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The Next Generation Science Standards: Saving K-12 Science Education

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The Next Generation Science Standards: Saving K-12 Science Education

Kaitlin Caylor

Western Washington University

Honors Capstone Project

Advisor: Georgianne Connell

ABSTRACT

The United States has been struggling to provide effective K-12 science education. In response, states began adopting the Next Generation Science Standards (NGSS) in 2013 with the hopes of improving science education in the United States. As the NGSS become more common throughout schools in the U.S. it is important to begin collecting data on how they are affecting science education. This study was designed to collect preliminary data on the effectiveness of the NGSS in preparing students for college-level biology. University students with varying levels of exposure to the NGSS were given a biology benchmark assessment that is aligned with the standards to determine preparedness for university level biology. In addition, participants were given a demographic survey to determine if factors outside of exposure to the NGSS that could affect performance on the benchmark assessment. After analyzing the benchmark assessment scores, I identified the content areas with the weakest performance and thus a future point of focus for high school biology courses. Furthermore, I analyzed the benchmark assessment scores in relation to the demographic survey and determined that there were very few factors that affect benchmark assessment scores. It is important to continue to watch and evaluate the effectiveness of the NGSS since without satisfactory science education, students will be unprepared for college level coursework.

INTRODUCTION

In today's world, science is everywhere; technology, environmental concerns, and a professional world that values scientific skills such as inquiry, problem solving, and collaboration. Yet, the United States continues to struggle in K-12 science education. According to the 2015 Programme for International Student Assessment (PISA), the United States ranks 24th out of 71 countries on the science portion of the assessment (Desilver, 2017). The United States is failing to adequately prepare its students for a world that is becoming more and more centered around science. While there have been attempts over the years to fix science education in the United States, relatively few efforts have resulted in significant progress. **(**Pellegrino, Wilson, Koenig, & Beatty, 2014).

In 2013, states began to voluntarily implement the most recent attempt to improve K-12 science education, the Next Generation Science Standards (NGSS). The NGSS are a new set of content standards for physical, life, and earth and space sciences, as well as engineering design for every grade level (K-12). The NGSS use a three-dimensional model of science learning to create standards, or performance expectations, within each discipline (Figure 1). The three dimensions are crosscutting concepts, science and engineering practices, and disciplinary core ideas. Crosscutting concepts are designed to help students make connections between the four science disciplines. Science and engineering practices aim to help students apply their knowledge in the same methods of inquiry investigation used by scientists. Finally, the disciplinary core ideas are the key ideas within each science discipline. Together, these three dimensions are designed to create a cohesive science education for K-12 students (NGSS Lead States, 2013).

Figure 1. Infographic describing the three-dimensional science model used in the Next Generation Science Standards. Reprinted from *Measured Progress*. (n.d). Retrieved from https://www.measuredprogress.org/wp-content/uploads/2016/12/NGSS-Poster.pdf. Copyright 2017 by Measured Progress.

It has been six years since states began adopting the Next Generation Science Standards and as of 2019, 20 states and the District of Columbia have adopted the NGSS, including Washington state (National Science Teaching Association, n.d.). Washington adopted the NGSS in October 2013, along with a 4-year implementation plan, completing the full transition to the NGSS by the end of the 2017-2018 school year (Office of Superintendent of Public Instruction, 2015). In spring of 2018, Washington state administered the Washington Comprehensive Assessment of Science (WCAS) to 5th, 8th, and 11th grade students for the first time. This assessment measures students' science knowledge based on the NGSS for each grade level (Office of Superintendent of Public Instruction, n.d.a). Only 30.3% of the 11th grade students who took the assessment met grade level standards. When compared to 5th and 8th grade, 11th grade had the fewest number of students meeting science standards. Additionally, when comparing subjects, science had fewer students meeting grade level standards across all grades than English language arts and math (Office of Superintendent of Public Instruction, n.d.b). As the testing occurred during the final year of NGSS implementation, these numbers are more of a reflection on the previous science curriculum than the NGSS. In the future, if NGSS are an effective method of teaching science, an increase in the WCAS scores should be expected. However, it is important to start collecting data on student performance now to build the basis for future comparisons.

