THE STARS EVOLUTION SUITCASE

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DEDICATION

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THE STARS EVOLUTION SUITCASE

by

CORBYN BEACH

THESIS

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THE STARS EVOLUTION SUITCASE

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To supplement the education and enthusiasm for the subject of evolution in high school, I developed a portable "science suitcase," containing an animation, a game and a lab, for use in the classroom. The Howard Hughes Medical Institute funded this project through a grant written by Joel Goodman, Ph.D., for the STARS Science Triathlon. I surveyed teachers from the surrounding school districts, researched evolution and existing materials, and built lesson plans for the suitcase components. Teachers in the surrounding community evaluated these components, and I made revisions based on those evaluations. Once the STARS Evolution Suitcase assimilates into the high school curriculum, the teachers and students will demonstrate and evaluate its effectiveness.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER ONE
Introduction

GOAL

The goal of this project is to provide high school biology teachers and students in the Dallas ISD and surrounding districts a comprehensive, conceptual framework to better understand and appreciate the subject of evolution. The content includes all the basic, empirical observations made supporting evolution, including: the fossil record, the mechanisms such as natural selection and genetic drift which act on populations, embryological development, and genetic and structural homologies between species. Not only is the goal to explain these observations, but also to illustrate how they work in a detailed, concise, and simplified manner.

To achieve this goal, the project is divided into three components to fit inside a portable science suitcase for use in the classroom. The three components include an animation, a game and a lab. The animation is designed primarily for auditory and visual learners, while the game and lab are included to help the kinesthetic learner. The purpose of the animation is to guide or supplement classroom lecture and discussion of evolution. The purpose of the game is to provide a quick and simple in-class demonstration of the mechanisms of evolution, reinforcing concepts learned in the animation. Lastly, the purpose of the lab is to reinforce certain concepts in the animation, specifically the fossil record, homologies, and the phylogenetic tree.

BACKGROUND

The STARS Science Triathlon

The project is part of the annual STARS (Science Teacher Access to Resources at Southwestern) Science Triathlon in Dallas, Texas. The Triathlon resulted from a pre-college initiative by the Howard Hughes Medical Foundation. It is a collaborative effort between The University of Texas Southwestern Medical Center, Advanced Placement Strategies, and The Museum of Nature and Science. Their stated goals are to improve the biology education at poorly funded DISD schools, provide an environment that encourages the development of successful Advanced Placement courses in these schools, and to spark interest and enthusiasm for science in the Dallas and surrounding communities. The Triathlon consists of a 12-day workshop at UTSW Medical Center, symposia and in-service activities, collaborative research projects guided by UTSW PhD students, staff and faculty, and the development and use of Science Suitcases (STARS Science Triathlon). The idea behind developing these suitcases was to equip biology teachers with a lightweight, portable carrier that can easily fit in the trunk of their car and be transported from school to school. Essentially, these suitcases will contain all the seeds for the drama, passion, innovation, ingenuity, and excitement behind the collaborative effort of the STARS Science Triathlon and enable teachers to effectively present fundamental concepts in science to high school biology students, to motivate them to pursue AP Biology credit, and to convince them that science is worth their time, effort, and dedication.

Why Evolution?

Evolution was selected as the subject of this project for several reasons.

1) Evolution is a foundational process in biology.
2) Biology teachers in the surrounding community need help covering it in the classroom.
3) Historically, the Texas education standards did not cover many of the foundational concepts in evolution.
4) The Texas education standards for evolution are currently expanding to cover its foundational concepts; and this is placing more demand on the teachers and students to learn the new material.
5) Evolution has interesting unknowns and is rife with possibilities for future research.

First, evolution is a foundational process in biology. On the website for the National Center for Science Education, Andrew J. Petto, Ph.D. states that evolution “is the fundamental, unifying theory that underlies all the life sciences.

It has formed the basis of productive and active research for over 140 years and continues to do so. This is why evolution is universally accepted among professional biology researchers” (Petto). The National Academy of Sciences states,

> “The concept of biological evolution is one of the most important ideas ever generated by the application of scientific methods to the natural world.” The evolution of all the organisms that live on Earth today from ancestors that lived in the past is at the core of genetics, biochemistry, neurobiology, physiology, ecology, and other biological disciplines (*Science and Creationism* VIII).

Second, the teacher surveys (p. 18) and the teacher interviews (p. 36) confirmed the need for new materials to help teach evolution. Biology teachers in Texas must often confront the religious home life of the student, a state school board which is divided on evolution, and all the allurements of modern entertainment (videos, animations, games, etc.), to effectually cover evolution in the classroom.

Third, the educational standards in Texas for evolution and other science subjects are reviewed and updated annually. Not only have the standards for evolution been reworded for scientific accuracy, but 5 new TEKS standards were created for the 2010-2011 school year (pg. 29). This trend will need to continue to meet the current demands in research. The Science Teachers Association of Texas states on its website,

> If evolution is not taught properly, students will not achieve the level of scientific literacy needed for science-related careers and life in a society where understanding of the core concepts of science is critical. A thorough understanding of evolution is essential to scientific literacy, and must therefore be one of the goals of science education in our schools. This position is shared by the National Academies, the American Association for the Advancement of Science, the National Science Teachers Association, the National Association of Biology Teachers, the Texas Association of Biology Teachers, and many other scientific and educational organizations ("Teaching Evolution | STAT.").

Lastly, we do not know everything about evolution, and this “not knowing” is exactly what makes science interesting and worth pursuing. The fact that there are answers out there, which have yet to be found, is what drives research. While evolution needs to be presented as scientific fact, there are also many opportunities to show the student in this field where to look to uncover new things: new species, new fossils, new genetic homologies, new discoveries in developmental genes, new DNA mutations, and new research in genetic expression.

CHAPTER TWO
Methods and Materials

TEACHER SURVEYS

Two teacher surveys were conducted collaboratively with Derek Wu, creator of the Photosynthesis suitcase, during STARS meetings in the spring of 2009. The collection of first surveys is in Appendix A, and the collection of second surveys is in Appendix B. Two individuals from each survey were not included in the results because they are from different scientific fields and "do not teach evolution."

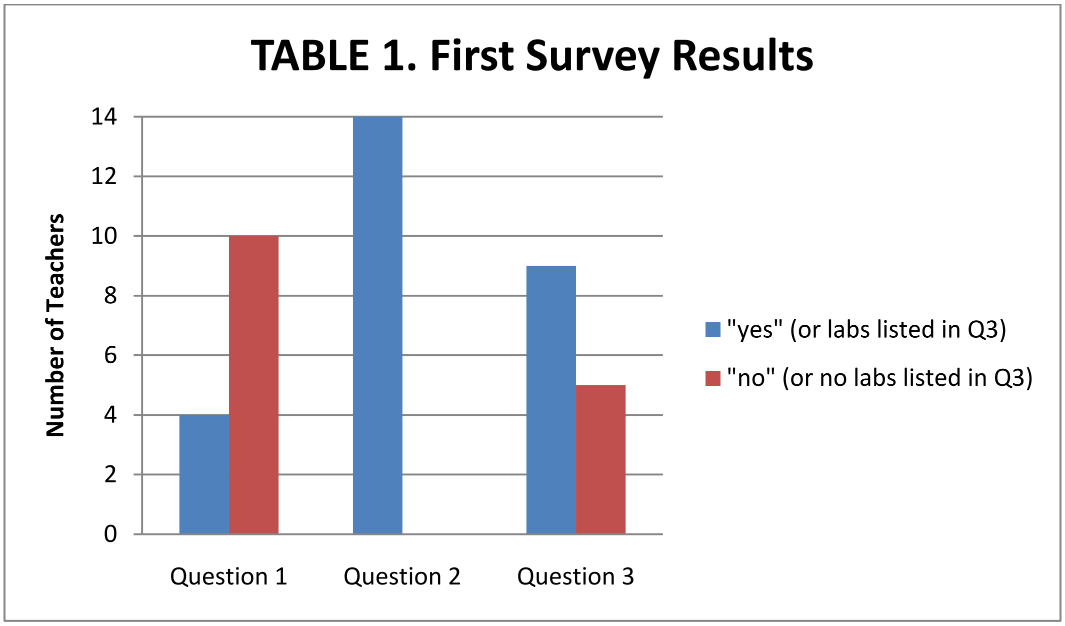
The first survey was designed to assess the technological resources available to the teachers, whether or not they used any materials to teach evolution, if these materials were effective, what kind of labs they used, and if they had any ideas to help teach these subjects. The questions about student access to computers and internet were included to assay the value of designing an educational video game. Since the design of a video game was halted mid-project, the findings to these questions are irrelevant here.

The questions from the first survey, which are significant for this project, are the following:

> Question 1: "Do you currently use any kind of visual aids, models, animations, or games to teach about evolution?"

Question 2: "Do you think visual aids, models, animations and games are an effective way to help teach the subjects of evolution and photosynthesis?"

Question 3: "What kind of labs do you conduct to teach about evolution? Please list:"



10 out of 14 teachers answered "no" to question 1, "Do you currently use any kind of visual aids, models, animations, or games to teach about evolution?" However, all 14 of the teachers answered "yes" to question 2, "Do you think visual aids, models, animations and games are an effective way to help teach the subjects of evolution and photosynthesis?" This indicates supply is low and demand is great for these materials; so, a need is established in this survey. However, regarding question 3, "What kind of labs do you conduct to teach about

evolution?" 9 out of 14 teachers listed labs they used to help teach evolution. Some listed more than one. This fact, coupled with a few oral statements made by teachers during the presentation of the Enzyme Instigator suitcase (another "science suitcase" funded by the STARS grant), led me to consider how the project resources should be allocated. Both orally and written in the first survey, more interest and need was expressed for the visual aids, models, animations and games than for lab activities. While knowing the lab needed to be interesting and engaging to the student on both a conceptual and a tangible level, from this survey, it was apparent that more time, energy, and resources should be spent on the animation and game.

Teacher Survey for Science Suitcases

Do your students have access to computers in class? Yes No

Do they have access to computers and the internet outside of class? Yes No Don't know

Does your class have a Smart Board? Yes No

Do your students have interactive SchoolPads? Yes No

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes No

Please list:

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes No

Please list :

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? Yes No

What kind of labs do you conduct to teach about Evolution?

Please list:

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

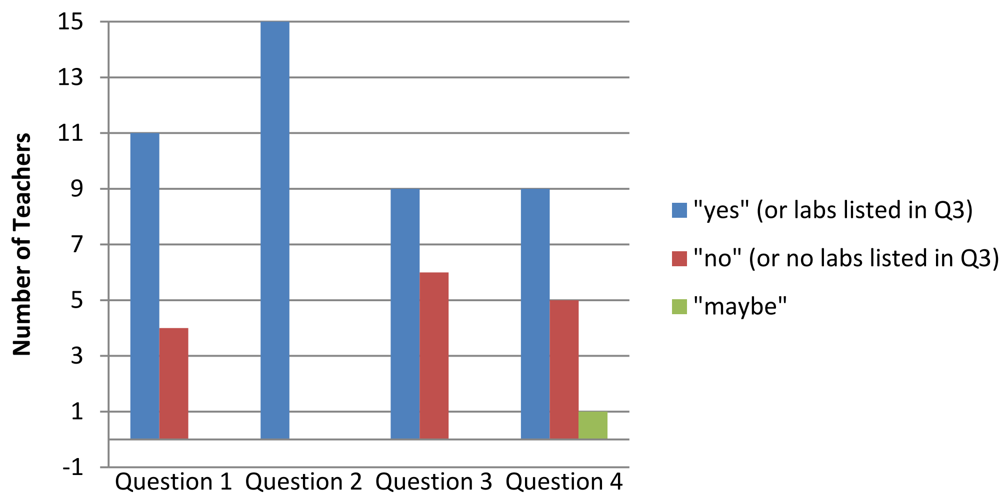
FIGURE 1. First Survey

The second survey was designed to find out more about the teachers, where and what level they teach, what parts of evolution are difficult to teach, and whether or not they were willing to go beyond TEKS requirements.

The questions from the second survey, which are significant for this project, are the following:

> Question 1: “Do you currently use any kind of visual aids, models, animations, or games to teach about evolution?”
>
> Question 2: “Do you think visual aids, models, animations and games are an effective way to help teach the subjects of evolution and photosynthesis?”
>
> Question 3: “What kind of labs do you conduct to teach about evolution? Please list:”
>
> Question 4: “Do you have time in your class to teach material about evolution (and photosynthesis) that goes beyond the TEKS requirements?”

TABLE 2. Second Survey Results



While this survey revealed much more teacher use of the materials detailed in question 1, the results of both surveys combined show that 48% of the teachers (14 of 29) do not have these materials. As in the first survey, all teachers answered "yes" to question 2. The responses to question 3 from the second survey are consistent with the responses in the first survey, in that a majority of teachers (9 of 15) did list one or more labs they use to teach evolution. When the results of both surveys are combined, it shows that 62% of the teachers (18 of 29) already have evolution labs that they use. In addition, 11 of the 15 teachers in the second survey said they were willing to go beyond TEKS requirements.

A list was compiled from the question, "What concepts about evolution are difficult for your students to grasp?"

TABLE 3. Difficult Concepts	
Concept	**Frequency**
Creationism, religious home life, “didn’t come from monkeys thing”	6
Natural selection	4
“theories”	3
Homologous	2
Time	2
Adaptation	1
Analogous	1
“everything”	1
Genetic understanding	1
Molecular basis	1
“species not individual”	1
variation	1

Ultimately, each of these concepts was included in the animation. Moreover, the most frequently mentioned scientific concepts (e.g. natural selection and homologies) were reinforced in the game and lab.

Survey for Science Suitcases

Are you a teacher? Yes No

If yes, what grade and subject do you teach?

Do you teach within the DISD? Yes No

Do your students have access to computers in class? Yes No

Do they have access to internet in class? Yes No

Does your class have a Smart Board? Yes No

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes No

Please list:

Are they effective?

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes No

Please list :

Are they effective?

FIGURE 2A. Second Survey (front)

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? Yes No

What kind of labs do you conduct to teach about Evolution?

Please list:

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

Have you ever used an interactive educational flash game in your class? Yes No

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? Yes No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? Yes No

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models , games, etc.)?

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

FIGURE 2B. Second Survey (back)

RESEARCH

TEKS/TAKS Review

The TAKS exam (Texas Assessment of Knowledge and Skills) is a standardized state test that evaluates student comprehension of the TEKS objectives (Texas Essential Knowledge and Skills).

In the winter of 2009, the Texas State Board of Education considered revisions to the scientific standards of education in evolution. This was based on pressure from social conservative groups promoting an outdated wording of the standards, including evaluation of "strengths and weaknesses" in the Theory of Evolution (Stutz). Many revisions ensued, concerning the exact language to be used. Ultimately, what remained implemented for the 2009-2010 school year were the following TEKS objectives:

(7) Science concepts. The student knows the theory of biological evolution. The student is expected to:

(A) identify evidence of change in species using fossils, DNA sequences, anatomical similarities, physiological similarities, and embryology; and

(B) illustrate the results of natural selection in speciation, diversity, phylogeny, adaptation, behavior, and extinction.

These were the TEKS objectives for biology, found on the Texas Education Agency's TEKS website ("Texas Education Agency - Texas Essential Knowledge and Skills."). While most scientific organizations applauded the abandonment of the “strengths and weaknesses” clause, and considered the final rewording of the objectives a significant step forward for science education in the state of Texas ("Victory over "weaknesses" in Texas | NCSE."), the standards still do not cover much of the content of evolution. Natural selection is listed in objective 7B, and while this is probably the most important mechanism of evolution, it is not the only one. Genetic drift, gene flow, and even artificial selection are other important mechanisms of evolution. Natural selection is also not put in a proper context to understand how evolution works. All the mechanisms, including natural selection, depend on a population’s genetic variation, which is supplied by mutation and sexual recombination (Campbell 459-466). None of these foundational concepts in evolution are mentioned in the objectives.

There are also organizational problems in the TEKS objectives. Objective 6C states,” the student is expected to identify and illustrate how changes in DNA cause mutations and evaluate the significance of these changes.” The mutation and recombination of DNA provides the genetic variation through which evolution works (Campbell 459). However, this is not found under the “theory of biological evolution” mentioned in objective 7; rather, it is found under the “mechanisms of genetics.” All the objectives listed under objective 8, which include the “applications of taxonomy,” and especially 8B, which states, “the student is expected to analyze relationships among organisms and develop a model of a hierarchical classification system based on similarities and differences using taxonomic nomenclature" is entirely dependent on the phylogenetic relationships established in the field of evolution.

During the spring and summer of 2009, the TEKS for evolution were reworded and 5 more objectives were added to the TEKS website for the 2010-2011 school year. Below are the new TEKS for evolution, effective in the 2010-2011 school year:

> (7) Science concepts. The student knows evolutionary theory is a scientific explanation for the unity and diversity of life. The student is expected to:
>
> > (A) analyze and evaluate how evidence of common ancestry among groups is provided by the fossil record, biogeography, and homologies, including anatomical, molecular, and developmental;
> >
> > (B) analyze and evaluate scientific explanations concerning any data of sudden appearance, stasis, and sequential nature of groups in the fossil record;
> >
> > (C) analyze and evaluate how natural selection produces change in populations, not individuals;
> >
> > (D) analyze and evaluate how the elements of natural selection, including inherited variation, the potential of a population to produce more offspring than can survive, and a finite supply of environmental resources, result in differential reproductive success;
> >
> > (E) analyze and evaluate the relationship of natural selection to adaptation and to the development of diversity in and among species;

> (F) analyze and evaluate the effects of other evolutionary mechanisms, including genetic drift, gene flow, mutation, and recombination; and
>
> (G) analyze and evaluate scientific explanations concerning the complexity of the cell.

This project does not cover 7G because its exact meaning is unclear. It was reworded during an intentional political maneuver to obfuscate a non-scientific TEKS proposal initiated by creationist, Don McLeroy ("Live Blog of Texas SBOE Meeting, 2009 March 25-27."). Originally, 7G was worded: "analyze and evaluate the sufficiency or insufficiency of natural selection to explain the complexity of the cell." This is the same creationist and intelligent design sentiment of "irreducible complexity." While its rewording leaves the exact meaning up to the discretion of the teacher, 7G was not included in the materials for this suitcase because it was originally not intended to teach the science of evolution.

Literature Review

A thorough examination of appropriate material was necessary to understand the content of evolution, consider possibilities for designing this project, and improve on existing materials.

First, I reviewed the textbooks the students use in DISD. In the non-AP classrooms they read Johnson's Biology, in which Chapter 13: The Theory of Evolution covers some content. However, the 7th edition of Campbell's Biology, which was being used in the AP class I observed, covers Evolution much more thoroughly in multiple units and chapters. Unit Four: Mechanisms of Evolution, includes: Ch.22 Descent with Modification, Ch.23 The Evolution of Populations, Ch24 The Origin of Species, Ch 25 Phylogeny and Systematics. Unit Five: The Evolutionary History of Biological Diversity begins with Ch. 26 The Tree of Life, and for the next 8 chapters discusses, in detail, the specific evolution of each group in the phylogenetic tree. Other units and chapters reference evolution as necessary. Furthermore, the word "theory," in reference to evolution, is not mentioned in the chapter titles at all in Campbell's Biology. Instead, a brief section on p.451 describes why evolution is not a theory in the colloquial sense of the word, how scientific theories have historically been considered quite different than *other* theories, and then henceforth not mentioned in the text. This is the book I used for almost all of the definitions and core concepts contained in the suitcase. It is also the book required by all of the core Biology courses I took at The University of Texas in Austin.

I also reviewed Dr David Cannatella's syllabus for the Comparative Vertebrate Anatomy course, at UT Austin. This was helpful in creating phylogenies for the early video game storyboards, and later for the fossil lab. His material was also instrumental in deciding on which homologies would be covered.

Another excellent resource for drawing phylogenetic trees was the Tree of Life Web Project. As stated on the website, their goals are to provide "information about biodiversity, the characteristics of different groups of organisms, and their evolutionary history" (*Tree of Life Web Project)*. A great number of books on vertebrate anatomy and paleontology in the Dallas Public Library were also used to get ideas for phylogenetic trees.

A vital resource for this project was Your Inner Fish by Neil Shubin. Shubin simplifies the fossil record down to an accessible level (4-12). I tried to use his basic strategy in my animation, for Chapter 2: The Fossil Record. His colleague, Randy Dahn, as described in this book, provided the research for the Sonic Hedgehog genetic homology shown in Chapter 5: Phylogeny, of the animation (53-59). This book also provided a backdrop for learning about the gill arch homologies in more depth, which is also included in the animation (81-96).

