Part B: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question and write out your answer in the space provided.

Are all of the owls within a population exactly alike?	V. #1

<u>Part A</u>: Spend 2-3 minutes answering the question.

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question and write out your answer in the space provided.

What is the random part of natural selection?	O.V. #1

Part A*: *Spend 2-3 minutes answering the question.

Part B*: *Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question and write out your answer in the space provided.

A man and a woman are both physically fit. Will their current fitness impact their children's fitness later? V.I. #1

<u>Part A</u>: Spend 2-3 minutes answering the question.

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question and write out your answer in the space provided.

Consider a population of guppies (a type of fish). What determines which guppy is the most fit? D.S. #1

<u>Part A</u>: Spend 2-3 minutes answering the question.

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Did your answer change?   YES   NO

If so, why did your answer change? What argument/evidence helped change your mind?

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COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question and write out your answer in the space provided.

What is adaptation?	C.P. #1

<u>Part A</u>: Spend 2-3 minutes answering the question.

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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COMPARISON OF MASSED VS DISTRIBUTED

Instructions: Read the question and write out your answer in the space provided.

Two populations of the same squirrel species are separated by a river. How can they become two different species? O.S. #1

<u>Part A</u>: Spend 2-3 minutes answering the question.

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<u>Part B</u>: Now gather with your small group to discuss the question. Then answer the questions below. You will have 3-4 minutes.

Did your answer change? YES NO

If so, why did your answer change? What argument/evidence helped change your mind?

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Appendix E – Bidimensional coding scheme for student interviews

Descriptions of coded responses to be used in a bidimensional coding scheme

Conceptions		Descriptions
A — Expert conceptions/conceptions		These statements represent current level of scientific understanding regarding the various topics addressed. They can be supported with examples.
	B —Compatible/Elaborate	Statements concur with expert proposition and have sufficient detail to show the thinking behind them and/or recur throughout the transcript in the same form
	C —Compatible/Sketchy	Statements concur with expert proposition, but essential details are missing. Often represent correct guess among choices provided, but no ability to explain why choice was made.
Novice conceptions	**D —Compatible/incompatible**	Makes sketchy statements that concur with preposition, but those are not elaborated, and makes sketchy statements that disagree. Contradictory statements are found in the transcript. -Statements teleological (need/want). -Statements claim weather-based changes.
	E —Incompatible	Statements disagree with preposition. Details may or may not be given.
	F —Nonexistent/No evidence	Student response is “I don’t know” or no mention of the topic when asked.

Appendix F – Mean CINS scores by concept within each treatment group

Distributed

	Pretest	Posttest A	Posttest B
BP (1,11)	68.54%	48.15%	59.52%
SP (2,12)	69.66%	50.62%	61.90%
LR (3,13)	24.72%	44.44%	36.90%
LS (4,14)	24.72%	39.51%	30.95%
V (5,15)	37.08%	81.48%	79.76%
OV (6,16)	16.85%	20.99%	13.10%
VI (7,17)	35.96%	44.44%	47.62%
DS (8,18)	37.08%	41.98%	35.71%
CP (9,19)	22.47%	27.16%	16.67%
OS (10,20)	38.20%	27.16%	19.05%

Distributed Control

	Pretest	Posttest A	Posttest B
BP (1,11)	76.92%	56.47%	62.50%
SP (2,12)	53.85%	62.35%	57.95%
LR (3,13)	34.07%	35.29%	27.27%
LS (4,14)	35.16%	30.59%	32.95%
V (5,15)	50.55%	72.94%	73.86%
OV (6,16)	13.19%	23.53%	20.45%
VI (7,17)	36.26%	52.94%	48.86%
DS (8,18)	39.56%	14.12%	25.00%
CP (9,19)	21.98%	23.53%	25.00%
OS (10,20)	37.36%	27.06%	12.50%

Massed

	Pretest	Posttest A	Posttest B
BP (1,11)	78.99%	50.82%	75.42%
SP (2,12)	72.27%	67.21%	77.97%
LR (3,13)	39.17%	31.97%	30.51%
LS (4,14)	27.73%	34.43%	44.92%
V (5,15)	42.02%	79.51%	81.36%
OV (6,16)	14.29%	28.69%	28.81%
VI (7,17)	38.38%	71.31%	74.58%
DS (8,18)	34.11%	39.34%	52.54%
CP (9,19)	28.57%	32.79%	20.34%
OS (10,20)	35.29%	37.70%	33.90%