The purpose of this study was to collect preliminary data on the effectiveness of the NGSS, specifically focusing on the life science discipline. University students of varying high school demographics, and thus varying exposure to the NGSS, participated in the study. Using a benchmark assessment, I determined if students were meeting the NGSS standards, which biology topics students struggle with the most, and if demographic factors affect performance on the benchmark assessment. This study was designed to be exploratory and was used to collect preliminary data on the NGSS. I hypothesized that the students who had taken multiple NGSS-based science classes would have the highest assessment scores.

METHODS

The Next Generation Science Standards for life science at the high school level was used to create a benchmark assessment to test for proficiency for each standard. The assessment was divided into five sections matching the topics of the high school life science NGSS. These topics are: structure and function, matter and energy in organisms and ecosystems, interdependent relationships in ecosystems, inheritance and variation of traits, and natural selection and evolution. Each question on the benchmark assessment was written to target one performance expectation of the life science NGSS for a total of 24 questions. Questions were written in a multiple-choice style with four answer options for each question (Appendix A).

The benchmark assessment was given to students in Western Washington University's Biology 101 course during Spring 2019. Biology 101 is an introductory course to biology intended for students not majoring in biology. All students enrolled in the course were eligible to participate. I gained approval for human subject research through the Institutional Review Board (IRB approval number: EX19-076). This particular course was used for the assessment because it encompassed a wide range of students with varying high school backgrounds and students who had no other university biology experience. Students were given a total of 40 minutes in class to complete the assessment. Students were then asked to complete an online Canvas survey that contained seven demographic questions, including high school graduation year, state of high school attendance, and if they had ever heard of terms associated with the NGSS. Questions were written in a variety of formats including short answer and multiple choice (Appendix B). Students were given unlimited time to complete the survey, however the average time to complete the survey was about 5 minutes. Both the benchmark assessment and online survey were optional for students, but they received extra credit points for each completed part as incentive.

The benchmark assessment results and survey answers were then analyzed for trends between assessment score and survey answers. Each participant had an overall assessment score and five section scores. These were then averaged across all participants. In addition, participants were grouped based on their responses to the online demographic survey and again their scores were averaged within each group to search for differences between demographic responses. Not all demographic questions were used during the analysis. The first demographic I focused on was if NGSS terminology was used by high school teachers, a clear indicator NGSS presence in the classroom. This is an important question to focus on as it will reveal if there has been any success with the NGSS in its early stages of implementation. Additionally, I chose classroom type, which is an indirect indicator of the NGSS. Students were asked to identify the classroom environment that best matched their high school science classrooms and were given four different classroom environments from which to choose. Classroom type 1 was a classroom that was mostly lecture based with very little independent or group work. Type 2 was mostly composed of lecture and independent work with very little group work. Type 3 classrooms were half lecture, and half group and independent work. In type 4 classrooms, students did mostly group work with some lecture and independent work. Classroom types 3 and 4 are indirect indicators of the NGSS which promote a more student-centered learning environment. Next, I focused on if students had previously taken biology in high school and the total number of science classes they had taken in high school. And finally, students were asked which state they attended high school in, which was grouped as in-state (Washington) or out of state (outside of Washington). This question was selected to provide insight on how Washington’s science education compares to other states. I disregarded the remaining demographic survey questions during the analysis as the range of responses was too wide to draw conclusions.

RESULTS

Using all participants scores (n = 171), the average score for the benchmark assessment was 60.14% (Figure 2) with the following average section scores in order from highest to lowest: interdependent relationships in ecosystems (69.59%), structure and function (68.23%), matter and energy in organisms and ecosystems (64.62%), natural selection and evolution (55.44%), and inheritance and variation of traits (39.04%) (Figure 3).

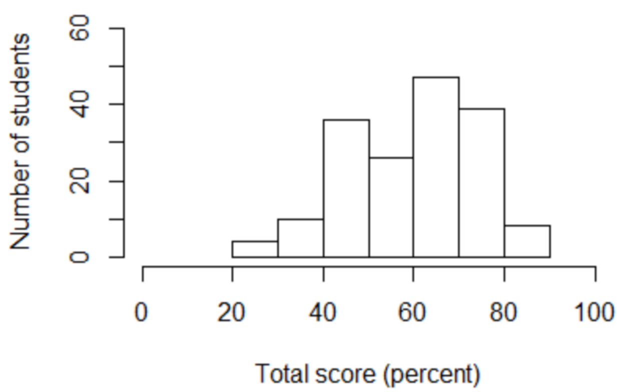

Figure 2. Histogram of overall student scores on the benchmark assessment (n = 171). Mean score was 60.14 with a standard error of 1.06.