A great number of books in the UT Southwestern library were also used to reference the gill arch homologies. Netter's Atlas of Human Embryology was the main reference for human pharyngeal arch anatomy (Cochard) and A Photographic Atlas of Shark Anatomy was the main reference for shark pharyngeal arch anatomy (Gans).

Another important reference was Why Evolution is True, by Jerry Coyne, in which I reviewed content about the bird-dinosaur relationship and various homologies. Page 83 illustrates the ductus arteriosus homology with fish, which I referenced as an example of a vestigial structure in humans in Chapter 5: Phylogeny, of the animation.

Trey Fondon's research paper on dog skull morphology was simplified to use as an example of modern Evo-devo research at UT Southwestern, illustrated in Ch. 4 Embryology, of the animation.

I reviewed the materials, papers and bibliographies for the Enzyme Instigator suitcase (McArthur) and the Organelle Extravaganza suitcase (Hulsey). I also reviewed some of their cited articles, which detailed the effectiveness of animations and games in the classroom.

The UC Berkley website for evolution was very instrumental in providing ideas for simplifying many of the complex subject matters, such as genetic drift, in the animation (*Understanding Evolution*).

A number of labs were researched and considered as possibilities for including in the suitcase. One was a Magnetobacteria lab, which is a wet lab for natural selection (Culp). However, this was abandoned due to the amount of class time required and unavailability of cultures. Kits available online were considered as a possibility on some sites, such as www.enasco.com and www.carolina.com. After doing research on the web for evolution dry lab activities appropriate for high school level, I designed an activity roughly based on fossil labs detailed in Larry Flammer's lab activity on the Indiana University website (Way) and other labs on the Bellarmine College website ("Evolution Labs.").

PBS 8 hour Special: Evolution

In the surveys collected, the PBS 8 hour Special on evolution was mentioned twice. Bibiana Mendez also mentioned she used parts of it in her classroom. I watched the entire collection and took copious notes on the each section to observe what worked and what did not work for teaching evolution in the classroom.

In general, this video collection has great narration provided by Liam Neeson, interviews with prominent evolutionary biologists, like Dr. Sean Carrol and Neil Shubin, interesting case studies on evolving pathogens, video footage of animals interacting in nature, footage of fossil sites, animations, and a historical dramatization of the life of Charles Darwin (*Evolution.* DVD).

However, concerning classroom use, I found weaknesses in this video. Firstly, it is 8 hours long. In the attempt to make this more accessible for the classroom, PBS issued shorter 5-10 minute segments on their website (Evolution. Web). There remain other shortcomings, even in the segments.

Overall, this video is drama driven, not concept driven. There’s little to no text to accompany the key concepts. So, students will not know what to write down. Foundational concepts like natural selection are never defined or put in the correct context. In the entire 8+ hours I spent watching this video, I do not remember once hearing the words homology, homologous structures, or vestigial structures. Phylogeny is based on these concepts. The video showed phylogenetic trees, but phylogeny was not defined. How evolution works in populations was not covered. The fossil record was not explained in a systematic way to demonstrate how it supports evolution (e.g. fossils are found in layers). Its covering of embryology was limited to a case study of *Drosophila* and it did not illustrate similar stages in development between species. It shows what I recognize to be Hox genes, but it does not mention the term “Hox genes” or describe them in a meaningful way.

After watching this video, I realized it has a completely different purpose than the purpose for this project. Its purpose is to create an appreciation of evolution, but not to make sure its audience is equipped with the vocabulary and the conceptual foundation to *understand* evolution. However, understanding evolution *is* the purpose for this project.

I watched a number of other videos, which share the same purpose as the PBS series. *What Darwin Never Knew* by NOVA and *In the Womb: Cats and Dogs* by National Geographic were both created in 2009. These movies move fast with fascinating images of embryos, good animations and interviews. However, as in the PBS special, there is no text or conceptual framework to accompany the terms. In the National Geographic film, the topic of evolution is also not covered directly. It has more to do with the specific variation of dogs (*In the Womb: Cats and Dogs*).

Early in this project, I also began a literature review on educational video games. To get ideas for including a video game in the suitcase, I read about Immune Attack, watched Spore, and played SimLife, Darwin's Evolution Game, and various simulations on the web. I also scanned some articles that showed the effectiveness of video games in education (Foley, Hoppock, and Kebritchi).

Lectures, Discussions, and Interviews

Research was supplemented with lectures at UT Southwestern, discussion with experts in the field of evolution, and teacher interviews.

On March 4, 2009, I attended Dr. Sean Carroll's lecture, "Endess Flies Most Beautiful: Cis-Regulatory Sequences and the Evolution of Animal Form," and found basic parallels in Dr. Trey Fondon's research on dog skull morphology. Both biologists researched mutations in areas of DNA which affect genetic expression. So, the lecture by Dr. Carroll was useful in understanding and simplifying the content in the evo-devo section of the animation. In October 28, 2009, I attended Dr. David Haig's lecture, "Prader-Willi Syndrome and the Evolution of Human Childhood," which illustrated how genetic imprinting and expression of Prader-Willi and Angelman Syndromes affect the evolutionary fitness of the parents. While much of this content was too specific for my audience, it demonstrated the importance of teaching the fundamentals, such as mutation and fitness. These lectures also opened new doors for future research, beyond the scope of this project.

In addition, I had discussions with experts in the field of evolution. I initiated an email correspondence with Dr. Carroll to discuss specific Hox gene mutations in the vertebrate phylogeny. I met with Richard Mclaughlin, who gave me a tour of Dr. Ranganathan's lab at UT Southwestern. He recommended several articles on evolution, and gave me a lecture on the "reducible complexity" of the coevolution of proteins. Next, I met with Dr. Trey Fondon, who discussed his research on dog skull morphology and tandem repeat mutations. Finally, I met with Dr. Lewis Jacobs, who teaches Evolution and Vertebrate Paleontology at SMU. He helped me in constructing several versions of vertebrate phylogenies, and then we proposed a few possibilities for an educational video game on evolution.

I also interviewed several teachers to discuss content and ideas for materials. I met with Ben Jones, Bibiana Mendez and a former DISD Pre-AP Biology teacher. They shared ideas with me, discussed my storyboards, and supplied me with labs and PowerPoint presentations they use to cover evolution. I also met with STARS Program Coordinator Lynn Tam to discuss the content of my materials and their appropriateness for my audience.

Classroom Observation

In October 2009, I observed an AP Biology class, taught by Bibiana Mendez, at Adamson High School, in the Dallas ISD. I took notes while the class used the Enzyme Instigator suitcase, to record what worked and what did not work. Of all the research I did for this project, the classroom observation was the most important in providing direction.

During the animation, it was clear that all the students paid attention during the two brief sections, which illustrated an enzyme analogy. This analogy was presented in a simple 2d style cartoon. However, the rest of the animation was a more sophisticated 3d style; and the class seemed to get bored with these parts fairly quickly. Eyes wandered and random scribbling ensued. One might think that the Organelle Extravaganza (another “science suitcase” funded by the STARS grant) animation, since it was mostly a 2d style animation, would have been more effective in this environment. However, both the teacher and the class said they liked the Enzyme Instigator animation more than the Organelle Extravaganza animation. They also confirmed orally that what they appreciated the most were the analogies in the Enzyme Instigator animation. It was the unfolding of the concept, to include parallels with a teenager’s life, which seemed the most effective way to keep all eyes on the screen. The Organelle Extravaganza animation uses visual metaphors to illustrate all the cellular organelles. But from the classroom observation, I found what creates a deeper connection with the class is a narrative which relates to teenage life. Everyone was immediately interested in the story of a small group of friends riding in a car to go play basketball, and how this story could explain the functionality of enzymes. So, in the animation for the evolution suitcase, I tried to include narrative-based analogies with which teenagers could relate. In fact Chapter 3: Mechanisms, which was designed after this classroom observation, is one long narrative about teenage giraffes.

After watching the animation, the teacher demonstrated the physical model in the Enzyme Instigator. I noticed that the physical model was not being used as intended by the designer. Instead of being a kinesthetic learning tool for the student, the teacher stood at the front of the classroom and demonstrated the model to the class. It became another visual learning tool, repeating the purpose of the animation. None of the students touched the model after the demonstration; it wasn’t necessary because the mystery was already solved. However, I could also see why this was desirable for the teacher, in that, the entire demonstration lasted less than a minute. It was a quick and easy review of the concepts. In light of these observations, I decided to try to make a kinesthetic learning game for the student, but which was also a quick and easy demonstration, just to review the concepts.

Next, the class did one of the labs. There was an issue with the materials because not all that was required was included in the suitcase. So, it was explained to me that often the teachers had to “make due” or not do a particular lab if they didn’t have all the necessary equipment. In general, the students were not engaged in the lab at all. In fact, a few got up and left to go wander the halls outside of class. I decided that the lab for the evolution suitcase needed to include materials (e.g. fossil casts) that are visually interesting, and possibly have little narratives of their own, to better engage the students.

In an after school science club meeting, I observed an evolution program delivered by the Museum of Nature and Science. They gave a history lesson on Charles Darwin, measured bird beaks, and then played a game using seeds and various grasping hardware tools. This was just to demonstrate variation and fitness, though I don’t recall these terms being mentioned in the game. I noticed the kids enjoyed playing the game because there was a simple objective: get as many seeds as you can. This was very unassuming. It broke the routine of formulaic lessons and involved a little action. The shy students, I observed, were smiling and clearly connecting to the other students in the class, while playing this game.

From these classroom observations, I decided to include a game that would be an improvement over the museum’s seed game. I noticed that their game didn’t involve much of a lesson plan, nor did it go over any critical concepts in evolution. Expanding the vocabulary of the game, to include terms like population, phenotype, fitness, natural selection, adaptation, gene flow and genetic drift, was one way to improve game. Also, I realized there should be more than one environment and multiple generations to show how populations can evolve and adapt differently, under different selective pressures, over time. This would teach the student that it is the environment that selects the individuals. Also, it would teach that fitness is relative to the environment, meaning there are no absolute “superior” phenotypes. Furthermore, it would teach the most important lesson in this activity; that is, genetic variation is very important in a population because the environment changes.

PLANNING THE MATERIALS

Proposed Class Schedule

After doing research, I formed lesson plans for the materials in my suitcase. The Animation was divided into 5 chapters to cover the content systematically, to allow for flexibility in the teacher’s schedule, and to help the student easily organize the information. During the formative evaluation for this project, teachers expressed differences in how they would use the animation; some said they would show the entire animation in one day, while others said they would rather watch pieces of the animation, combined with the other activities, over the period of 1 to 2 weeks. While the intent is to keep this project as flexible as possible for the teachers, my proposed schedule is as follows:

Day 1: Watch Chapters 1, 2, and 3. Then play *Beak Niche*.

Day 2: Watch Chapters 4 and 5. Then do the fossil lab.

Lesson Plan for the Animation

Learning Objectives

Chapter 1 Introduction

1. The student will understand the definition of evolution, and that it is a scientific fact not a theory.

2. The student will have an overview of all the empirical observations that support evolution, which are covered in detail in the subsequent chapters.

Chapter 2 The Fossil Record

1. The student will understand that the Earth and its fossils are found in layers, and that in sedimentary rock, the newer layers are generally on top of the older layers.

2. The student will have a basic understanding of what radiometric dating is and how it is used to determine the age of rocks.

3. The student will know that radiometric dating shows that the Earth is about 4 ½ billion years old.

4. The student will know the general history of humanity's evolutionary lineage from ancestral Deuterostomes to Mammals.

5. The student will understand that our relationship to other living species is based on an expanding phylogenetic tree, not a "ladder" or "chain of being," and that this phylogenetic tree does not support any concept that there are "superior" species. In other words, humans are not "better" or "higher up" than living lizards, starfish or monkeys. We are, in fact, one random living twig among other random living twigs on this tree of life.

6. The students will understand how knowing the age of rocks helps scientists find certain fossils (e.g. by knowing the age of rocks, they know where to look to find dinosaur fossils vs. where to find human fossils).

7. The students will be able to relate evolution to the analogy of a jigsaw puzzle, so they can understand that, while scientists feel compelled to complete the picture, they don't need to find all the pieces to know that the picture does, in fact, exist.

Chapter 3 Mechanisms

1. The student will know that evolution works on populations over generations, and not individuals.

2. The student will be able to define population, and understand that it can be relative to what a scientist is comparing, or how closely the scientist is zooming in on a particular group or groups.

3. The student will be able to define natural selection.

4. The student will know some examples of how natural selection works in a population, such as: competition for food, predation, and sexual selection.

5. The student will understand the 2 types of sexual selection: intersexual selection and intrasexual selection.

6. The student will understand the concept of gene flow, and be able to give an example.

7. The student will understand the concept of genetic drift, and be able to give an example.

8. The student will understand the concept of artificial selection, and be able to give an example.

9. The student will know the 3 modes of selection: directional, stabilizing, and disruptive selection. They will also understand what these modes of selection do to a population, its distribution curve, and how the population will evolve and adapt to different environments.

10. The student will understand how speciation happens through reproductive isolation, usually over a long period of time.

11. The student will know that all these mechanisms work through a population's intrinsic genetic variation, which is supplied by sexual recombination and mutations in genetic material.

Chapter 4 Embryology

1. The student will understand the definition of embryology, and how the observations in this field support evolution.

2. The student will have a general idea of the similarities in the progression of stages in the embryological development of all vertebrates. They will be familiar with the stages of the single cell, cleavage, morula, blastula, and gastrula. They will know that all the vertebrate species also develop into an embryo with similar (homologous) structures, such as: a head, post-anal tail, pharyngeal arches, and notochord.

3. The student will understand that the aforementioned developmental similarities are the result of conservation of similar genes, specifically: egg polarity, segmentation, and homeotic genes.

4. The student will understand the importance of the genes with respect to evolution, and why they have been conserved for such a long time.

5. The student will gain an appreciation of where evolutionary-developmental (Evo-devo) research is headed, including: mutations in developmental genes, epigenetics and mutations in cis regulatory regions. They will know an example of new research done at UTSW, which relates to modern Evo-devo research. The example is Dr. Trey Fondon's research on dog skull morphology and its link to tandem repeats in cis regulatory regions.

Chapter 5 Phylogeny

1. The student will be able to recognize a phylogenetic tree and know that it depicts relationships between species.

2. The student will be able to identify the most recent common ancestor between 2 taxonomic groups.

3. The student will understand an example of the hierarchical naming format of taxonomic groups. Specifically, they will know that humans are in the taxa Primates, which are included in the taxa Mammals, which are included in Amniotes, then Tetrapods, etc.

4. The student will be able to define homology and understand its relationship to the phylogenetic tree.

5. The student will know what homologous structures are, be able to give examples, and place them appropriately on a phylogenetic tree.

6. The student will know what analogous structures are, be able to give an example, and place them appropriately on a phylogenetic tree.

7. The student will be able to define vestigial structures and give examples.

Lesson Plan for the Game

Conceptually, the game mimics what you would find in nature; that is, it is based on probability. There are environments with selective pressures and individuals in populations with varying degrees of fitness, so it is very likely that (A) the populations will evolve and (B) the mechanism for that evolution will be natural selection. As in nature, the dice are heavily loaded for this scenario. Also, as in nature, the game does not produce black and white results; it is not absolute. It is possible your population may not evolve. And it is possible your population may evolve, but more through genetic drift, and not natural selection (i.e. if the group with the least fitness somehow manages to be the most reproductively successful - it would be genetic drift as a result of that particular sample – it is possible, but very unlikely). The point of the game is to have some physical object to use to review these concepts and see how they relate.

Learning Objectives

1. The student will understand the concept of population.
2. The student will understand what genetic variation is and its effect on observable traits in a species.
3. The student will know the process of natural selection, which works, through the environment, on populations with genetic variation.
4. The student will understand how an individual's fitness is dependent on the environment. If the environment changes, so might fitness.
5. The student will understand how natural selection causes a population to adapt differently to different environments.
6. The student will understand the effect of gene flow on a population.
7. The student will understand the effect of genetic drift on a population.
8. The student will know why variation is important to a population's survival (i.e. because the environment can change).

Scenario

The game is designed to reinforce the concepts illustrated in Chapter 3: Mechanisms, in the animation. So, after watching this chapter, the class will pretend to be a population of birds competing for food in two different environments. There is a shallow-hole environment with big seeds and a deep-hole environment with small seeds. The population has "genetic variation" as indicated by the 3 different phenotypes: a green long beak bird with a slick mouth surface, a blue medium beak bird with an average mouth surface, and a yellow short beak bird with a rough mouth surface.

Logistics and Points of Discussion during the game

1. Set up both environments and have 6 students at each environment.
2. Each of the 12 students at an environment will get a phenotype. Start off with 2 of each phenotype at each environment.
3. The teacher will explain to the class that they are a population of birds and ask the class if they remember, from the animation, the definition of a population.
4. The teacher will ask the class how they know their population has genetic variation (the answer is that there are different phenotypes).
5. The students will now take turns (one at a time) trying to get as much food as possible. They each get two, 10-second turns. Record the food score on the board for each player, and replace the food after each turn.
6. After they compete for food, the teacher will explain that if they got enough food they can support reproductive offspring.
7. The teacher tallies the food score on the board and determines the number of offspring each individual gets.

0 food = 0 offspring
1-6 food = 1 offspring
7-13 food = 2 offspring
14-20 food = 3 offspring
21-25 food = 4 offspring

8. Those 12 students replace the food, sit down and the new generation gets up. They get the same phenotype as their parent. If the class is small they can recycle students.

9. If needed, the teacher can explain that, while this is a very simplified version of genetics, it's useful in this demonstration to quickly show a basic selective inheritance of traits.

10. The new generation will repeat the game. The teacher can repeat this as much as necessary to demonstrate how different environments, with different selective pressures can cause populations to evolve and adapt differently.

11. The teacher will ask the students if their population is adapting to the environment. If they didn't already go extinct, the answer will likely be yes, in both environments.

12. The teacher will also ask the students, "For which traits are the environments selecting?" (answer: beak length and mouth surface)

13. At some point, the teacher will tell two random students from each environment, in one generation, to migrate to the other environment. The teacher will ask, "What just happened? Remember from the animation?" (The answer is gene flow). "Does this cause the population to adapt? (Most likely it does not).

14. Then play the game again.

15. Now, after competing, instead of tabulating offspring in one environment, the teacher explains how a number of human corporations, motivated solely by profit, begin a vast wave of deforestation, obliterating an entire ecosystem. All the students at that environment sit down. No offspring for them. The teacher will ask, "What just happened? Remember something like this from the animation? Something very random, and not usually part of the natural environment, causes what??" (answer: genetic drift). "Did it cause the population to adapt?" (answer: no, they all died)

16. Play the game again, only for the other environment.

17. Now the teacher will switch the environments, and asks "So what happens if the environment changes?"

18. Play again.

19. The teacher will ask, “So why do you think genetic variation is so important for a healthy population?” (answer: because the environment can change)

Lesson Plan for Fossil Lab

Learning Objectives

1. The student will gain hands-on experience working with fossil casts and replicas.

2. The student will understand the phylogenetic tree, which is based on homologies.

3. The student will understand homologies and how they show common ancestry between species.

4. The student will use deductive reasoning to discover how these fossil species evolved and how they are all related.

Instructions

1. After watching the video, place the fossils on a table (the fossils are numbered).

2. Have the students come up with a hypothetical phylogenetic tree, based on what they think shows the relationships between the species. Allow the students to pick up and observe the fossil casts.

3. After forming their hypothesis, have the students read the descriptions of the species and then match them to the fossils.

4. Go over the correct answers with the class.

5. Then have the students fill out the blanks with the correct species in the phylogenetic tree worksheet, and place the listed homologies in the appropriate spots on the tree.

6. Have the students complete the post-lab questions.

7. Have the students evaluate their hypothetical tree and make changes to correct it, if needed.

PRODUCING THE ANIMATION

Script, Storyboard and Animatic

After establishing lesson plans for the materials with my committee, I began designing the components of the suitcase. Further research and revisions to all aspects (including learning objectives, script, storyboard, and final product) of all materials were necessary during all stages of this project, as numerous recommendations were made by my committee each time we met.

First, I wrote a script for my animation and presented it to my committee. Revisions were made and several drafts of the script were written. The final script is in the Teacher Guide, which is in Appendix F. Next, I designed a storyboard, based on the script, in Adobe Photoshop CS4. A storyboard is created, prior to the production of an animation, to establish the conceptual flow of ideas and images. I used both existing and created assets in the storyboard.

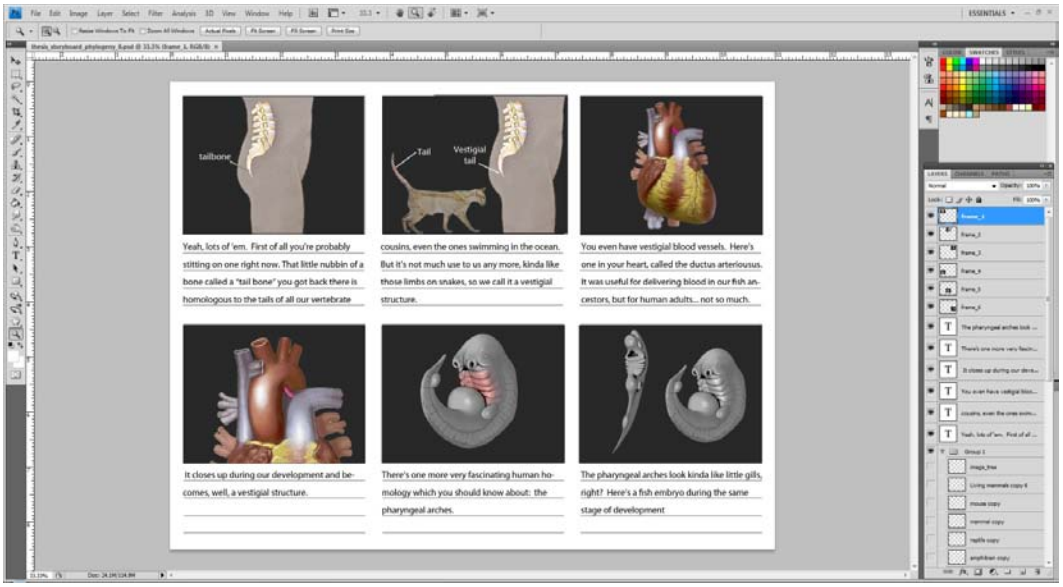


FIGURE 3. Building the Storyboard in Adobe Photoshop

I met with my committee many times to review the progress of the storyboard, and discuss revisions to both the storyboard and script. By the end of fall 2009, I had a complete storyboard and script, which is in Appendix C. I was then instructed by my committee to begin working on an animatic to present for a formative evaluation.

An animatic is a rough draft for an animation and, in the production process, comes between a storyboard and a final animation. First, I created assets from images in the storyboard and audio segments I recorded of myself narrating the script. I imported these into Adobe AfterEffects CS4. I animated some of the assets and created transitions to fit the audio.

FIGURE 4. Building the Animatic in Adobe AfterEffects

I completed animatics for each chapter in the storyboard, and imported these into Adobe Encore to build a DVD.

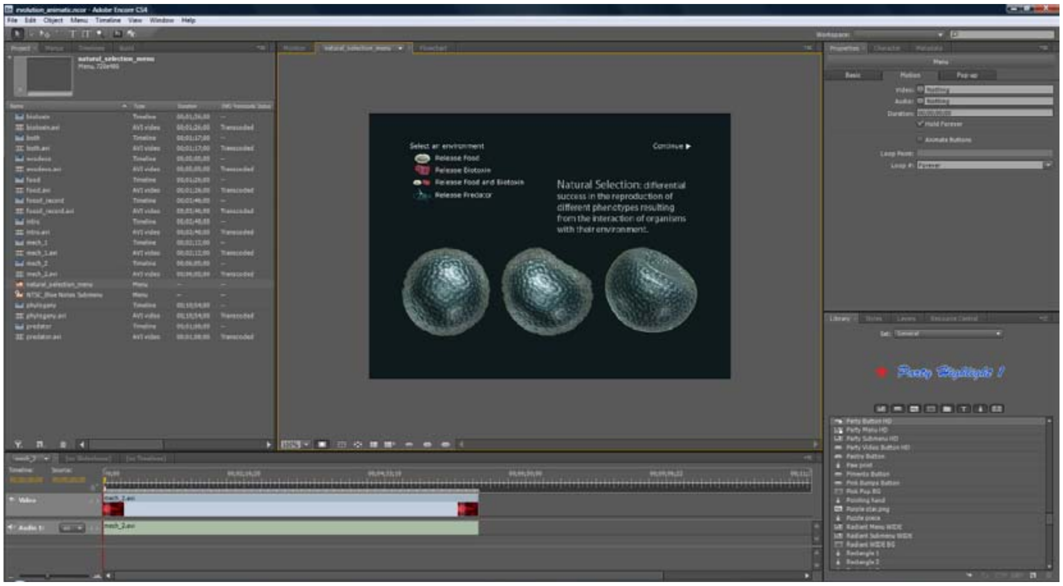
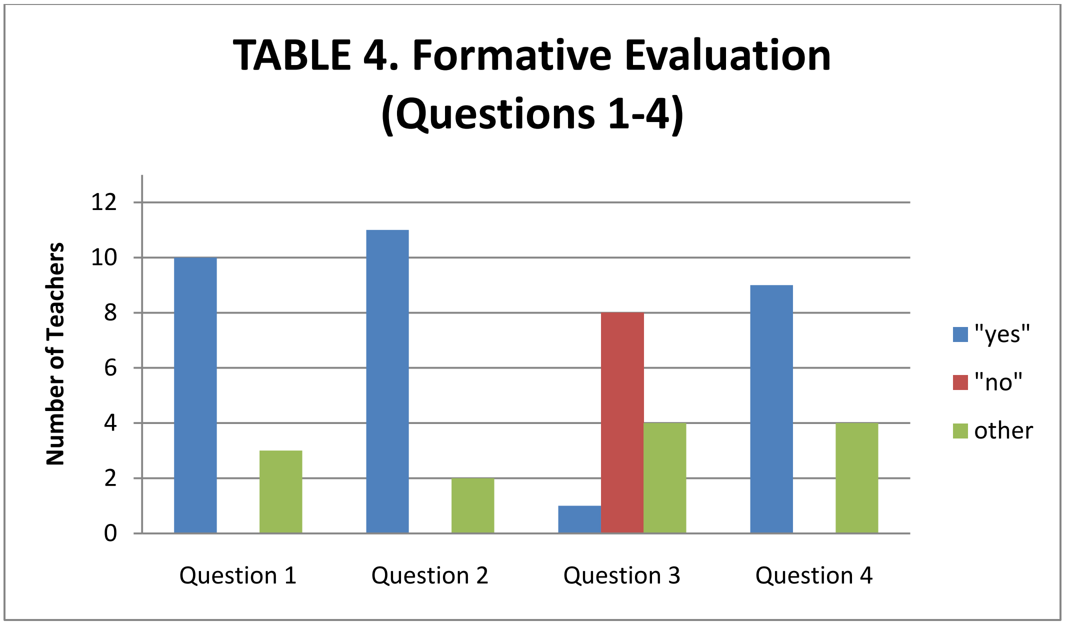


FIGURE 5. Building the Animatic DVD in Adobe Encore

Formative Evaluation

On December 5, 2009, STARS held a Mini-Symposium for a preview of the new science suitcases. I showed the animatic and asked the audience, mostly teachers in the DISD, to fill out a formative evaluation to help direct the final animation. Overall, the audience was both receptive and positive, offering useful constructive criticism and encouraging feedback. The collected evaluations are in Appendix D. In addition, copies of the script were dispensed for the teachers to comment on specific parts as they watched the animatic. Their notes on the script are also included in Appendix D. The first 4 questions listed are quantifiable and subsequently illustrated on a chart below.



Question 1: “Do you think your students would connect with this content?”

- “Yes”
- “Yes, definitely my students will connect with the content about fossil record, natural selection, and speciation.”
- “Yes. It is a great visual representation for the students to help them understand the concepts.”
- “Yes, the idea of where we come from is still important and peaks the curiosity.”
- “Yes, needs a little mathematically connection w/ SA/V ratio.”
- “Yes, this is long past due for today’s students.”
- ”mostly but right now it’s higher level than freshman biology, maybe Pre AP to AP level,”
- “for the most part yes [but] some [material is] above my students,”

- “yes – but some parts are beyond the scope of what I teach”
- “great job with making deep/difficult subjects understandable – good level.”
- “possibly”
- 2 left no answer.

Question 2: “Would you be interested and enthused about teaching it, and using this as a discussion aid?”

- 4 responses were “yes”
- “Yes, I would use this as a great tool for Exit TAKS review for juniors and seniors [who] struggle with retention of concepts needed for exam.”
- “I teach 7th and 8th grade and much is beyond what we do, but I would use it to reinforce what they have learned, and into deeper topics. I may even use some in 7th [grade] for evolution/adaptation and 8th [grade] in fossil rock geologic time scale.”
- “Yes I am very excited about your handout... very basic, simple but informative, interesting and engaging.”
- “Yes this information is great! It gives students a more “in your face” approach to learning the material, especially in this “video age” we are living in today.”
- “Yes – I like that we can pause and discuss w/ class”
- “very much so”
- “yes, if it’s in a good form esp. for freshman level”
- 2 left no response.

Question 3: “Are there any parts that you would rather me leave out completely?”

- 5 responses were “no”

- "No, will not leave out anything."
- "No – everything was linked well and even revisited."
- "Everything" (From other positive comments on this particular evaluation, it is assumed that the teacher meant *include everything*, and leave out nothing.)
- 1 response was to not get "argumentative" about whether evolution occurs or not (the full response is in Appendix E)
- 4 left no response.

Question 4: "Will you use this when it's done?"

- 3 responses were "yes"
- "Of Course!"
- "Yes, yes, definitely. I love it. This is complicated for students to understand because of misconceptions and complexity of topic.
- "I would like to."
- "Yes, definitely."
- "Yes – would love to just have the CD even w/o the rest of the suitcase"
- "Yes, to teach and train other teachers."
- "you would make a great teacher."
- "definitely consider it."
- 2 left no response.

Question 5: "What do you think are the most interesting parts in the animatic?"

- "Visuals and future interactivity"
- "Evo-devo, the questions and answers are very informative. The vocabulary words."

- “comparing embryos development”
- “I liked the mix of real images, cartoons, graphs, and charts.”
- “Graphics used to explain, extend info will build on prior knowledge of students.”
- “The SA/V ratio and how it affects natural selection. Homologous structure tree.”
- “The connection of evolution throughout history. Excited about animations with verbiage.”
- “Evo-devo. Students always are curious to know how we might be related to other species. This is a great introduction and tool for the lesson.”
- “Evo-devo.”
- 4 left no response.

Question 6: “Is there anything that you think should definitely be added in terms of content for this animation?”

- “The parts that you covered are the most challenging to most students.”
- “Genetic drift and gene flow. I think will both be tested on the new Biology end-of-course test.”
- Many other possibilities for extensions were mentioned (included in Appendix D)

Question 7: “Feel free to share any other ideas or concerns.”

- varied responses (included in Appendix D)

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

Do you think your students would connect with this content?

Would you be interested and enthused about teaching it, and using this as a discussion aid?

Are there any parts that you would rather me leave out completely?

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution... the list goes on)?

Will you use this when it's done?

Feel free to share any other ideas or concerns:

FIGURE 6. Formative Evaluation

Revisions Resulting from the Formative Evaluation

Several questions arose from Chapter 3: Mechanisms. During my presentation, Biology teacher Bibiana Mendez orally expressed some concerns about the SA/V section, but she also mentioned that she liked the parts with the different modes and curves of natural selection. She wrote on the evaluation, "Would like more of an introduction before you start in SA/V ratio. What is the point of explaining this and how is this relevant to a teenager's life?" She also wrote, regarding another part in this chapter, "I'm not sure the students would understand the graphics here. Using a more creature-like graphic that changes slowly might be easier to understand." Another recommendation was to "reduce and simplify the SA/V portion." However, another teacher stated that she liked the idea of reintroducing SA/V ratio in another context, like evolution. Ultimately, what was recommended was that I begin with another creature, which has a recognizable trait any 9th grader can relate to, before delving into the SA/V ratio content.

In addition, there were comments about the end of Chapter 3, which covers Bergman's Rule. While this is certainly a very interesting topic in evolution (which also applies to humans), a couple of teacher comments made me reconsider including this material. During the presentation a teacher asked, "Does it have to be humans? I'm going to get phone calls." He recommended cacti or polar bears as alternatives. Another teacher approached me about Bergman's

Rule and asked, “Is that why black people need to wear an extra coat in cold weather?” I explained that skin pigmentation was initially an adaptation to sun exposure and related to a population’s proximity to the equator, but had nothing specifically to do with the SA/V ratio adaptation described in Bergman’s Rule. I decided to take out the Bergman’s Rule part for fear that it would be misunderstood and used to teach some unintended ideas concerning race. At another meeting, a DISD teacher asked me which race I thought was the “most successful,” because she was concerned the “whites” were going extinct. These kinds of sentiments strengthened my commitment to remove Bergman’s Rule, although it has nothing to do with race. It was causing confusion and I feared the consequences in the classroom. From the perspective of evolution, “race” is an historical construct resulting from a sociopolitical agenda. I have no intention of referencing race in any way because race is both an arbitrary and non-scientific idea, which predates the study of evolution.

From the evaluations, genetic drift and gene flow were mentioned by 2 teachers as possible expansions for the content. In fact, one teacher mentioned, “I think both will be tested on the new Biology end-of-course test.” Also mentioned in one evaluation, is “artificial selection.” Another response generally stated, “more evidence for evolution needs to be added.” Reviewing the content in the animation, I cover the fossil record, embryology, phylogeny, and genetic and anatomical homologies. Natural selection was covered in Chapter 3. However, I knew that all the population mechanics in evolution, described in Campbell's Biology, could be explained more effectively to provide more concepts that support evolution.

Considering all these questions, concerns and criticisms of Chapter 3, I revisited an earlier narrative-based storyboard I created about a giraffe population. I needed an obvious trait on a recognizable creature to make the content more accessible to a teenager. Giraffes, with their long necks, are often cited to illustrate principles in evolution. I chose to make the giraffes in my animation have human teenager-like personalities. They are angsty, expressive, and obsessed with sex, which is also convenient because population mechanics in sexually reproducing organisms has everything to do with sexual reproduction. I did this to make the content more accessible and interesting to teenagers. I also designed the chapter to cover more content, based on teacher comments for possible add-ons and in foresight of the new TEKS objectives. In this expanded chapter, I included definitions, illustrations, and explanations of the following concepts: populations, natural selection, sexual selection, gene flow, genetic drift, artificial selection, genetic variation, mutation, recombination, and speciation through reproductive isolation. The giraffe storyboard is in Appendix E.

The SA/V ratio part was reduced to an optional lab in the middle of the chapter, to cover the specific modes of natural selection (directional, stabilizing, and disruptive) in more detail.

No recommendations were made for Chapter 1. However, concerning Chapter 2, a comment was made that the fossil record illustrated in the animatic "gives the wrong impression that evolution is 'goal oriented.'" Regarding the same section, another wrote, "I like the analogy and making the point that humans aren't really 'on top.'" These statements referred to this part in the script: "So in case you're feeling on top of it all, keep in mind that these ancestral species split into millions of other lineages, which evolved into all the species alive today." The script needed revision to clarify my intentions with the teacher who made the first comment. However, it needed further revisions later, under the oversight of my content advisor, to maintain scientific accuracy.

As human beings, we have an intrinsic interest in how we relate to the rest of life on Earth. One of the implied goals for this project is to show high school students, not only that evolution is substantial, but also how we are all a part of it. My intentions in the above mentioned section were to show how we fit in to a specific branch on a phylogenetic tree, which relates to geological time, and that this is not any kind of goal-oriented structure, like a "chain" or "ladder." I clarified this in the script and the final animation.

Two comments were made regarding Chapter 4. One said to include a definition of embryology, in the beginning, which I did. The other, concerning the section on dog skull morphology, said, "My 9th graders would get lost with this info, but I like including the latest research. Is there a way to simplify this?"

I attempted to simplify this part many times in both script and imagery, to make this research more accessible for the student.

One teacher wrote she "liked the jigsaw puzzle analogy" in Chapter 2, but regarding the fireworks analogy in Chapter 3, wrote "analogy OK." Another teacher commented, "the fireworks analogy didn't work for me." So, I took out the fireworks analogy when I rewrote Chapter 3, but I animated the jigsaw-puzzle analogy in Chapter 2.

A few things were mentioned in Chapter 5. A label in the phylogenetic tree was missing, which I corrected. Regarding the part in my script which says, "But did you know all fish have lungs, or swim bladders, which evolved from lungs," a teacher wrote, "would need some explanation." Considering the amount of information I had to cover, and the complexity of this particular homology, I decided to remove the "lungs" section and focus more on limb homologies. This is a less convoluted example to illustrate to high school students, and the homologies are easily referenced on their own bodies. One teacher wrote "vestigial structures – would liked to have seen the word as you pronounced it." All of the important vocabulary, in all of the chapters, was included in the final animation.

One last comment worth mentioning here is "more animations." The animatic was like a motion-graphics lecture, almost a slide show in some sections.

A lot of time was needed to produce the final art, record and revise the final audio, and animate the imagery for clarity and interest.

Final Animation

First, I made a list of all the assets I needed in Microsoft Excel. Some of the assets were created, some were downloaded from sites like Creative Commons on Flickr, and some were purchased through websites like TurboSquid and 3dScience. There was some flexibility in the list and I generally bought assets as needed, while I worked on specific parts in the animation. So the list was revised, as the animation progressed, to include the most necessary and least expensive models. Everything I bought came with a copyright for use in my animations.

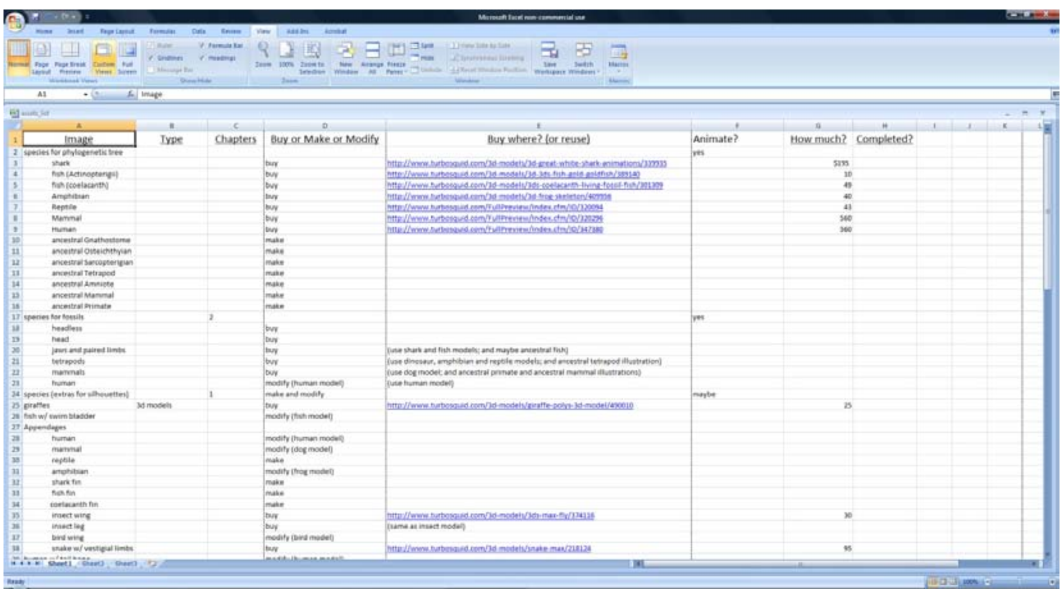


FIGURE 7. Asset list in Microsoft Excel

All assets, initially created by myself or not, were adjusted and manipulated, in Photoshop and/or Maya, for use in the animation. Texture maps were altered. Lighting and camera angles were adjusted. Shaders were made or downloaded, and then adjusted. Rigs were animated. Animations were adjusted through their rigs. Layers were created for control. Nothing I downloaded or bought remained "untouched."