For simplicity, when analyzing the assessment scores in relation to the demographic survey responses, I used overall assessment scores. There was no significant difference in scores between participants who were aware of the NGSS used in their high school based on teacher language or based on classroom type. However, while not significantly different, the overall expected trend of higher scores in participants that had NGSS or classroom type 3 or 4, was present (Figures 4 and 5). While the total number of science classes taken in high school did not impact overall assessment score (Figure 6), students who took biology in high school had an average score of 61.59% which was 15.49% higher and significantly different than their peers without previous biology experience

(53.55%) (Figure 7). Finally, the state in which participants attended high school did have a significant impact on overall assessment score as out of state students scored 8.53% higher (65.15%) than in-state students (60.03%) (Figure 8).

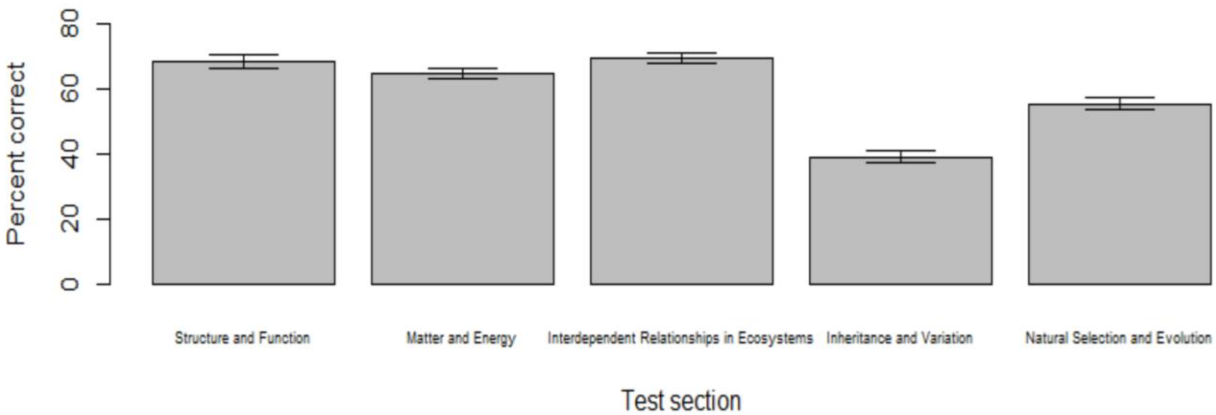

Figure 3. Mean section scores for all students (n = 171). Error bars indicate standard error.

DISCUSSION

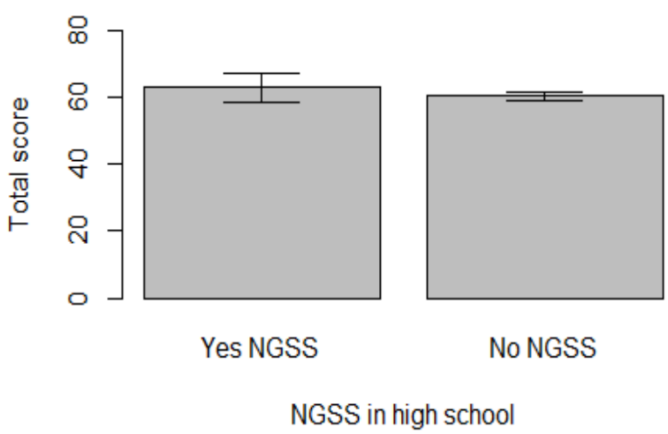

Figure 4. Mean scores for students who were exposed to the NGSS in high school (n = 14) compared to those who did not have NGSS in high school (n = 138). Errors bars indicate standard error. Scores were not significantly different than each other.