FIGURE 8. Creating Final Assets in Adobe Photoshop

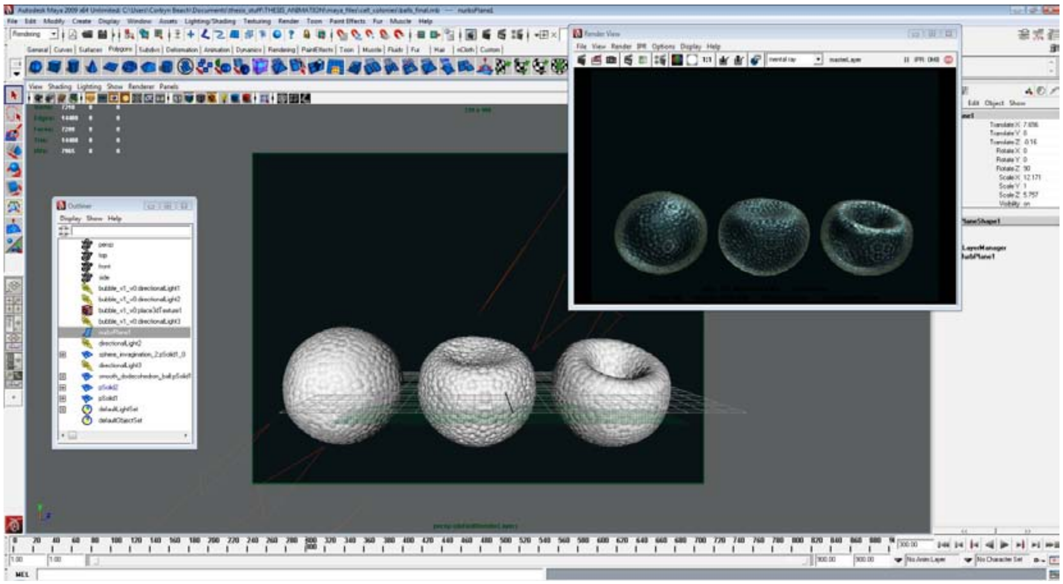


FIGURE 9. Creating Final Assets in Autodesk Maya

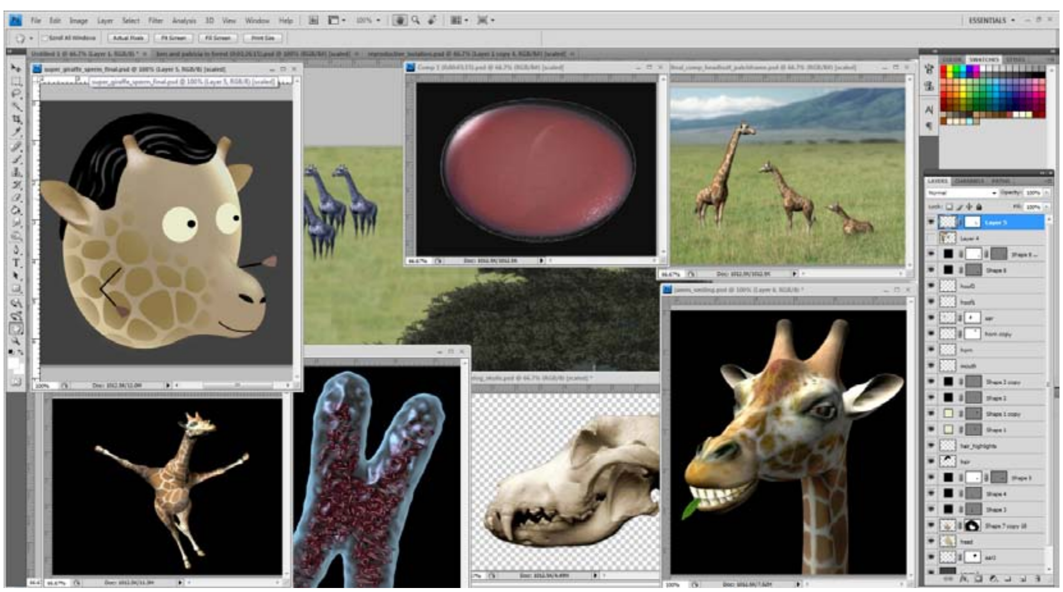


FIGURE 10. Adjusting Final Assets in Adobe Photoshop

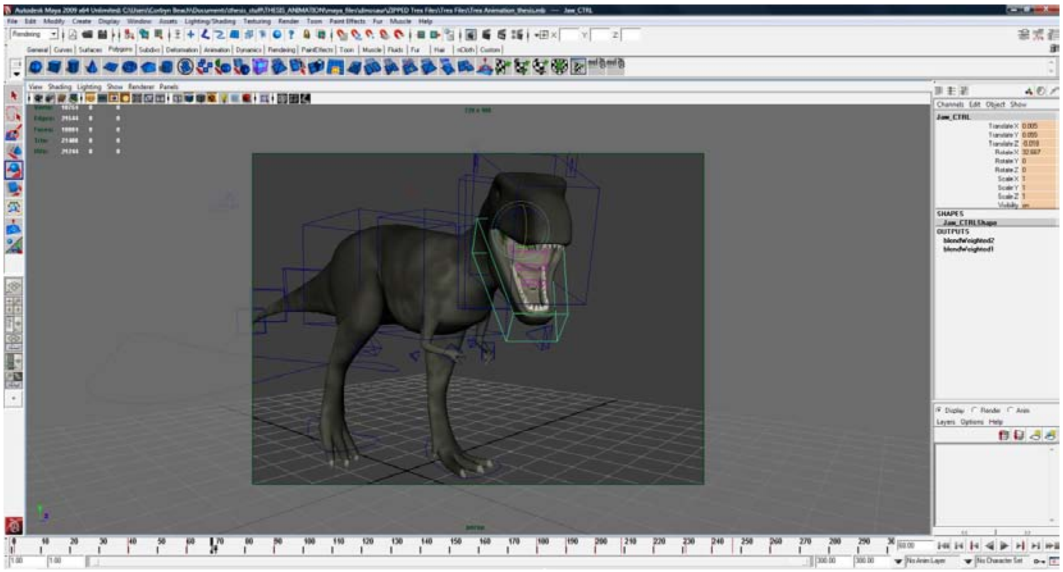


FIGURE 11. Adjusting Final Assets in Autodesk Maya

All assets were then imported into Adobe After Effects, and put into compositions to highlight, label and animate in time with the audio.

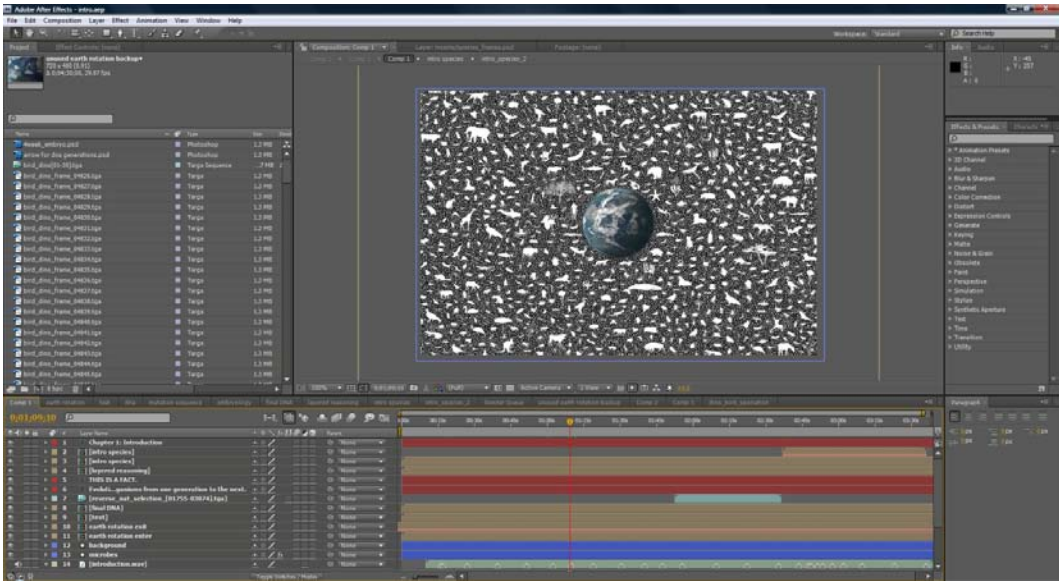


FIGURE 12. Final animation in Adobe After Effects

I made separate files for each chapter, except Chapter 3: Mechanisms, which needed multiple files for the natural selection lab menu. Using Adobe Dynamic link, the final After Effects compositions were imported in Adobe Premiere for final editing. Adobe Premiere was used primarily to edit audio and extend or cut sections in the animation. It was also used to add some transitions between scenes and images.

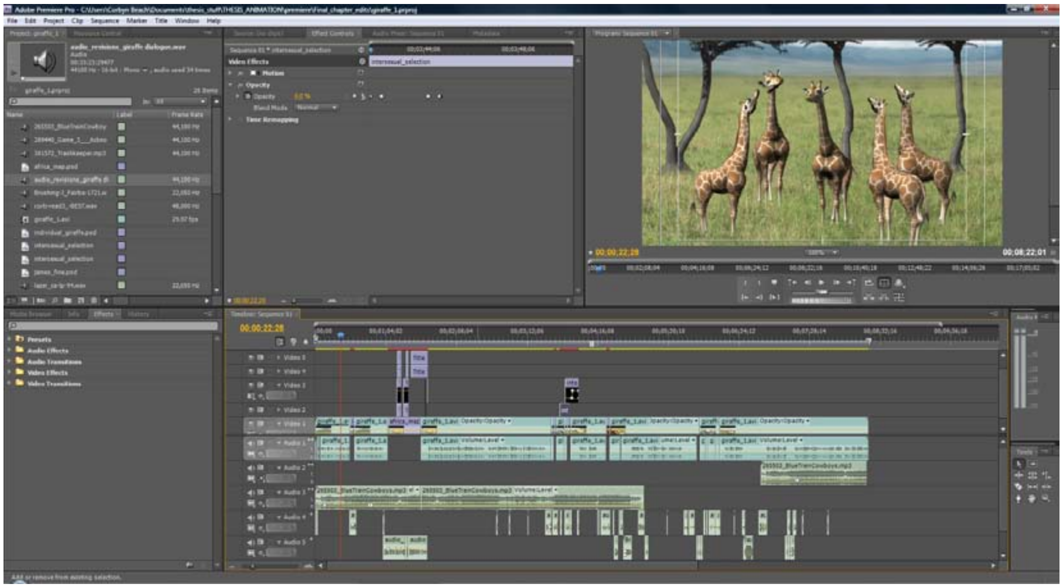


FIGURE 13. Final Editing in Adobe Premiere

Again, using Adobe Dynamic link, files from Premiere and After Effects were imported directly into Adobe Encore to create the DVD. I created the title menu, the natural selection lab menu, and motion menus for the end of chapter quizzes in Photoshop.

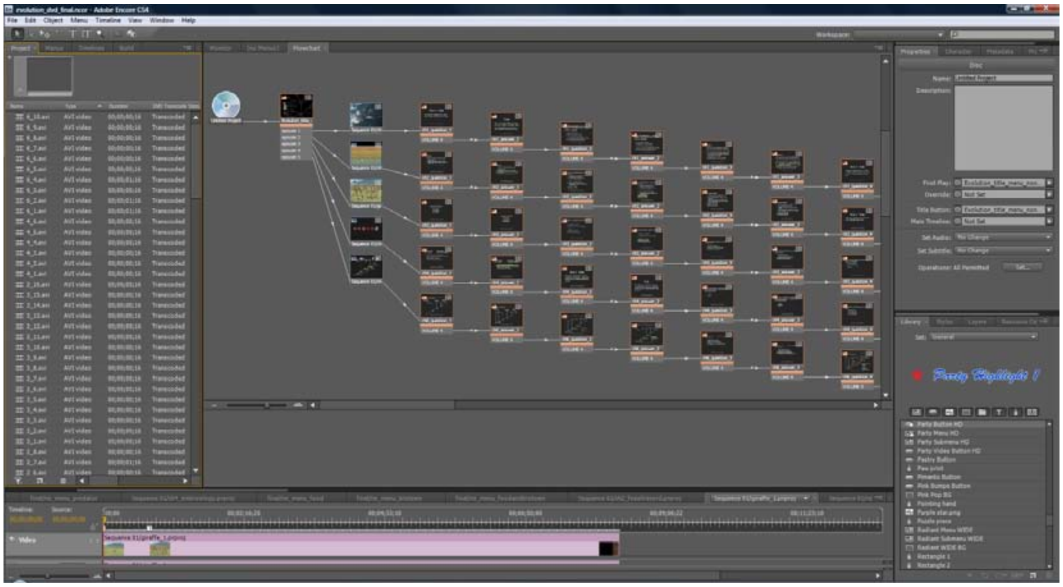


FIGURE 14. Building the DVD in Adobe Encore

Once the flow chart was organized with the correct links for chapters and questions, I built a final DVD in the NTSC 720 x 480 format, for use in the classroom.

Producing the Game

Working with the Museum of Nature and Science

First, I created a rough outline for the game on paper.

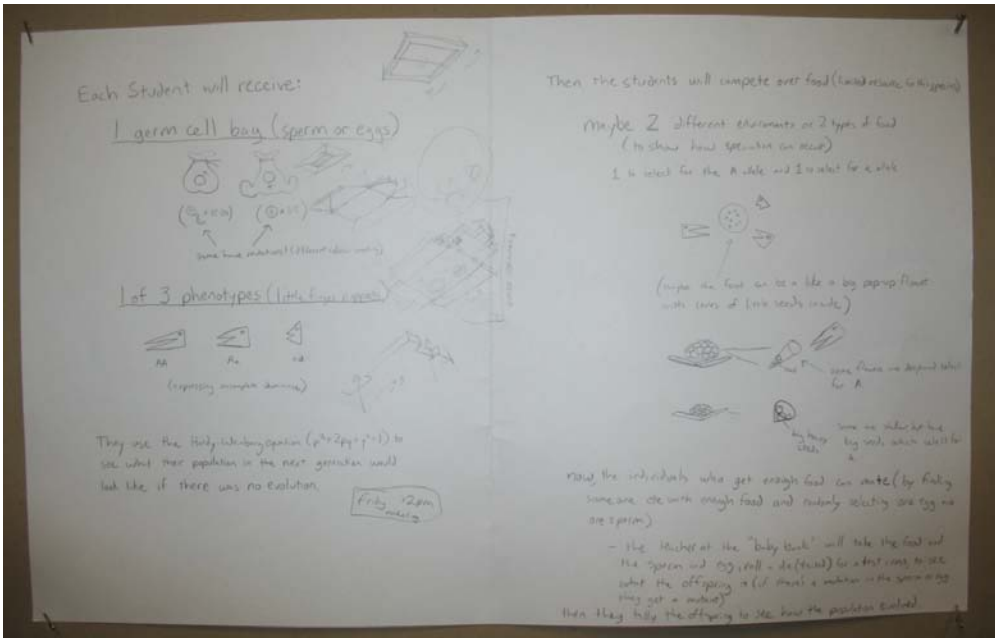


FIGURE 15. Rough outline of game

Then meetings were held with my thesis committee and the Museum of Nature and Science for possible revisions to the concept. The game was simplified; germ cells, mating, and Hardy-Weinberg content were removed, and the game was revisualized to focus more on fitness, natural selection and adaptation.

A prototype of paper and foam core was constructed and presented to the museum to discuss the process and materials for the final product.

FIGURE 16. Prototype of game

FIGURE 17. Early food material

The food used in the prototype consisted of steel nuts (hardware) of different sizes and weights. Both the food and the depth of the holes in the 2 environments created selective pressures on the different beak types. Originally, selection was caused by the *weight* of the food, and the length of the beak was the only determining trait for both hole depth and food weight.

The game was slightly reconceptualized to include a large group, and new plans were drawn.

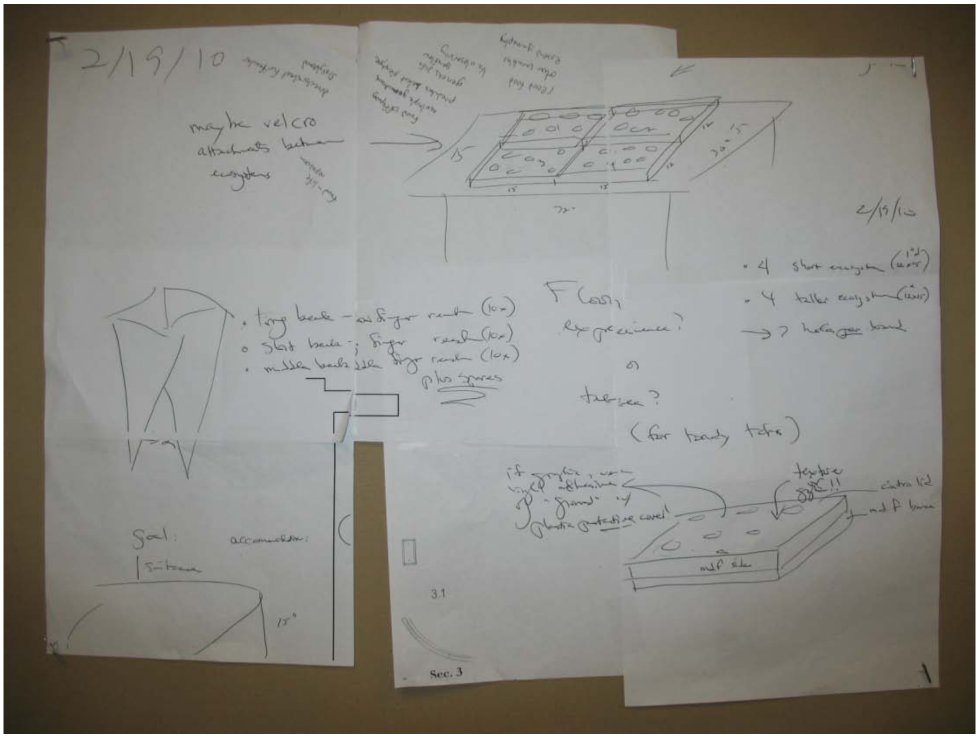


FIGURE 18. New plans for game

I held meetings about twice a week with the museum staff for several months, as they experimented with some new, more durable materials. PVC pipe was used to create the holes in a base made with MDF, which was chosen to add weight so the board would not move during game play. Cintra was chosen as a lid because of its durability.

FIGURE 19. PVC and MDF

FIGURE 20. Cintra lids

FIGURE 21. Printed beak template

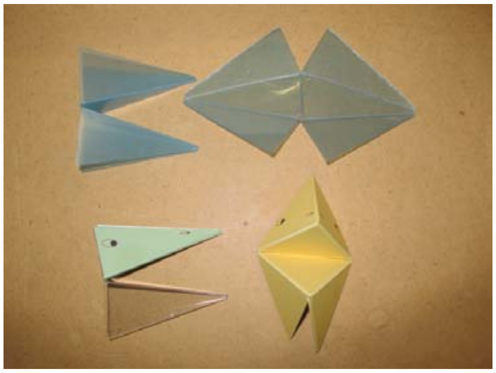


FIGURE 22. Plastic coverings

The bird beaks were set in a template in Adobe Illustrator CS4 and printed on vinyl. A scored and folded plastic covering gives protection to the beaks. Meanwhile, Satoko Sato began designing the patterns on the beaks.

FIGURE 23. New materials

It soon became apparent that the new materials did not have the same functionality as the prototype model. Firstly, the food weight now had no selective effect with the beaks, so the game was not producing the desirable results. I tried a number of different things, using different materials for food. I drilled holes in the beaks. I put tongue "limits" in the beaks. I experimented with different mouth surfaces. Ultimately, I chose balls made of Delsym (a slick lightweight plastic), as the new food. Since food *weight* and beak *strength* were no longer relevant, the new trait I tried to pass along to the museum was tongue size.

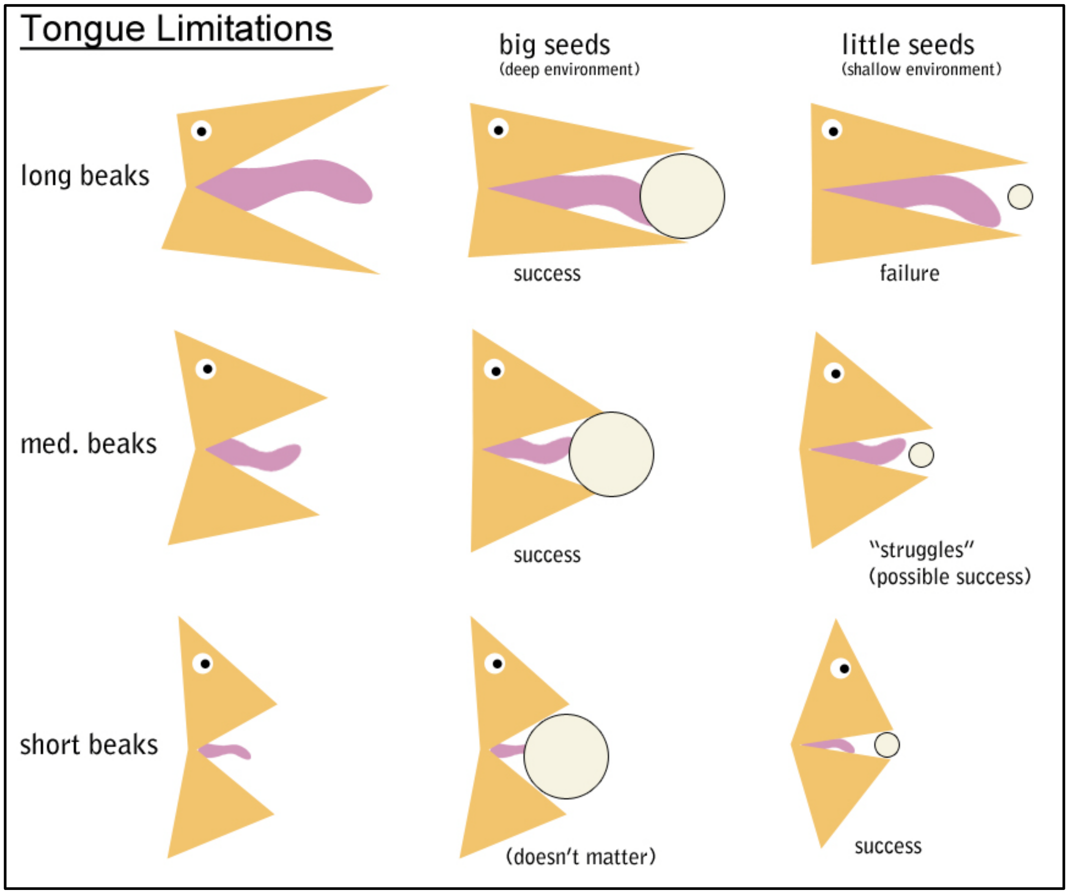


FIGURE 24. Improvising new traits

I created little tongue prototypes out of paper and tape and explained what I wanted to the museum staff. However, when the museum made the tongues they all came out the same, thus becoming merely decorative. This required more improvisation on my part, and I experimented again with mouth surface and found that duct tape worked well to pick up the slick Delsym balls. I made more prototypes, this time with different mouth surfaces. This time the museum staff produced a working long beak and a working short beak, but the medium beaks were exactly the same as the short beaks. The mouth surface in the medium beaks was revised, as per my instructions, to produce the desired results for the game.

Teacher Evaluations of the Game

Two informal evaluations of the game were held with STARS teachers at the Summer Research Program. In the first meeting, I just wanted to gauge the emotional response of the teachers and find out if they had any recommendations. They were very positive about the game. One teacher said the students "will play with this for hours." A couple of people mentioned that it was a little like Hungry, Hungry Hippos. I went through the instructions with them, but no recommendations were made to improve the game. However, I asked the teachers to take a copy of the instructions and to email me if they thought of anything.

FIGURE 25. Teachers playing *Beak Niche*

At another Summer Research Meeting, a group of STARS teachers played through the instructions to test the results. The mechanics of the game worked fine on that group. A few revisions were made to the instructions prior to that meeting, but both populations evolved through natural selection pretty convincingly.

List of teacher considerations in the second meeting:

1) One teacher had a great idea, both for expanding the game time and forcing

participation of the students. Instead of all players going for the food at once (which could cause problems), have the students take turns (one at a time) trying to get as much food as possible in about 5-10 seconds. Increase the amount of food, or replace it each turn, so who goes first is not a factor. And then repeat. This would force participation via social pressure. And all the teachers seemed to be in agreement that this was the best idea. So, I included the "one-at-a-time, 10 second rule" in the instructions.

2) Another teacher said she needed 2 sets. Her point was that having half the class wait to be the next generation would cause issues in the classroom. It was expressed that all the students need to play the game at once, and not wait to play. Again, the teachers were in agreement over the" 2 set rule." So, I included 2 sets in the suitcase (despite the extra weight).

3) A couple of teachers wanted cups for the food. This became a further consideration, to possibly include in the future.

4) Some kind of "moat" around the board, which would catch the errant food, was an add-on considered. This was also a further consideration.

5) A few teachers discussed Hardy-Weinburg, and then asked if the game could

be used to demonstrate a Hardy-Weinburg population. The answer is yes, and this idea became a further consideration for the game, as well.

The final game instructions are in the Teacher Guide in Appendix F.

Producing the Fossil Lab

First I searched for fossils on the web, but most were not within budget. Another possibility was fossil casts and replicas, which allowed for a much greater variety in materials. The Museum of Nature and Science was considered as a resource for casting fossils; however, the staff expressed the desire to order materials online, if that was an option. I searched a number of sites for fossil casts, including: PaleoScene, Taylor Made Fossils, Skullduggery, The Stone Company, The Black Hills Institute, Fossil Reproductions, and more.
I chose fossils based on the following criteria:

1) *Phylogeny*: I chose fossils belonging to major groups in the vertebrate lineage because this most closely related to the fossil record and phylogeny discussed in the animation.

2) *Interest*: The vertebrate fossils, offered in casts online, included some of the most interesting, and historically important species. I searched for fossils with interesting narratives in evolution, aside from the lab project, to supplement the activity if possible. Sometimes the goal became to break

"stereotypes" associated with species. The tree-climbing dog, the tiny horse, and the miniature dinosaur fit this strategy. Also, some fossils were chosen based on their significance in the field, like the Berlin specimen of the Archaeopteryx (which is one of the most famous fossil discoveries ever made), and the Placoderm (armored fish), which is one of the earliest discovered Gnathostomes. Moreover, specific casts were chosen to illustrate some interesting homologies, which teenagers are likely to understand, such as: teeth, jaws, wings, symmetry, and limbs.

3) *Weight*: Fossil casts are available in gypsum cement and resin. When available, I opted for resin to reduce weight in the suitcase. I also specifically searched for small, and sometimes juvenile, specimens.

4) *Size*: Since the cast needed to fit in a portable suitcase, I searched for fossils under 2' in length and width, with a preference for very small fossils.

5) *Cost*: Some fossil replicas are extremely expensive, and I searched for ones which fit in my budget.

Based on the phylogenetic trees and homologies observed in my research, I created a lab activity to reinforce concepts reviewed in the animations, such as:

phylogeny, most recent common ancestry, major vertebrate groups, homologies, and taxonomical relationships. I included questions to help the student understand relationships between the species.

A committee meeting was held to discuss possible revisions. Then a meeting with STARS teachers was conducted to evaluate the lab.

FIGURE 26. STARS teachers reviewing the fossil lab

The teachers thought having the fossil casts in class would be great; however, no recommendations were made to improve the lab. I asked them to take copies and email me if they thought of any improvements.

The final fossil lab is included in the Teacher Guide in Appendix F.

Teacher Guide

A printed, spiral bound teacher guide was included in the suitcase to help teachers with the activities. It includes: lesson plans for the activities, the animation script, student worksheets for the animation, instructions for the game, and instructions and handouts for the fossil lab. A CD was also included with all the printable material. The final Teacher Guide is in Appendix F.

CHAPTER THREE
Conclusions

This project shares the general goals of the STARS Triathlon, including: the provision of resources to underfunded school districts in the surrounding areas, the development of an educational environment that encourages the successful completion of Advanced Placement courses, and the strengthening of interest and enthusiasm for science in the community. The specific goal of this project is to provide, to high school biology classes in the surrounding school districts, materials that facilitate the understanding and appreciation of evolution. I intend for the materials to be comprehensive and cover the major empirical observations that support evolution. These observations include the fossil record, the evolutionary mechanisms in populations, embryological development, and genetic and structural homologies between species. In addition, the goal is to illustrate the vastness of evolution, provide an example of current research in this expanding field, explain how we are connected to all life on Earth, and to generate empathy for this subject.

To accomplish these goals, it was necessary to simply and accurately explain and illustrate the empirical observations that support evolution to a high school audience. This required a particular methodology. I conducted surveys from teachers in the surrounding school districts, researched existing literature on evolution, engaged with experts and teachers in the field, and observed the use of a “science suitcase” in the classroom. From the surveys and interviews, I learned which materials are most requested and which concepts are most difficult to teach. From my research into the content of evolution, I developed a conceptual framework to simplify this complex subject matter. From my discussions with experts in the field, I uncovered interesting topics in current research. Lastly, from my classroom observation, I discovered an effective way to engage my audience.

I designed an animation, a game and a lab. The purpose of the animation is to guide or supplement classroom lecture and discussion of evolution. The purpose of the game is to provide a quick and simple in-class demonstration of the mechanisms of evolution, reinforcing concepts learned in the animation. The purpose of the lab is to reinforce certain concepts in the animation, specifically the fossil record, homologies, and the phylogenetic tree.

After creating the script and storyboard for the animation, I developed an animatic to show for a formative evaluation. From the constructive response of my audience, I learned both the early successes and failures of the animation. From the answers to Question 1 in the formative evaluation, it was conclusive that the teachers felt their students would connect with the material. Establishing a connection with the student is necessary to facilitate understanding, appreciation and empathy. So, in this respect, the material was successful. However, a few teachers expressed a concern that the content went beyond what they teach in the class. Perhaps, for these classes some of the material was too advanced; and, in this respect, the materials demonstrate a certain level of failure. The responses from Questions 2, 3 and 5 in the formative evaluation show an overwhelming level of interest and enthusiasm for the material, from the teachers. Again, this shows how the material succeeded in accomplishing the goals for this project. Moreover, the responses from Question 4 in the formative evaluation indicate that the materials will be used; and this also demonstrates a successful step in achieving this project's goals.

In the discussion following the formative evaluation, many of the questions, concerns and failures of the animatic were explained. With these problems in mind, numerous revisions ensued to produce the final animation, using Adobe CS4, Autodesk Maya 2009, and other software. The final production included a simplification of the material, numerous content revisions, and the attempt to make the animation more dynamic and interesting to high school students. Ultimately, its effectiveness in accomplishing the goals for this project will be tested once the materials are used in the classroom.

With the help of The Museum of Nature and Science, the game was designed to demonstrate the mechanisms of evolution. Once the materials produced the desired results, I held meetings with STARS teachers to evaluate the game. In the meetings, the teachers showed interest and enthusiasm for the material; and they said their students would connect with it. In a run-through of the instructions of the game, it successfully demonstrated fitness, adaptation, and natural selection over successive generations. Some teachers suggested a few rule changes and considerations for materials to improve the game, but overall, the game was received favorably. The teacher responses and the successful run-through indicate that the game is a kinesthetic learning activity that will help reinforce concepts in the animation. Consequently, it will likely help achieve the goals for this project. However, like the animation, its true effectiveness in attaining the goals I set forth will be tested in the classroom over many years.

The fossil lab was developed to reinforce the concepts of phylogeny and homology. After I researched other fossil labs online, decided on the best fossil casts to include, and designed the lab, I held a meeting with the STARS teachers to evaluate it. Their reception of the lab materials was positive; they felt having the fossil casts in class would add to their discussion and no recommendations were made regarding the lab instructions. I asked the teachers to take copies of the lab and contact me if they had any questions or concerns; however I received no negative feedback. The teacher response to the lab indicates that it is a kinesthetic learning experience that successfully reinforces the concepts of phylogeny and homology, which are covered in the animation.

In conclusion, the teacher responses to the animation, game and lab indicate a strong likelihood that the materials will be used to effectively facilitate the understanding and appreciation of evolution. The effect on test scores, AP enrollment, successful completion of AP classes, and student interest in the materials and activities, will be observed once the project is used in the classroom. The effectiveness in achieving the *higher goals* of creating empathy and a sense of connectedness in my audience, with both the subject and living manifestations of evolution, will be observed and evaluated throughout our whole lives.

FURTHER CONSIDERATIONS OF PROJECT MATERIALS

Game Materials

In consideration of the materials and construction of the game boards, it is preferable they be remade of lightweight plastic with a bottom surface which limits movement on the table (e.g. suction cups or other type of material). This will greatly improve the suitcase's portability. Cups could be added in which to place the food during the game, but it is recommended to redesign the game boards first. The reason for this is that the smallest possible suitcase was ordered for these supplies to keep the weight down to a reasonable level. The next size up was about 15lbs more, and adding stacks of cups would need more space. Ideally, the game boards could be redesigned in plastic, with a trough or moat to catch stray food, and attached or fold out cups for each individual in the population.

This would conserve space and weight, solve the issue of stray food, and the cup issue. For these reasons, a redesign of the game board is recommended.

Another possible expansion would be to include mutations in the game. This would involve redesigning the beaks to allow for little add-on pieces (i.e. “mutations”). Chance would play a part per generation in determining if a beak had a mutation, and its type. It would be one more way to illustrate the occurrence of evolution in their population.

Lab Materials

The fossil casts are not indestructible, but in principle, the lab will not need new supplies. If I were a Biology teacher, I would absolutely love to be able to check out a suitcase full of random fossils (if only for the purpose of simple show and tell at the beginning of class). It is my consideration, that if there is no need for upkeep of any of the existing materials in the suitcases, that the upkeep funds be used to purchase new fossil casts, or even fossils, each year for the teachers in the surround school districts. STARS could possibly set up a mini-gallery of fossils available for teachers to check out and show their students. For instance, if a particular teacher wanted to discuss only the convergent evolution of flight among different vertebrate groups they could check out the Archaeopteryx, the Pterosaur, and the ancient bat fossils. If they want to discuss the specialized teeth of mammals they could check out some mammalian teeth or skulls. The museum staff could make little bags or cases to carry these items, if needed.

Video Game Development

During the spring and summer of 2009, I did concept and storyboard work in designing an educational video game. It was abandoned, under the foresight of my thesis committee, due to time, programming, and budget constraints. However, from my research on educational gaming, I know this would be a valuable asset in or out of class. I would recommend a further investigation into forming program-enforced, and coordinated, collaborations between the Biomedical Communications Program at UT Southwestern and the programming department at UT Dallas. Possibly, they could pair students for joint projects.

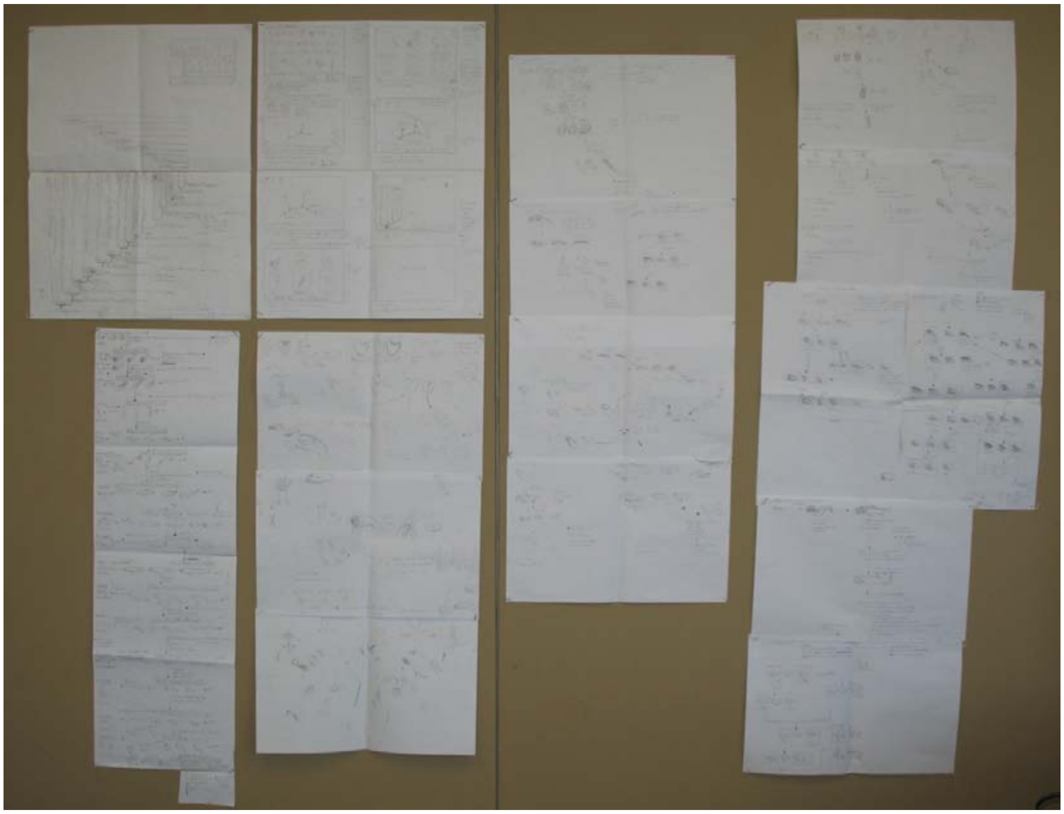


FIGURE 27. Concept work on video game.

RECOMMENDATIONS FOR FUTURE RESEARCH

The classroom observation was a pivotal point in my research. I encourage the students working on the new suitcases to contact DISD teachers and observe how the classes interact with these materials. Bibiana Mendez and her class were invaluable in establishing the priorities of this suitcase. Also, if completed at exactly the right time (when the teachers cover the subjects in class), the suitcases could be evaluated in the classroom.

There have been several complaints, made by teachers, about the size of the suitcases. The Enzyme Instigator is too large and too heavy. Organelle Extravaganza requires two people or two trips because it comprises two suitcases. The Photosynthesis suitcase, is not as heavy, but I received comments, within STARS, that it did not "look as professional" as the other suitcases (since it is an actual suitcase and the materials move around inside). I tried to balance out these concerns and have one smaller suitcase, like the previous two.

However, there is another overall concern with the suitcases; there is only one of each to check out and all the schools cover the same subjects at the same time. This was expressed a number of times at the first teacher meeting I held for the game. In fact, one teacher mentioned jokingly, while competing for food in the game, "Great. Now you can sit back and watch *us* compete for who gets to check out your suitcase." So, frustration has been expressed about the suitcases not being available to all the schools at once.

I am not sure how to solve this particular problem, but I would recommend more research into virtual labs, and virtual class activities. Perhaps, even a "virtual suitcase" could be developed. I think an extended interactive flash program that includes the whole class in some game or class activity with choices would be ideal for the class room. This might eliminate the need for an actual "suitcase."

As far as interaction with the Museum of Nature and Science, I would recommend STARS looking into having our program work with the museum staff to set up interactive displays or exhibits within the museum. The new students in the Biomedical Communications Program at UT Southwestern already have some experience doing this; additionally, the museum would have much more of a vested interest in guaranteeing these projects have some grand, functional and dramatic presentation. It could be called the STARS gallery. The teachers could organize field trips, which according to the surveys, they like to do anyway. And it would be available to all, during museum hours.

APPENDIX A
First Survey

Teacher Survey for Science Suitcases

Do your students have access to computers in class? (Yes) No

Do they have access to computers and the internet outside of class? (Yes) No Don't know

Does your class have a Smart Board? (Yes) No

Do your students have interactive SchoolPads? Yes (No)

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No)

Please list:

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes (No)

Please list :

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list:

I am Organic/Analytical Chemist. I enjoy working with students doing Sc. Fair/projects. Westinghouse...

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

I am teaching Honors and AP/PreAP Chemistry

I use during Intel Sc. Fair / Talent search Projects.

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Teacher Survey for Science Suitcases

Do your students have access to computers in class? (Yes) No

Do they have access to computers and the internet outside of class? (Yes) No Don't know

Does your class have a Smart Board? (Yes) No

Do your students have interactive SchoolPads? (Yes) No

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No)

Please list:

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list : overlays, videos, ~~DVD's~~

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: Transformation of E. Coli.
AP Biology Lab Kit

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Photosynthesis & Plant Pigments
AP Biology Lab Kit

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Teacher Survey for Science Suitcases

Do your students have access to computers in class? (Yes) No (2) only

Do they have access to computers and the internet outside of class? (Yes) No Don't know

Does your class have a Smart Board? Yes (No)

Do your students have interactive SchoolPads? Yes (No)

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes No

Please list: HHMI Video

Do you currently use any kind of visual aids, models, (animations) or games to teach about Photosynthesis? Yes No

Please list: [illegible] Hall animation w/ Bio Book

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: ~~[illegible]~~ [illegible] together - multi discipline project Could [illegible] [illegible] - would [illegible]

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Photo Cut out cartoon version

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective: model of ETC

Briegin
Central Jr High
NEB[illegible]

Teacher Survey for Science Suitcases

Do your students have access to computers in class? Yes (No)

Do they have access to computers and the internet outside of class? (Yes) No Don't know

Does your class have a Smart Board? (Yes) No

Do your students have interactive SchoolPads? Yes (No)

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No)

Please list:

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list : Jeopardy
Models

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: none

What kind of labs do you conduct to teach about Photosynthesis?