Overall, there seem to be very few demographic factors that determine academic preparedness for university level biology. Exposure to the NGSS in high school did not translate to higher benchmark assessment scores. There was only a nonsignificant increase of scores between participants who were aware of the NGSS in their high school science classrooms and those who were not (Figure 4). However, it is important to recognize the low number of students who indicated that they had the NGSS, which could contribute to the nonsignificant difference. Anticipating this outcome, I also used classroom type to assess the possible presence of the NGSS. Participants who indicated a classroom type 3 or 4 likely had some NGSS exposure, however scores were still not significantly higher than students who had a lecture-based classroom (Figure 5). While larger sample sizes could have provided more insightful conclusions, this preliminary data acts as a baseline to compare with future studies. As the NGSS become more common in schools, it will be important to revisit the relationship between knowledge retention and NGSS indicators to determine the effectiveness of the three-dimensional learning process.

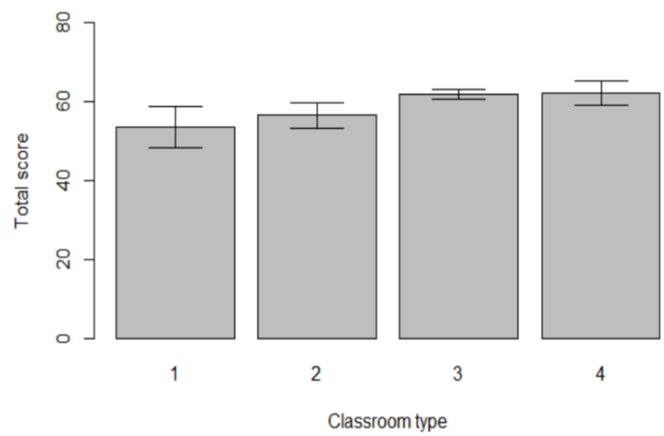

Figure 5. Mean scores for students based on classroom type. Error bars indicate standard error.

Another demographic factor that did not impact benchmark assessment score was the total number of science classes taken in high school (Figure 6). As students take more science classes it gives them opportunities to hone their scientific thinking skills. There are overarching themes that connect the different scientific

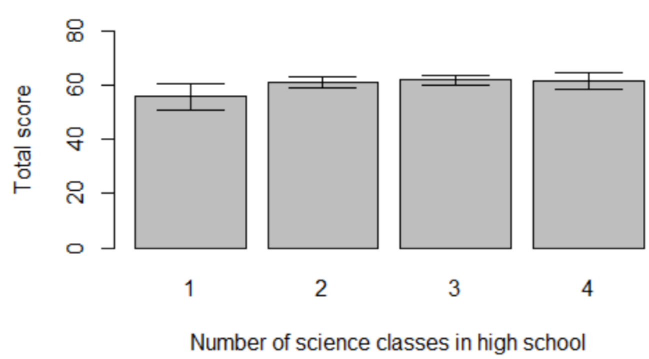

Figure 6. Mean scores for students based on how many science classes they had taken in high school. Error bars indicate standard error. Scores were not significantly different from each other.

disciplines such as structure and function, and cause and effect. It is expected that as students are exposed to more science disciplines, the skills of identifying those themes and applying that knowledge should increase (Fick, 2018). In the NGSS, these themes are addressed in the cross-cutting concepts. The cross-cutting concepts act as lenses that help students understand how science phenomena work (Fick, 2018). While the idea of overarching themes across the scientific disciplines is not new, the NGSS marks the first time they have been integrated into standardized instruction. Curriculum developers have struggled to integrate them into curriculum in the past due to their complicated nature of being stand-alone ideas as well as being the link that connects various science principles (Fick, 2018). The lack of overarching themes in science curricula prior to the NGSS could account for the nonsignificant differences between assessment scores of students with differing amounts of science experience. Moving forward, if cross-cutting concepts are applied correctly and effectively, students who have taken more science classes should have higher scores.