Please list: none

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Give us more hands-on activities & different strategies to teach evolution -

- if the content went above and beyond TEKS would ... time

Teacher Survey for Science Suitcases

Do your students have access to computers in class? (Yes) No

Do they have access to computers and the internet outside of class? (Yes) No Don't know

Does your class have a Smart Board? Yes (No)

Do your students have interactive SchoolPads? (Yes) No

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No)

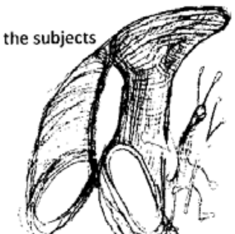
Please list:

Are they effective?

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list : Photosynthesis [illegible] don't [illegible]

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No



What kind of labs do you conduct to teach about Evolution?

Please list: - [illegible]

-

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Elodea lab (production of oxygen [illegible]) picking out the pigments (Isolating and [illegible])

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

weird

what's hard to teach

interactive game on evolution?

have you used flash/interactive game? ... effective?

[illegible] from student

Teacher Survey for Science Suitcases

Do your students have access to computers in class? **(Yes)** No

Do they have access to computers and the internet outside of class? **(Yes)** No Don't know

Does your class have a Smart Board? Yes **(No)**

Do your students have interactive SchoolPads? Yes **(No)**

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes **(No)**

Please list:

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes **(No)**

Please list :

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? **(Yes)** No

What kind of labs do you conduct to teach about Evolution?

Please list: Fossil exploration – hands on work with classifying fossils from around DFW

What kind of labs do you conduct to teach about Photosynthesis?

Please list: None

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Evo → time scale simulations

Photo → solar energy demonstration

Teacher Survey for Science Suitcases

Do your students have access to computers in class? Yes **(No)**

Do they have access to computers and the internet outside of class? **(Yes)** No Don't know

Does your class have a Smart Board? Yes **(No)**

Do your students have interactive SchoolPads? Yes **(No)**

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes **(No)**

Please list:

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? **(Yes)** No

Please list: BrainPop, Purple Cow

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? **(Yes)** No

What kind of labs do you conduct to teach about Evolution?

Please list:

Not sure about these, they do photosynthesis in 7th grade, I teach 8th

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

The students love labs & hands on activities. Anything that they wouldn't normally come into contact with is always exiting.

Teacher Survey for Science Suitcases

Do your students have access to computers in class? Yes No Sometimes — if we use comp. lab or get out laptops (but laptops would be for groups)

Do they have access to computers and the internet outside of class? Yes No Don't know

Does your class have a Smart Board? Yes No

Do your students have interactive SchoolPads? Yes No

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes No

Please list:

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes No

Please list :

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? Yes No

What kind of labs do you conduct to teach about Evolution?

Please list: Bird Beak lab w/ toothpicks.

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Teacher Survey for Science Suitcases

Do your students have access to computers in class? **(Yes)** No

Do they have access to computers and the internet outside of class? **(Yes)** No Don't know

Does your class have a Smart Board? Yes **(No)**

Do your students have interactive SchoolPads? Yes **(No)**

Do you currently ~~use~~ any kind of visual aids, models, animations or games to teach about Evolution? **(Yes)** No

Please list: WHITE BOARDS & MARKERS

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? **(Yes)** No

Please list: FLASH CARDS w/ STRUC. & FUNC.

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? **(Yes)** No

What kind of labs do you conduct to teach about Evolution?

Please list: BEAN SELECTION (NAT. SEL. DUE TO COLOR)

What kind of labs do you conduct to teach about Photosynthesis?

Please list: MICRO VIEWER (e-MICRO) & PROD. OF O_2 BY ELODEA

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

MODELS OF ORGANELLES SOME SORT OF FLOW-CHART. POSSIBLE SHOW "CHANGES IN FOSSIL REMAINS OVER TIME

Teacher Survey for Science Suitcases

Do your students have access to computers in class? (Yes) No

Do they have access to computers and the internet outside of class? (Yes) Most, not all No Don't know

Does your class have a Smart Board? Yes (No)

Do your students have interactive SchoolPads? Yes (No)

Do you currently use any kind of visual aids, models, animations or games to teach about

Evolution? Yes (No)

Please list: posters

Do you currently use any kind of visual aids, models, animations or games to teach about

Photosynthesis? (Yes) No

Please list : boxes, posters, models, (labs - look at real plants then talk about photosyn.)

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list:

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Take a look at evolution through diff areas — medicine
— animals (dogs/cats)
— Microbes
etc.

Teacher Survey for Science Suitcases

Do your students have access to computers in class? (Yes) No

Do they have access to computers and the internet outside of class? (Yes) No Don't know

Does your class have a Smart Board? Yes (No)

Do your students have interactive SchoolPads? Yes (No)

Do you currently use any kind of visual aids, models, animations or games to teach about

Evolution? Yes (No) will be teaching it the first time

Please list: this year in Freshman Bio

Don't use much except animations for AP Bio

Do you currently use any kind of visual aids, models, animations or games to teach about

Photosynthesis? Yes No

Please list : textbook CD has animations; also find from internet

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: Fresh Bio + peppered moths activity | For AP Bio, Lab 8 on Hardy Weinberg

no real lab

What kind of labs do you conduct to teach about Photosynthesis? For AP Bio, lab 4 on photosynthesis

Please list: Freshman Biology > BTB in flask breathing or Elodea in flask with BTB

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Needs to be EASY PREP and Clean up

Done within a 45 minute period

Good pre- and post assessments

Teacher Survey for Science Suitcases

Do your students have access to computers in class? (Yes) No

Do they have access to computers and the internet outside of class? (Yes) No Don't know

Does your class have a Smart Board? Yes (No)

Do your students have interactive SchoolPads? Yes (No)

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list: power points/video clips
moth/bird simulation – Industrial Melanism

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes No

Please list: Powerpoints / WS – count carbons

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: bird beak adaptations – seeds

What kind of labs do you conduct to teach about Photosynthesis?

Please list: none this year

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Really looking for more student hands-on activities

Teacher Survey for Science Suitcases

Do your students have access to computers in class? Yes (No)

Do they have access to computers and the internet outside of class? (Yes) No Don't know

Does your class have a Smart Board? Yes (No)

Do your students have interactive SchoolPads? Yes (No)

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list:
Video segment from PBS "Evolution" mini-series
Portraits of Darwin + Mendel

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list :
Models of plant cell and X-sec. of chloroplast

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list:
Variation within a species
Overpopulation
Competition among species

What kind of labs do you conduct to teach about Photosynthesis?

Please list:
Wet mount slides of Elodea leaves (chloroplasts)
X-section of leaf slide
Rate of photosynthesis with leaf discs + water/$NaHCO_3$ or clubsoda

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Teacher Survey for Science Suitcases

Do your students have access to computers in class? Yes **No**

Do they have access to computers and the internet outside of class? **Yes** No Don't know

Does your class have a Smart Board? Yes **No**

Do your students have interactive SchoolPads? Yes **No**

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes **No**

Please list:

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? **Yes** No

Please list : Visual aids
Films

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? **Yes** No

What kind of labs do you conduct to teach about Evolution?

Please list: No labs but four films.

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Pigment lab
etc.

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Haven't taught Biology classes for 4 years now,
so I'm a little rusty

Teacher Survey for Science Suitcases

Do your students have access to computers in class? Yes **(No)**

Do they have access to computers and the internet outside of class? **(Yes)** No Don't know

Does your class have a Smart Board? Yes **(No)**

Do your students have interactive SchoolPads? Yes **(No)**

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes **(No)**

Please list:

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes **(No)**

Please list :

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? **(Yes)** No

What kind of labs do you conduct to teach about Evolution?

Please list:

What kind of labs do you conduct to teach about Photosynthesis?

Please list: How color of light affects photosynthesis [illegible]

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Animated CD

Teacher Survey for Science Suitcases

Do your students have access to computers in class? Yes (No)

Do they have access to computers and the internet outside of class? (Yes) No Don't know

Does your class have a Smart Board? Yes (No)

Do your students have interactive SchoolPads? Yes (No)

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No)

Please list:

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes (No)

Please list :

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: don't teach any - I teach Nutrition + Anat. + Physiol. at a Community College.

What kind of labs do you conduct to teach about Photosynthesis?

Please list: I'm not sure what our botany teacher uses, but she would love anything new.

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

APPENDIX B
Second Survey

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? College – Inquiry Science

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? Yes (No)

Do they have access to internet in class? Yes (No)

Does your class have a Smart Board? Yes (No)

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list: EVOLUTION video Series (PBS)
Activities on EVOLUTION website

Are they effective?
Yes.

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?
That the process is fact, not theory.
Molecular basis of evolution.

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list: Foamy models of chloroplast with assorted foamy pieces to represent parts + molecules in Light Reactions. Patterned after an illustration in Campbell's BIOLOGY text.

Are they effective?
Yes.

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

Role of various molecules in Light Reactions + Calvin Cycle - seems to be ~~too~~ abstract.

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: Variation within a species
Competition within species (Natural Selection)
Overpopulation (with cherry tomatoes)

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Fast Plant Lab
Chromatography

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? (Yes) No

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models , games, etc.)?

Field work and investigations
More involved labs on the molecular level

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach?

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? (Yes) No

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? (Yes) No

If yes, how often do you use the Smart Board as an interactive tool?
My district is still installing the board.

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No)

Please list: I teach in the Health Science Technology Ed program so I do not have much of a chance to teach Evolution + photo-synthesis in my Pathophysiology, Anatomy + physiology or Medical microbiology classes.

Are they effective?

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes (No)

Please list :

Are they effective?

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list:

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? (Yes) No

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models , games, etc.)?

outdoor teaching, field trips, model, games
Virtual Lab and model would all be excellent
tools to use in teaching

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach?

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? (Yes) No

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? Yes (No)

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list:
Data projector
Powerpoints

Are they effective?
yes

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?
Genetic understanding and how it leads to adaptations.

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list :
Power point
Virtual Lab / [illegible]. Glencoe

Are they effective?
yes
Need Better.

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

PS I / PS II

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list:

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Paper Chromatography of pigment
Pigments LAB
Phototrophic /Taxis
Rate of photosynthesis Lab.

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? (Yes) No

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models , games, etc.)?

Teaching outdoors

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? SCIENCE, EIGHTH GRADE

Do you teach within the DISD? Yes (No) RICHARDSON I.S.D.

Do your students have access to computers in class? (Yes) No

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? Yes (No)

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list:
BRIEF VIDEOS
PHOTOS FROM VARIOUS SOURCES

Are they effective?
REASONABLY SO. I'M ALWAYS LOOKING FOR MORE/BETTER RESOURCES.

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

NATURAL SELECTION

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes No

Please list :
BRIEF VIDEOS
POWERPOINT PRESENTATIONS
STUDENT-GENERATED ILLUSTRATIONS
DIAGRAMS
LABS for STUDENTS TO LOOK at STRUCTURES INVOLVED IN PHOTOSYNTHESIS
3-D FOLDABLES

Are they effective?

REASONABLY SO

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

- IDENTIFICATION OF CHLOROPLASTS
- THAT NOT ALL PIGMENTS ARE GREEN

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list:

ACTIVITIES MORE THAN LABS. I'D LOVE TO KNOW OF AN EASILY ACCESSIBLE LAB ABOUT THIS TOPIC THAT I CAN DO WITH EIGHTH GRADERS.

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

SEE FRONT OF THIS PAGE.

Have you ever used an interactive educational flash game in your class? (Yes) No

Was it effective (or relevant)?

REASONABLY SO

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? (Yes) No

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models, games, etc.)?

ALL OF THE EXAMPLES LISTED ABOVE + SOME FORM OF STUDENT-GENERATED PRESENTATION (i.e. ILLUSTRATIONS, FOLDABLES, ORAL PRESENTATIONS, RESEARCH PAPERS)

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? 9th PreAP Biology

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? (Yes) No

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? Yes (No) (2 at the campus, though)

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list: 3x3 square to match terms w/ definitions, videos, genetic drift game

Are they effective? for PAP, yes + sometimes with regular

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?
Natural Selection + some of the theories

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list: formula cut apart that they put together, thylakoid membrane on the floor that they walk the e⁻ through, animations

Are they effective?
yes

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

Steps in order, photosystem II & I

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: Fossil lab, Camouflage/Natura Selection Lab, Peppered Moth Simulation on Computer

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Dark Reactions, Effects of Photosynthesis, Chromatography

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? Yes (No) Too busy teaching TAKS

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models , games, etc.)? games, models, field trips with PAP only (not regular)

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

☆ Games are the most important for at-risk students

Kathy Bodner
972-931-2187
experience with games & manipulatives

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? 9th - Pre-AP Biology

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? (Yes) No

work 469-593-5012

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? (Yes) No

If yes, how often do you use the Smart Board as an interactive tool? once a month

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list: video, (alleles) games
manipulatives, games, animations (genetic drift)

Are they effective?
yes!

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?
natural selection
theories

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list: manipulatives
models

Are they effective?
yes!

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

Calvin cycle / chemistry part Photosystem II & I

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: Archeopteryx Lab (Fossil)

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Effects of Photosynthesis

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? Yes (No)

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? Yes (No) We are busy teaching the TAKS test

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models, games, etc.)? anything but what we are doing

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

yes! Hand-on, labs, fun activities make it real for them.

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? 6th grade Science (7-8 Previous 3 years)

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? (Yes) No

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? Yes (No)

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No) Evolution not in curriculum standards for 6th grade

Please list:

8th grade- used Socratic seminar

Are they effective?

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

student are more familiar with the creatimtism ideas/theories because of religous home life (structure)

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list :

Power Point
Cells alive website has photosynthesis link

Are they effective?

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

younger students - chemistry - equation

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: None at present

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Use microscopes to view Elodea Plant / leaf
View cytoplasmic streaming - green organelles

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)? ?
use e-instruction

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? (Yes) No

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models, games, etc.)?

yea!

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

(NEW SCIENCE)
- Texas textbooks are on hold waiting for the board to decide on the Evolution!
- Regardless of curriculum, teaching Evolution + creationalism is up to the integrity + professionalism of the teacher

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach?

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? (Yes) No

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? Yes (No) I'm on list to get one!

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list: Visual for peppered moth
model - lab for natural selection - related to sickle cell anemia

Are they effective? yes, however, see misconception below -

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?
Geological time - how long Earth has been here; variations exist - misconception that organisms change to environment.

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list: Huge model (paper) of Chloroplast
Visual - PP on light reactions

Are they effective? Yes

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

Calvin cycle – often reduced so much that understanding is not very indepth.

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: Lab: Natural Selection – backgrounds change how impact survival of species

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Leaf lab – crossection
Stomata Lab –
Chromatography – pigment analysis

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? (Yes) No

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models, games, etc.)?

I would do any of the above.

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

You may contact me at 214-334-4664
HPHS
Highland Park High School

I teach
PreAP Bio

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? 7th grade - Life Science, 8th grade - Earth

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? Yes (No)

Do they have access to internet in class? Yes (No)

Does your class have a Smart Board? Yes (No)

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list: Natural Selection game
virtual lab

Are they effective? yes

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

Evolution or Creationism

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list: Overheads
virtual lab

Are they effective? Somewhat

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

They often think Carbon dioxide turns into Oxygen

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? Yes No

What kind of labs do you conduct to teach about Evolution?

Please list:

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Elodea's light and dark

Have you ever used an interactive educational flash game in your class? Yes No

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? Yes No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? Yes No

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models , games, etc.)?

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? 9th - Biology

Do you teach within the DISD? (Yes) No

Do your students have access to computers in class? Yes (No)

Do they have access to internet in class? Yes (No)

Does your class have a Smart Board? (Yes) No

If yes, how often do you use the Smart Board as an interactive tool? every day

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No)

Please list:

Are they effective?

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

everything - we don't have enough time to teach evolution; just introduce the concept and some terminology.

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list: animations from one of the biology websites; games - [illegible] game

Are they effective? Yes

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

Calvin Cycle

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: None

What kind of labs do you conduct to teach about Photosynthesis?

Please list: None

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? (Yes) No

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models, games, etc.)? teaching outdoors, field trips, using models, games and anything that will help students understand the concepts

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

more hands-on activities

Survey for Science Suitcases

Are you a teacher? **(Yes)** No

If yes, what grade and subject do you teach? 8th Grade Science

Do you teach within the DISD? **(Yes)** No

Do your students have access to computers in class? **(Yes)** No — if I schedule them

Do they have access to internet in class? **(Yes)** No

Does your class have a Smart Board? **(Yes)** No

If yes, how often do you use the Smart Board as an interactive tool? It just got installed but I have not used it

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? **(Yes)** No But I would LOVE more

Please list:

Games - flipping coins, using beans for allele frequency changes

Are they effective? Usually, somewhat.

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

The whole "we did not come from monkeys" thing. Students (and most non science people in general) fail to understand that evolution is happening at the species level, not the individual level.

Many inner city Kids have what is almost "Medieval" types of beliefs about science

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? **(Yes)** No

Please list: Just posters,

Are they effective? Could use something more

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

the cycles (esp back 'n' forth with respiration)

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: Mostly just allele frequency.

What kind of labs do you conduct to teach about Photosynthesis?

Please list: elodea in a flask with H_2O + Baking Soda - to see bubbles of O_2 given off.

Have you ever used an interactive educational flash game in your class? (Yes) No

Was it effective (or relevant)? Yes - a game called I have, who has -

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? (Yes) No

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models , games, etc.)?

all the above - anything is better than paper + textbook!

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach?

Do you teach within the DISD? (Yes) No

Do your students have access to computers in class? (Yes) No

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? Yes (No)

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No)

Please list:

Are they effective?

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?
naturol selection

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list :
visual aid: for chlorophyll & eletion transport chain

Are they effective?
for some students

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?
oxygen production (drives me crazy that so many fail to understand this)

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: none

What kind of labs do you conduct to teach about Photosynthesis?

Please list: Oxygen production by elodea

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? Yes No depends on the year

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models, games, etc.)? models & games

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

filled out one 2 months ago

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? soph. college micro biology + anatomy + physiology

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? Yes (No)

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? Yes (No)

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No)

Please list:

Are they effective?

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

don't really teach evolution

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes (No)

Please list :

Are they effective?

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list:

NA

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

NA

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? Yes No NA

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models , games, etc.)?

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Survey for Science Suitcases

Are you a teacher? **Yes** No

If yes, what grade and subject do you teach? 9th/10th BIOLOGY + HONORS BIOLOGY

Do you teach within the DISD? Yes **No**

Do your students have access to computers in class? **Yes** No

Do they have access to internet in class? **Yes** No

Does your class have a Smart Board? Yes **No**

If yes, how often do you use the Smart Board as an interactive tool? NA

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? **Yes** No

Please list: Musical chairs

Are they effective? ~~Camp~~ kindof – but weak...

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

vocabulary... Homologous, vestigial

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes **No**

Please list :

Are they effective?

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

all of it – the equation (they don't make the connection between the words + the formulas...)

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? Yes No

Yes! The more connections they can make + the more engaged they are, the better.

What kind of labs do you conduct to teach about Evolution?

Please list: Antibiotic Resistance LAB

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

Have you ever used an interactive educational flash game in your class? Yes No

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? Yes No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? Yes No we try, but there is never enough time + some students are lost

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models, games, etc.)?

all of the above sound great → key is getting them engaged.

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? 9th & 12th

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? Yes (No) only 1 in room

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? Yes (No)

If yes, how often do you use the Smart Board as an interactive tool? ___

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list: diagrams of evidence — fossils, embryos, homologous structures

Are they effective? Sometimes

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

that it is a very small scale & slow process (doesn't happen in one generation)

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? Yes (No)

Please list :

Are they effective?

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

the idea that plants can actually make their own food from just H_2O, CO_2 & sun (they don't get chemistry yet)

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list: Camoflaged animals survive & reproduce (using goldfish crackers)

What kind of labs do you conduct to teach about Photosynthesis?

Please list: mini labs with one reactant missing each time (sun-no sun, vaseline on leaf so no CO_2, etc.)

look at stomata on microscope

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? Yes (No)

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models, games, etc.)? go outdoors, use models & games

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? 9-12

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? (Yes) No

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? Yes (No)

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? (Yes) No

Please list: POWER POINT

Are they effective?