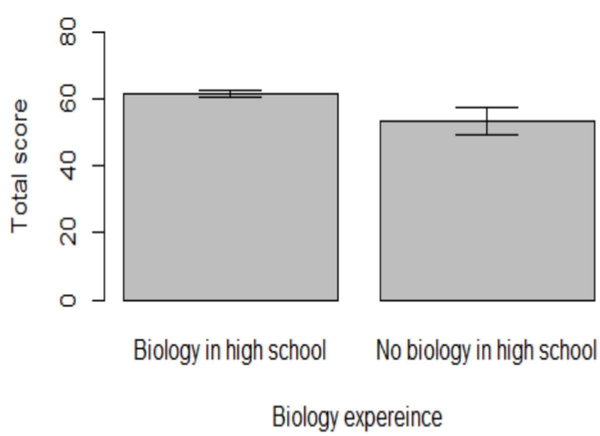

Figure 7. Mean scores for students who had previously taken biology in high school (n = 137), compared to those who did not (n = 15). Error bars indicate standard error. Scores were significantly different from each other.

The two demographic factors that had a significant impact on assessment score were if the participants had taken biology in high school and the state of attendance. Students who had previously taken biology in high school scored significantly higher than those who did not (Figure 7). This was expected as the benchmark assessment was created based on material that was covered in high school biology. Those without past biology experience did not have the background knowledge necessary to do well on the assessment (Loehr, Almarode, Tai, & Sadler, 2012).

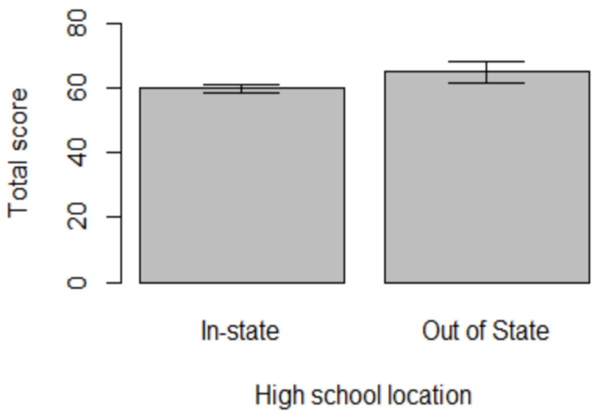

Figure 8. Mean scores for students who attended high school in the state of Washington (n = 130) compared to those who attended high school outside the state of Washington (n = 22). Error bars indicate standard error. Scores were significantly different from each other.

Finally, students who attended high school outside the state of Washington scored significantly higher than students who attend high school in state (Figure 8). The reason for this is unclear. One possible explanation is that more out-of-state students reported having the NGSS in their high schools (13.64%) in comparison to the in-state students (7.69%). However, it is important to consider the relatively small sample size of out of state students (N = 22) in comparison to in-state students (N = 130). Western Washington University attracts mostly Washington state residents, so the uneven sample sizes may have skewed the results.

While there were very few demographic factors that indicated preparedness for university level biology, I was able to identify content areas that need more attention at the high school level. Looking at the section scores, inheritance and variation was significantly lower than the other sections. This could be because inheritance and evolution are difficult topics for students to grasp as it requires abstract thought (Banet & Ayuso, 2013). Current methods for teaching inheritance could be to blame for this lack of understanding and should serve as a point of focus moving forward with the implementation of the NGSS. The NGSS are not only changing the way science is taught, but also learned by students. The three-dimensional science learning framework that the NGSS use, provides opportunities for students to learn and make sense of various science phenomena rather than memorize discrete facts (NGSS Lead States, 2013). This higher-level thinking is currently absent from most science classrooms and is the same type of thought processes that topics like inheritance and evolution require.

In a time of high STEM demand, the United States is falling short in preparing students for college level science courses. Of the top ten majors for incoming freshman in 2017 at the University of Washington, eight were in a STEM field, with biology being the third most common (“First-choice majors”, 2017). Nationally, 28% of college students are a declared STEM major. However, 48% of those STEM majors either switched to a non-STEM major or dropped out of college entirely (Han & Buchmann, 2016). This high attrition rate is partly attributed to the lack of proper science education at the high school level. Too many students are arriving to university science courses unprepared and as a result, fail (Han & Buchmann, 2016). Science education must be revitalized in the United States, otherwise, not only will students continue to struggle at the university level, but also in today’s science driven society. The Next Generation Science Standards could be the solution to this science education problem, but only time will tell.

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APPENDICES

Appendix A: Benchmark Assessment

Benchmark Assessment, 5 extra credit points. This assessment is **scored based on completion, not accuracy of answers**. Please answer each question to the best of your ability. Make a best guess when you do not know the answer. You may write on this assessment form.

Please turn in both this assessment form and your scantron once you are finished.

Structure and Function

1. Individuals who have sickle cell anemia (autosomal dominant disease) make red blood cells that are misshaped. Having two alleles with the sickle cell mutation results in errors to ________.

a. Polypeptide chain folding
b. RNA sequence
c. The sequence of amino acids in the polypeptide chain
d. All of the above

2. Which two organ systems interact to help you transport nutrients to the cells throughout your body?

a. Nervous system and circulatory system
b. Digestive system and circulatory system
c. Digestive system and muscular system
d. Respiratory system and muscular system

3. Which is not an example of homeostasis?

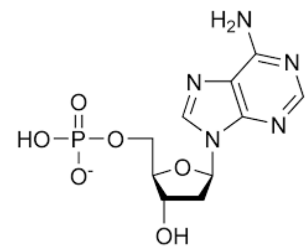
a. When it is cold, muscles shiver to increase metabolic activity.
b. When oxygen in the blood is low, the heart pumps faster.
c. When you see food, you become hungry.
d. When your body needs to conserve water, the kidneys produce more concentrated urine.

Matter and Energy in Organisms and Ecosystems

4. Which of the following correctly summarizes the process of photosynthesis?

a. Carbon Dioxide + Water → Oxygen + Glucose
b. Oxygen + Water → Glucose + Carbon Dioxide
c. Glucose + Oxygen → Carbon Dioxide + Water
d. Oxygen + Carbon Dioxide → Glucose + Water

5. Plant cells contain DNA molecules that are made up of nucleotides. See the example of a nucleotide. How do plants acquire the phosphorous and nitrogen atoms present in the molecule?



a. They are by-products of photosynthesis.
b. They are absorbed through the roots from nutrients in the soil.
c. They are by-products of cellular respiration.
d. They diffuse through the leaves.

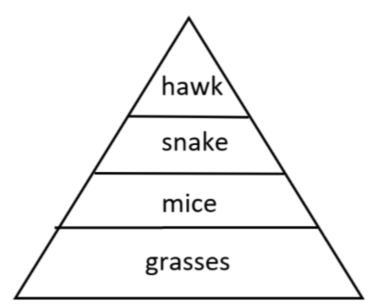
6. You eat a grape, which is high in glucose content. How could a glucose molecule provide you with the energy to move your little finger?

a. The glucose is digested into CO_2 and H_2O, which have more energy than the original glucose molecule and are used to fuel your finger cells.
b. The glucose molecule is rearranged into ATP molecules. The ATP fuels your finger cells.
c. The glucose molecule is energy and directly fuels your finger cells.
d. The energy of the glucose molecule is transferred to ATP as glucose is broken down, the ATP fuels your finger cells.

7. Lactic acid fermentation typically occurs in your muscle cells during a workout. This process occurs because your cells are struggling to get ____________.

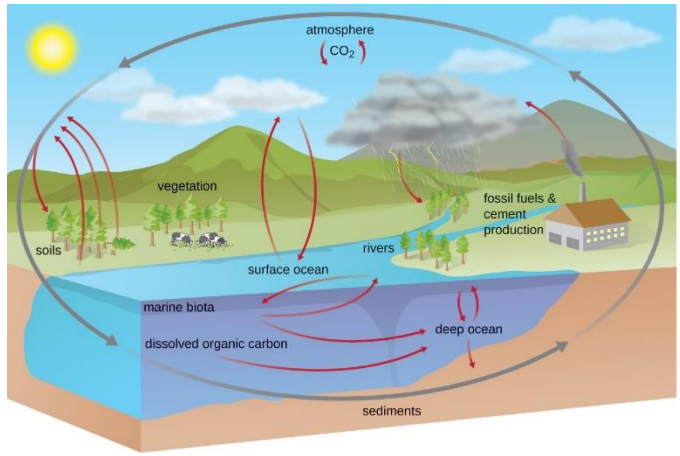
a. Glucose
b. Oxygen
c. Water
d. Carbon Dioxide

8. This is an example of a biomass pyramid for a terrestrial ecosystem. Each section of the pyramid represents the biomass, or amount of organic matter, at each trophic level. Which of the following explains why there is generally less biomass at the top of the pyramid than at the bottom?



a. At each level, some biomass fuels the life functions of the organism.
b. At each level, some biomass is stored in newly made structures of the organism.
c. At each level, some biomass is not used and excreted.
d. All of the above.