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list : POWER POINT

Are they effective?

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list:

What kind of labs do you conduct to teach about Photosynthesis?

Please list:

Have you ever used an interactive educational flash game in your class? Yes (No)

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? Yes (No)

If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models , games, etc.)?

FIELD TRIP

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

Survey for Science Suitcases

Are you a teacher? (Yes) No

If yes, what grade and subject do you teach? Biology

Do you teach within the DISD? Yes (No)

Do your students have access to computers in class? (Yes) No

Do they have access to internet in class? (Yes) No

Does your class have a Smart Board? Yes (No)

If yes, how often do you use the Smart Board as an interactive tool?

Do you currently use any kind of visual aids, models, animations or games to teach about Evolution? Yes (No)

Please list:

Are they effective?

What concepts about Evolution are difficult for your students to grasp (or difficult to teach)?

They do not want to think we "came from apes"

Some only want to go with creationism so they turn off the entire thing sometimes

Hard concepts: analogous, homologous because it requires effort to learn.

Do you currently use any kind of visual aids, models, animations or games to teach about Photosynthesis? (Yes) No

Please list: unitedstreaming videos

cartoon cut out paper Lab

Are they effective?

More than lecture

What concepts about Photosynthesis are difficult for your students to grasp (or difficult to teach)?

The equation.

Do you think visual aids, models, animations and games are an effective way to help teach the subjects of Evolution and Photosynthesis? (Yes) No

What kind of labs do you conduct to teach about Evolution?

Please list:
paper Lab analogous + homologous

What kind of labs do you conduct to teach about Photosynthesis?

Please list:
Colored light lab is awesome

Have you ever used an interactive educational flash game in your class? Yes No

Was it effective (or relevant)?

Are you willing to use an interactive educational game as part of your curriculum? (Yes) No

Do you have time in your class to teach material about Evolution and Photosynthesis that goes beyond the TEKS requirements? Yes (No)

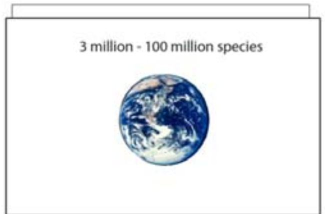
If you could do anything to teach a subject in a class, what would you do (i.e. teaching outdoors, field trips, using models , games, etc.)?
all of the above

Please feel free to express your ideas about how we can make teaching the subjects of Evolution and Photosynthesis more fun, interactive and effective:

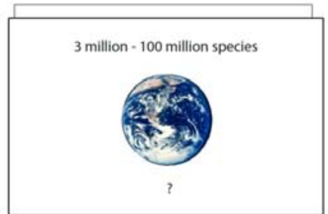
Less TAKS - more time for Labs
hands on models help
games help

APPENDIX C
Pre Animatic Storyboard

Viruses?? We still haven't decided if they are within the confines of life. They have their own entire taxonomic system!

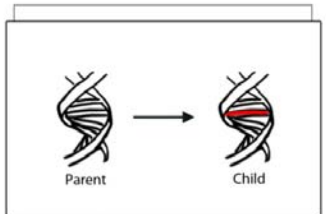


Scientists have discovered about 2 million living species, but their estimates for the total number of species living on Earth range anywhere from 3million-100 million.

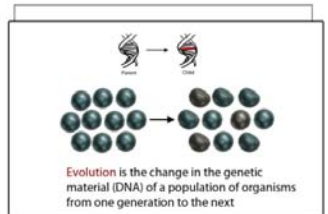


So, where did all these species come from? They didn't just pop into existence out of nowhere, at least we've never seen that happen.

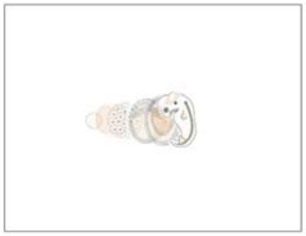
This is what we DO know: DNA is a shared trait of all life and DNA mutates.



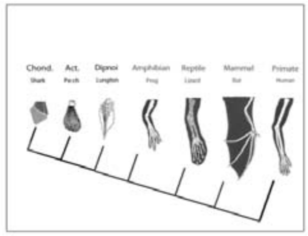
In fact, within a population, we know that DNA mutates from generation to generation.



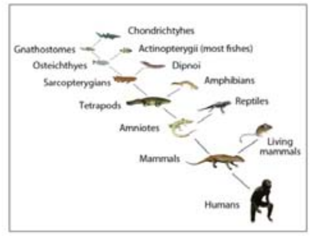
Interestingly enough, this is the very definition of evolution: that is, change in the genetic material (DNA) of a population of organisms from one generation to the next.



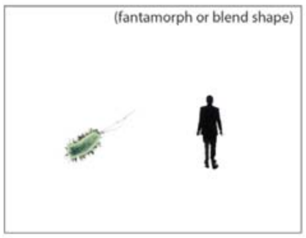
comparative embryology



and all the homologies, or shared traits, between organisms

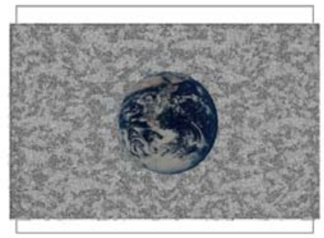


show that species do arise from other species.

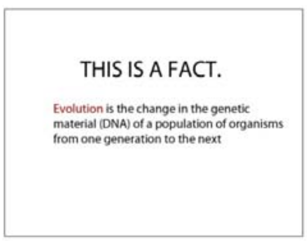


Of course, this can take thousands, sometimes millions, of years in a process called speciation.

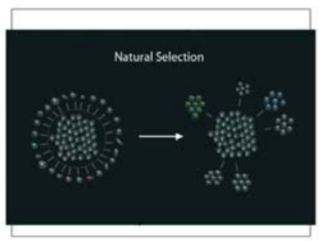
Evolution is the cause for all the variation of life on Earth. Without it there would be no reason for you to have Biology class. Biology would be meaningless.



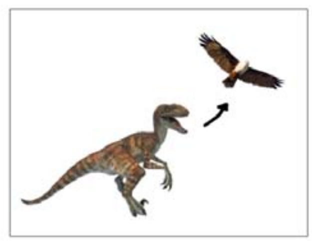
In fact, the class wouldn't even exist. There wouldn't be chairs, or desks, or walls. This very animation would cease to be... along with my fading voice because...



This is a fact. There is no scientific debate on whether or not evolution exists. It does exist: genetic change in a population from generation to generation does occur.

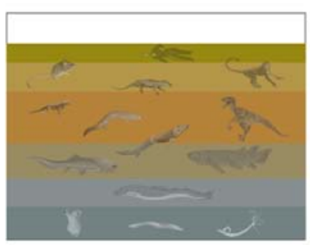


We also know why evolution doesn't expand populations limitlessly in all directions; the environment selects only for certain mutations in a process called natural selection.

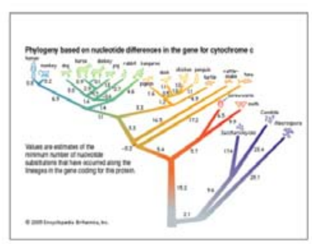


More on that later... But, does evolution cause new species to arise from older species?

Again, this is what we do know:

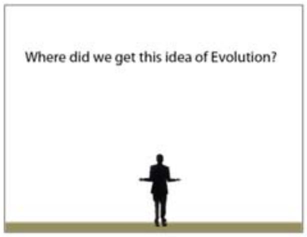


The fossil record

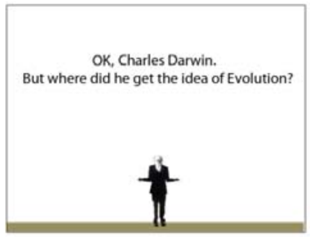


DNA and protein analysis

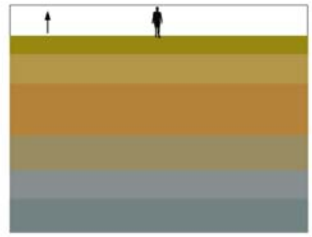
you would not exist, either.



So, where did we get this idea of Evolution?

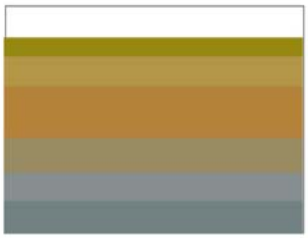


So, Charles Darwin gave us an explanation for how evolution works, but where did HE get the idea?

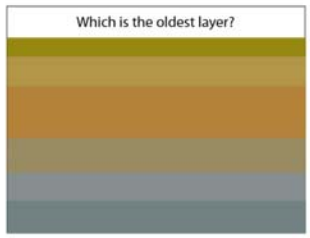


Well, you're standing on it.

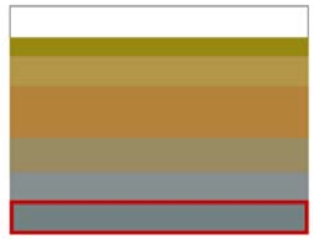
(to see the quality I have in mind for this image see attached jpeg)



The Earth's surface is composed of layers of rock.



Now, if you had to guess, which layer do you think would be the oldest layer of rock?

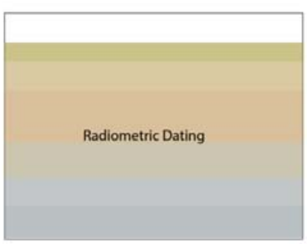


It's the layer on the bottom.

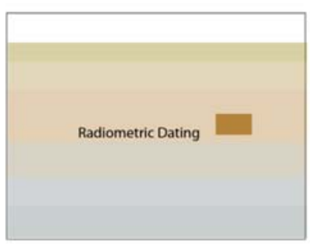
It's like a sand bottle, in which you pour one color of sand that settles to the bottom.

Then you add another color of sand, which settles on top of the first color.

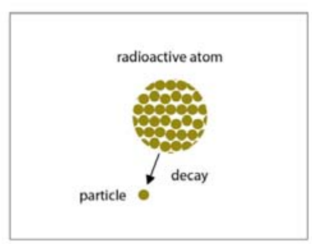
In general, this is how the Earth's surface is arranged, with older layers on the bottom, and newer layers on top.



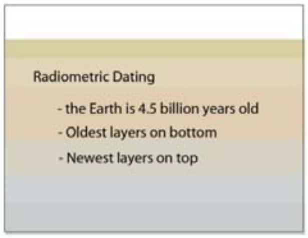
The data which supports this concept is gathered using a technology called radiometric dating (radioactive carbon dating is one such technique).



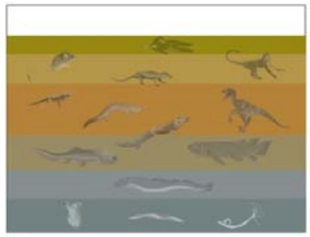
If they take a sample of rock from one of these layers



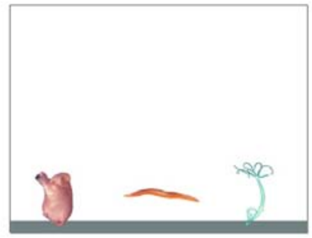
there will be atoms in that sample, which have been releasing particles over time. This is called decay. Scientists can measure these radioactive atoms and deduce the age of the rock sample.



Radiometric dating has shown that the Earth is about 4 ½ billion years old, and in general, the oldest layers are on the bottom, with the younger layers on top.

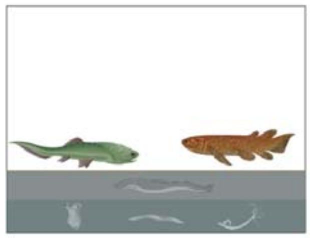


And just like the rocks in the Earth's surface, fossils are arranged in corresponding layers.

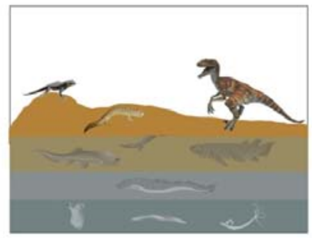


In the oldest rocks on the bottom, we find only the life forms without a head.

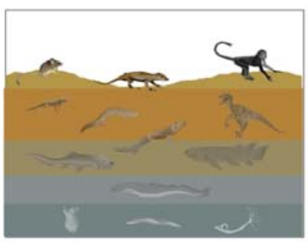
On top of that we find everything with a head,



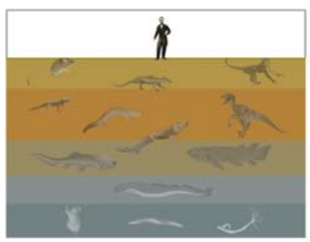
on top of that we find everything with a head, jaws, and paired apendages,



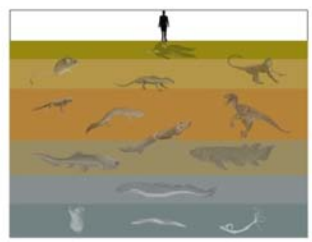
on top of that we find everything with a head, jaws, and paired apendages that walk on land,



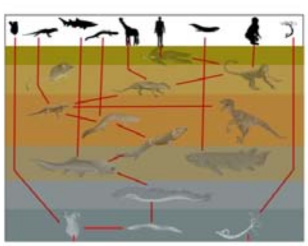
on top of that we find everything with a head, jaws, paired apendages that walk on land, and hair,



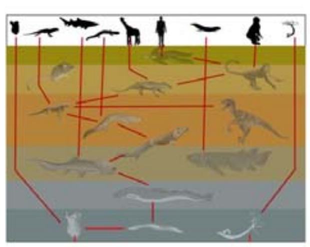
and on top of that we find everything with a head, jaws, paired apendages that walk on land with 2 legs, hair, and a well developed brain.



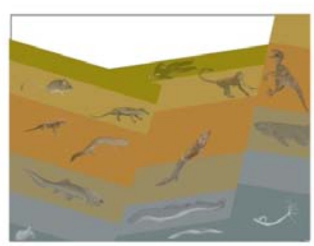
But in case you're feeling on top of it all, keep in mind that these ancestral species split into millions of other lineages, which evolved into all the species alive today.



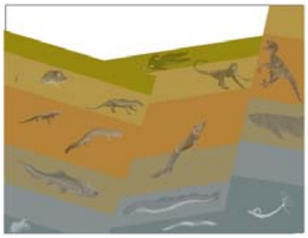
So, we are not "more evolved" than other living species. Just like us, they have been evolving for a very long time



and they are equally adapted to their respective environments. Instead, think of these other living species as our very distant cousins.

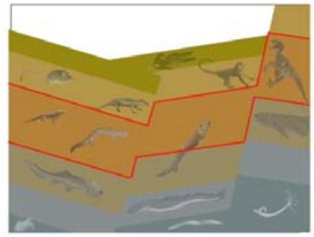


Now, tectonic shifts (think massive earthquakes, volcanic eruptions, continental drift) have in specific areas, disrupted the layers, but geologists can still discern the pattern of rocks

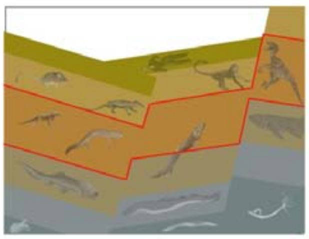


and, remember, they can use radiometric dating to confirm the identity of the layer.

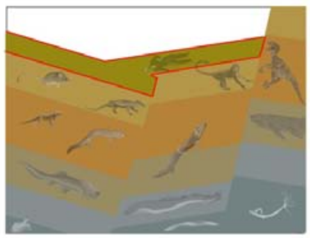
This is how scientists are able to create vast and intricate geological maps, which evolutionary biologists can then use to find certain fossils.



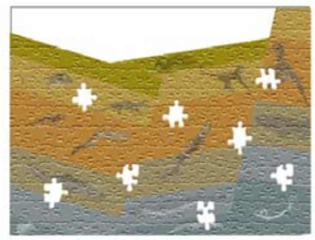
For instance, if they are searching for dinosaur fossils they will know in which layer to look.



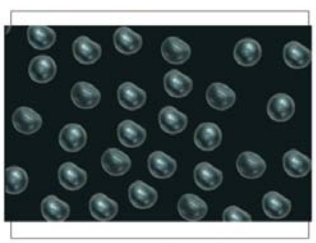
However, if they were looking for human fossils they wouldn't find any in this layer because the rocks are too old and humans hadn't evolved yet.



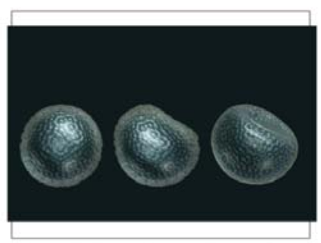
Rather, they would know to look in newer rocks to find human fossils.



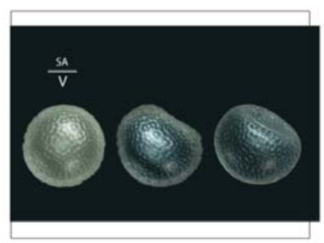
In a sense, the entire field of Evolution is like a giant jigsaw puzzle. We've put enough pieces together to know it's there, but there are many pieces that have yet to be found.



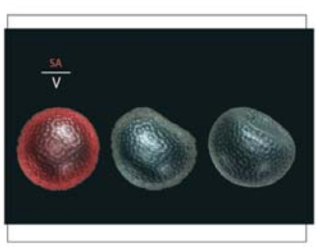
Let's say we have a population of microscopic organisms, and they are multicellular.



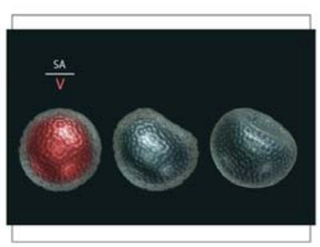
When we look more closely at their trait for surface area to volume ratio, we discover that there are 3 different types, or 3 different "phenotypes" to be more exact.



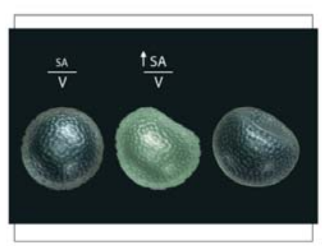
So let's discuss the different types. One has a low surface area to volume ratio.



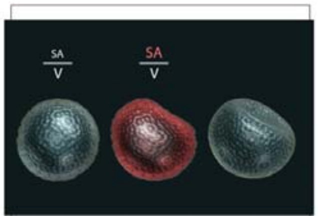
In other words, the outer surface is about as small as it can get



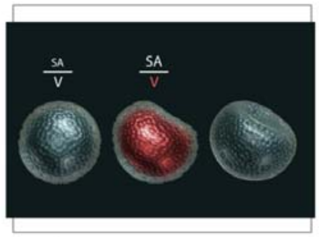
for this volume.



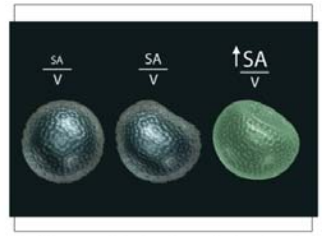
The type beside it has the same volume, but because the outer surface has expanded, and folded in a little bit, it has



more surface area. Therefore it has more surface area



per volume.



The last one, with a deep invagination, has the most surface area per volume, and therefore the largest surface area to volume ratio. (highlight SA/V like in previous 2)

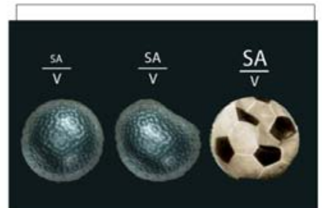
Have you ever left a ball out in your yard just a little too long? Let's say you leave out a soccer ball, and over time

it deflates a little bit, such that the outer surface pinches in some. Or, we could say that it creates an "invagination".

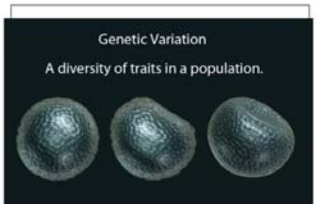
Now, since a soccer ball is not a living thing, and doesn't carry genes that can expand its surface area during development, what do you think changes over time in the soccer ball?

It's volume changes; it decreases, right? And thinking about simple division, this does what to the surface area to volume ratio?

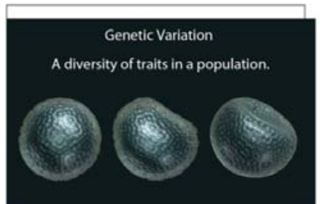
It increases the surface area to volume ratio.