9. The image illustrates the carbon cycle. Which processes are responsible for releasing carbon dioxide into the atmosphere?



a. Combustion and Photosynthesis
b. Cellular Respiration and Photosynthesis
c. Photosynthesis and Decomposition
d. Combustion and Cellular Respiration

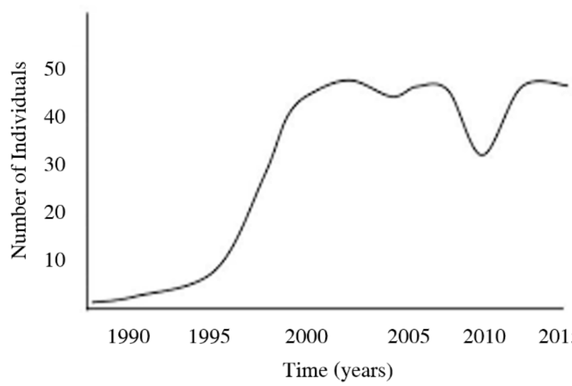
Interdependent Relationships in Ecosystems

10. African wild dogs hunt in packs in order to take down large prey. By working together, the fitness of all the dogs increase. This group behavior is known as ____________.

a. Altruism
b. Mutualism
c. Cooperation
d. Eusociality

Use the graph showing the size of a population of deer over time to answer the next two questions.

11. Which ***is not*** a possible explanation for the decrease in individuals below the carrying capacity in 2010?

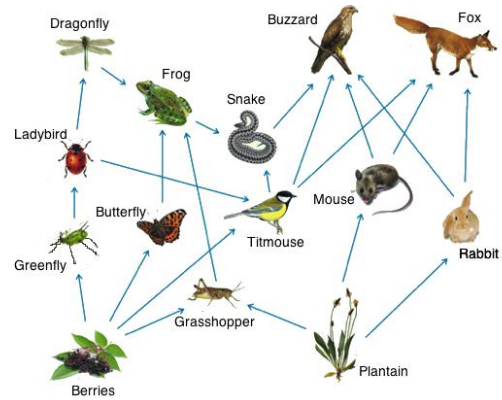


a. A drought that decreased the vegetation available to the deer.
b. An increase in hunting that season.
c. A disease that spread through the herd.
d. A decrease in elk, which occupy the same habitat.

12. Estimate the average deer population from 2000 to 2015.

a. 45
b. 40
c. 30
d. 20

13. This is an example of a stable food web. What would be the immediate effect on the food web, if the foxes became targets for human hunting?



a. Buzzard population would decrease.
b. Plantain populations would decrease.
c. Rabbit populations would decrease.
d. Mouse populations would decrease.

14. The mountain pygmy possum, a small marsupial in Australia, was once thought to be extinct. However, three small populations have recently been discovered. Which of the following would help ensure the natural survival of the mountain pygmy possum?

a. Removing all other species from their habitat.
b. Introducing another animal that occupies the same niche.
c. Limiting the amount of human activity in their habitat.
d. Removing the populations from their habitat and place them in a zoo.

15. We are currently in the 6th mass extinction in which scientists estimate 75% of species will go extinct in the next 5 centuries. Unlike previous extinctions, this one is human induced. For example, climate change is one of the major causes. Which of the following will be ***least likely*** to have a positive impact on climate change?

a. Carbon sequestration.
b. Consuming local crops.
c. Releasing chlorofluorocarbons (CFCs) into the atmosphere.
d. Investing in alternative energy sources.

Inheritance and Variation of Traits

16. Recall the last time you cut your finger. The new cells that grew to replace the damaged cells were produced through which process?

a. Meiosis
b. Mitosis
c. DNA replication
d. Protein synthesis

17. All cells in your body have the same DNA, however, each cell uses the genetic material differently. Which ***is not*** a possibility for the functions of DNA?

a. Some DNA transports amino acids during protein synthesis.
b. Some DNA codes for proteins.
c. Some DNA is involved in regulatory functions.
d. Some DNA has no known function and is cut out.

18. Genetic variation causes a variety of phenotypes, such as eye color in humans. This results from __________________.

a. New genetic combinations created through meiosis.
b. Mutations occurring during DNA replication.
c. Environmental factors that cause mutations.
d. All of the above.

19. Cystic Fibrosis (CF) is an autosomal recessive disease that causes mucus buildup in the lungs. If one parent is a carrier for CF and the other has CF what is the probability that their child will have CF?

a. 25%
b. 50%
c. 75%
d. 100%

Natural Selection and Evolution

20. These images shows two different species of finches found on the Galapagos Islands. Which piece(s) of evidence could be used to prove the finches share a common ancestor?

I. Similarities in DNA sequence
II. Similarities in geographic location
III. Similarities in embryonic development

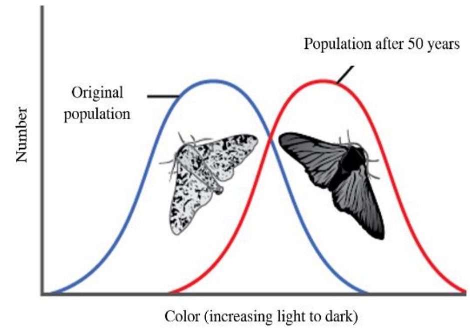
a. Only I
b. Only II
c. I and III
d. I, II, and III

21. The process of evolution results from which factors?

I. Genotypic variation due to mutations and sexual reproduction.
II. Selection pressures such as competition for resources.
III. The proliferation of organisms with an increased fitness.
IV. The potential for the species to increase in number.

a. Only I
b. I and IV
c. I, II, and IV
d. I, II, III, and IV

22. Peppered-moths come in two colors, light and dark. In the original population, light moths were more common, but over time the population shifted to favor the dark moths. Which statement is the best explanation for this trend?



a. Predation on the dark moths increased.
b. Light moths are physiologically superior to dark moths.
c. An environmental change caused the darker color became a more favorable trait.
d. Light moths reached reproductive maturity earlier than dark moths.

23. Many infectious diseases are becoming difficult to treat because of bacterial resistance to antibiotics. Populations of bacteria can become resistant when they are exposed to an antibiotic. What is the best general explanation for how this occurs?

a. Over time, the antibiotic triggers the bacteria's immune system to destroy the antibiotic so it can live.
b. The antibiotic activates enzymes within the bacteria cells, which destroys the antibiotic and allow the bacteria to live.
c. The antibiotic causes bacteria to mutate, so that resistant bacteria are more likely to arise.
d. The antibiotic kills all the bacteria that do not have antibiotic-resistant mutations. Resistant bacteria with higher fitness are able to survive and reproduce.

24. Overfishing can have dramatic effects on the ecosystem. If salmon fishermen are catching all of the largest salmon in the area, what is ***least likely*** to happen to the rest of the ecosystem, when all of the large salmon are fished out?

a. The salmon will decrease in size overtime as only the small salmon are surviving to reproduce.
b. The salmon will grow larger in response to the fishing demand.
c. The organisms below the salmon in the food chain will increase in population.
d. The salmon predators will decrease in population and possibly go extinct.

Appendix B: Online Demographic Survey

1. What year did you graduate high school?

2. When was the last year you took a science class (either high school or college)?

3. Which science courses did you complete in high school? Select all that apply.

   a. Biology
   b. Chemistry
   c. Physics
   d. Environmental science
   e. Other

4. Which state did you attend high school in?

5. What district was your high school located in?

6. Using the following scale, select which of the following best represents your high school science classrooms?

   a. Mostly lecture, very little independent/group work
   b. Mostly lecture and independent work, very little group work
   c. Half lecture, half group/independent work
   d. Mostly group work with some lecture and independent work

7. Did your high school teachers ever refer to “NGSS”, “cross-cutting concepts”, or “disciplinary core idea”?

   a. yes
   b. no