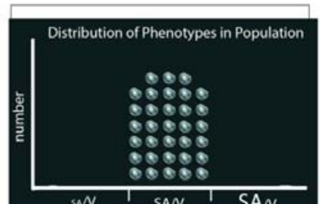
(move and fade in)



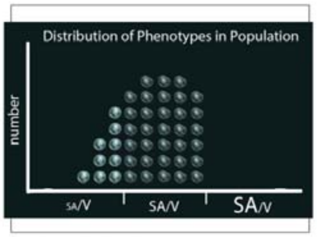
And because our population has this "diversity" of traits, we say it has genetic variation. Look around your classroom, it's a population. Does anyone look exactly the same?



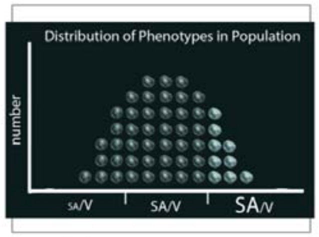
Unless your class has identical twins, probably not. So the population of your classroom has genetic variation, just like this one.



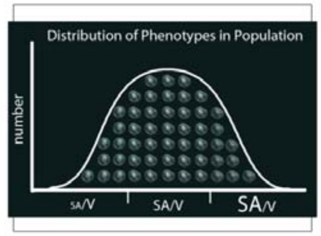
This variation can be plotted on a distribution curve, so we can see that most of our population has an average SA/V ratio.

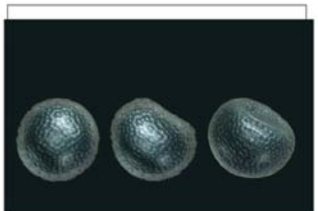


But few individuals have a very low

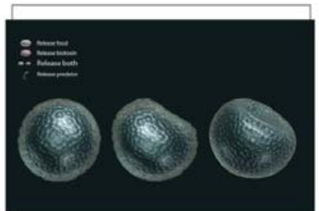


or a very high SA/V ratio.





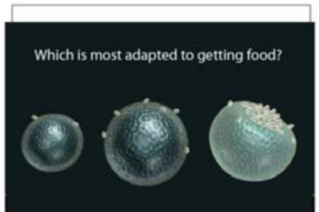
So, now that we've analyzed our 3 phenotypes for this trait, and placed them on a distribution curve, let's see what happens with selective pressures from an environment.



Choose an environment. You can release food, biotoxin, both food and biotoxin at the same time, or a predatort.

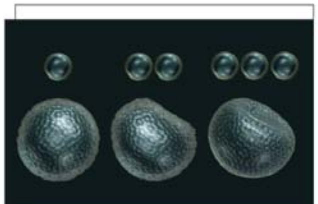
The food is a positive, life-sustaining environmental factor for our population.

(these will be the actual phenotypes, ignore the small one for now)

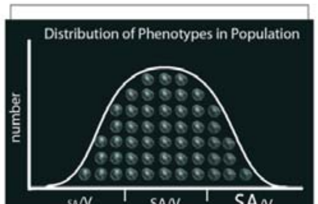


Which type seems to be the most well adapted to getting food? *(pause)* The one with the highest SA/V ratio will have a higher chance of getting food because of its larger SA, and since

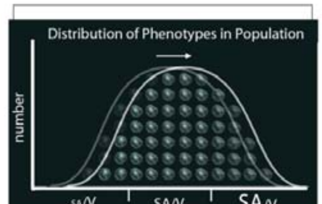
the volume is the same as the other 2 types, it only needs the same amount that they do. So, which type would likely be the most successful in reproducing offspring in this environment?



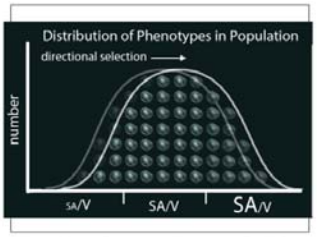
Yes, the type that is most adapted to getting food will have a better chance of living long enough and having the energy to reproduce more, and more successfully



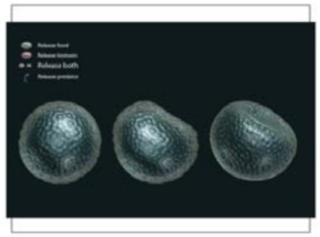
Now what do you think will happen to our distribution curve in the next generation?

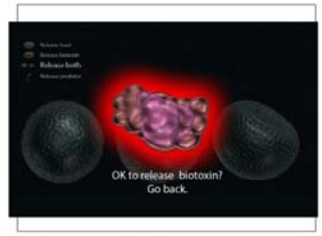


It shifts more towards the individuals with the highest surface area to volume ratio because they were the best at getting food, and therefore could reproduce more.

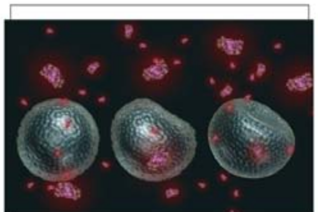


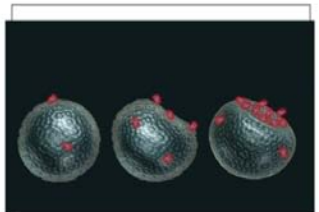
This is a kind of natural selection is called directional selection. In this case the "direction" is towards the phenotype with the highest SA/V ratio.



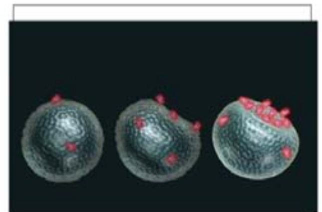


The biotoxin is a harmful molecule produced by another organism in this environment. If an individual in our population gets too much biotoxin, it will die.

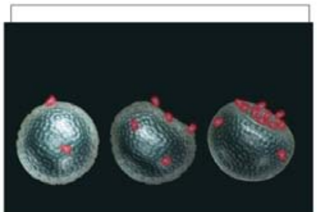




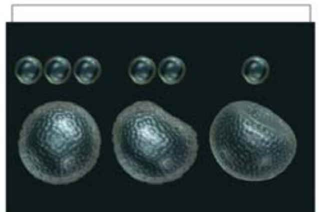
So, what organism is most susceptible to the biotoxin?



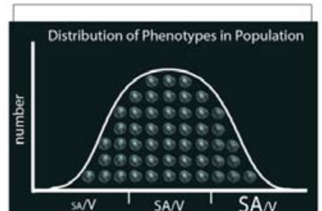
The one with the highest surface area to volume ratio will likely be most affected by the biotoxin. But which one will be the most reproductively successful?



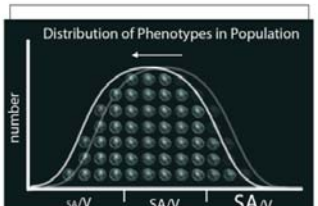
Since they all have the same volume, the biotoxin is equally harmful to all types, but since the one with the lowest SA to volume ratio receives less, it is safest from the biotoxin.



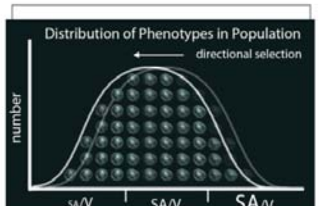
Therefore, in this environment, it is more likely to survive to reproduce. So, in the next generation there will be more individuals with a lower SA/V ratio.



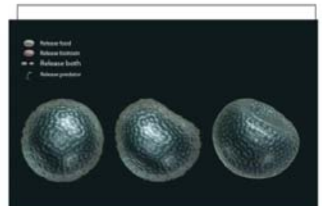
So, what happens to our distribution curve in the next generation?



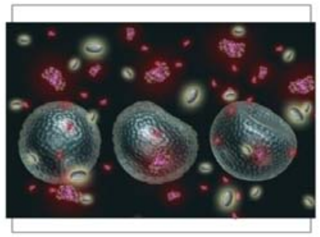
It shifts towards the individuals with the lowest SA/V ratio to reflect that there are more of them being reproduced in this environment.

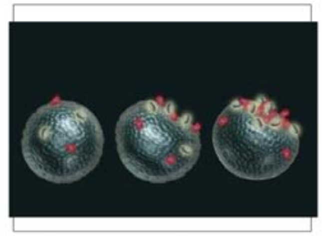


This kind of natural selection is called directional selection. In this case the "direction" is towards the type with the lowest SA/V ratio.

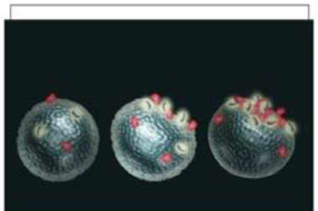


Releasing both the food and biotoxin, a positive and negative stimulus, respectively, at the same time, will create a more complex environment.

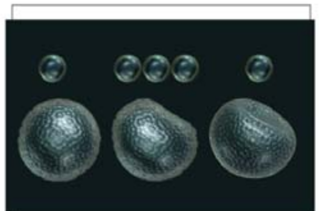




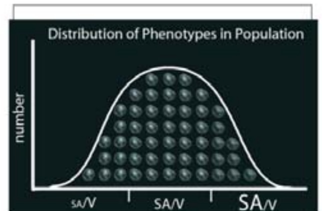
So, what type is the most adaptive to this environment? It's hard to say, and in real life there are often an incredible number of environmental factors, each balancing the benefits and



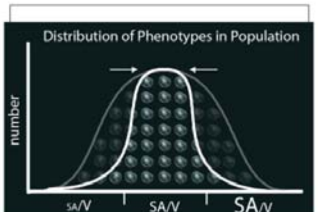
costs of an individual's traits, but perhaps we find that the type with the average SA/V ratio gets just enough food and avoids the biotoxin just enough to survive, so that



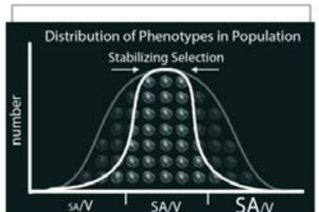
in this environment, we find it to be the most reproductively successful.



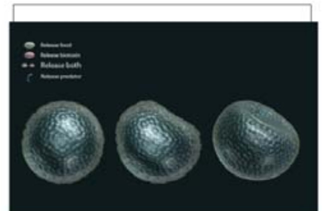
But what do you think will happen to our distribution curve in the next generation?

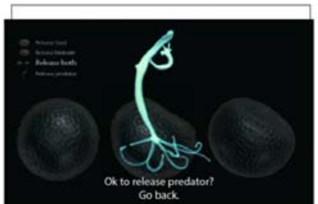


In this environment our distribution curve will be reduced on both sides, showing that in the next generation our population will have even more individuals with an average SA/V ratio.

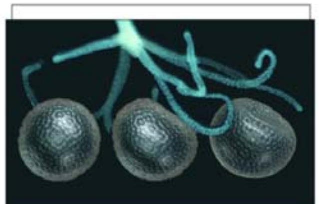


This type of natural selection is called Stabilizing Selection. Think of this as selecting for the most "stabile" or "balanced" set of traits, in between the 2 extremes.

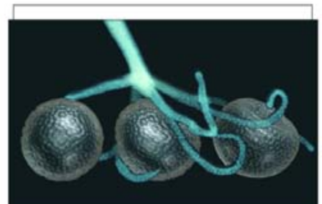


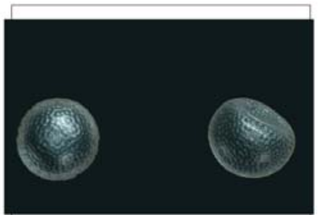


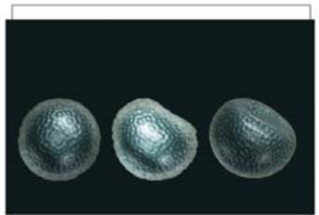
The predator is a hydra that has adapted to feed on our population.



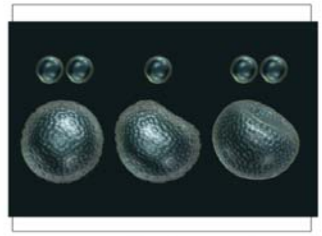
While the hydra can devour any of the phenotypes, it is specifically adapted to eat the most numerable phenotype, which are the ones with the average SA/V ratio.



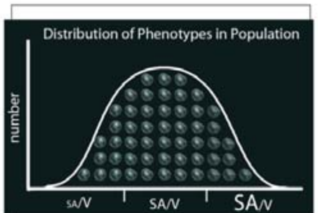




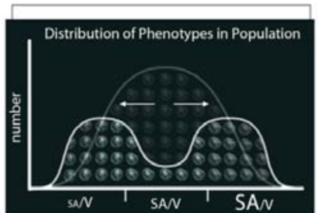
So, which phenotype will show the least reproductive success in this environment?



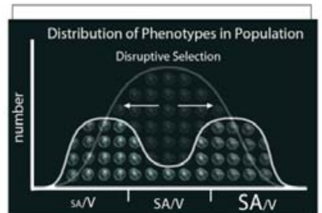
The one in the middle right? Because that's the type the predator is most adapted to eat.



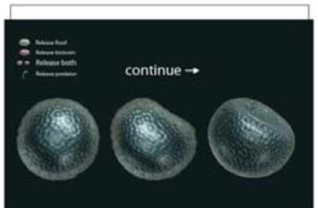
And what do you suppose might happen to our distribution curve in the next generation?

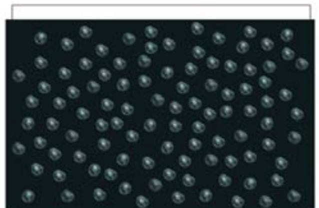


Well, the individuals with an average SA/V ratio will decrease and the 2 phenotypes at the extremes will reproduce more. So, our curve would look something like this.



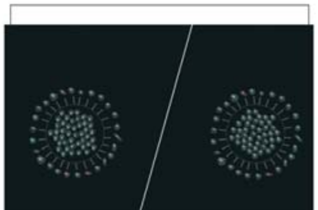
This is a kind of natural selection called disruptive selection. So, the predator apparently "disrupted" our nice singular curve into 2 smaller curves.



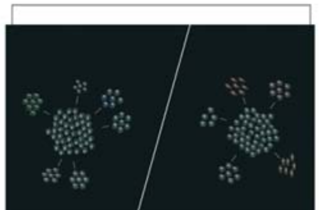


Now we've seen how different environments can select for different individuals in a population. But what happens if a population splits into 2 by occupying different environments?

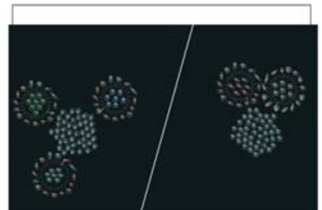
Let's say one group gets carried off by water currents, so that they are now geographically isolated from the other group.



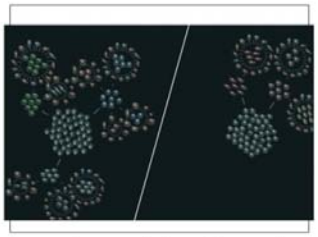
They reproduce, and with each generation, random mutations in DNA cause little developmental changes in the offspring that set them slightly apart from their parents.



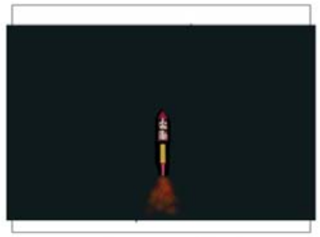
Because the two groups are now in different environments, they have different selective pressures. As you have seen, these pressures select different individuals. Then those reproduce,



and over millions of years of random mutation and natural selection,



many species can evolve from what started as one population of organisms.

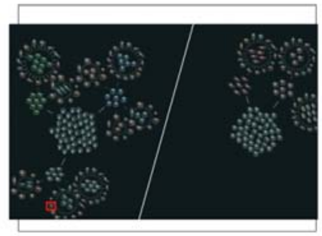


In this way, evolution is sort of like a fireworks display. In fact, it's like one very long, messed up firework. Let's call our rocket here, the first generation.

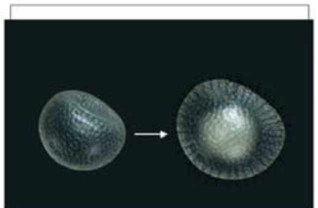
When it reproduces, it's like an explosion of DNA with little random mutations in all directions. This would be the 2nd generation. But the wind has picked up, and there's a little

moisture in the air, so some of the embers diffuse and fade away. That's just natural selection. However, some of them create new explosions of DNA, resulting in the 3rd generation,

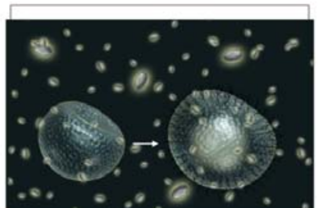
which has different shapes and colors that set it apart from the preceding generation. That is what evolution is like: one big, continuous, out of control, fireworks display.



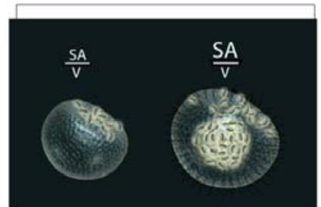
In our lineage, one of these populations



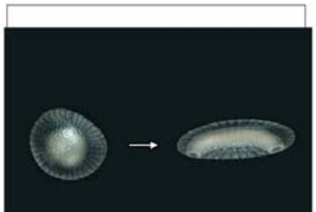
of little multicellular, microscopic organisms, gradually formed a gut.



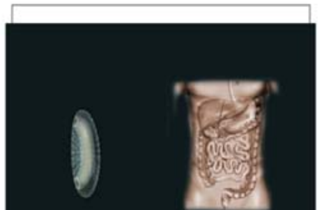
And what does a gut do in terms of surface area to volume ratio?



Well a gut can catch and hold even more food, right? So, we can say that it increases the SA/V ratio to maximize the absorption of nutrients.



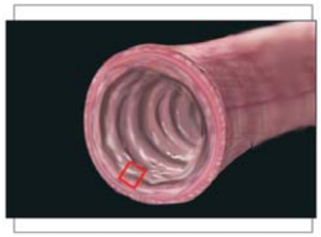
Over millions of years, one of these populations of multicellular organisms with a gut, evolved into little worms, with longer guts.



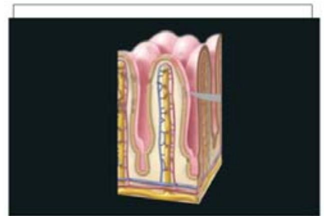
So, let's see the human gut in comparison to this worm gut. Now, why do you think our digestive tract has all those twists and turns and loops and compartments?

Well, aside from more specialized digestion, it REALLY increases the SA/V ratio, right?! It really increases the amount of nutrients you can get from food.

But that's not the only way your gut has evolved to increase SA/V ratio.

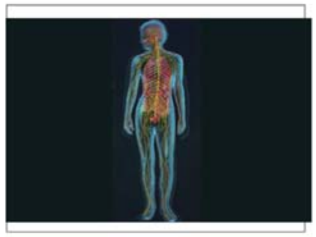


On the tissue level, it has all these all these little bumps and folds. So, what do you think is the function of these little bumps and folds?



Well, these would increase absorption by increasing SA/V ratio., right? If we zoom in, we see smaller bumps and folds, and this also increases absorption by increasing SA/V ratio.

In fact, each individual cell on your digestive surface, also has even smaller bumps and folds, which also increase SA/V ratio! The surface area of your digestive tract is about the size of a



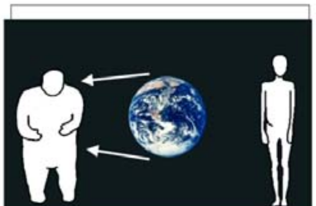
tennis court. But evolution of SA/V ratio is not limited to your digestive tract. Many of the tissues in your body have evolved to increase SA/V ratio to increase absorption or

connectivity, or some other function. Again, think of this as evolution's way of selecting for more and more surface crammed into a limited volume.

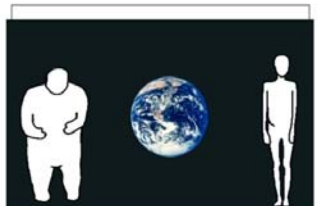
And we also see SA/V ratio showing the macro effects of evolution on the Earth's geographical distribution of humans.

Did you know that the average human has a higher SA/V ratio the closer you get to the equator? It's true.

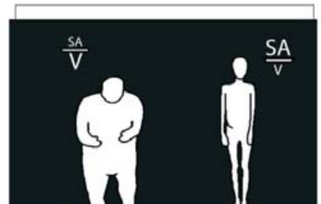
Over thousands of years, humans have adapted to different environments. Humans nearer the equator generally have longer arms and legs and smaller torsos and frames. Whereas,



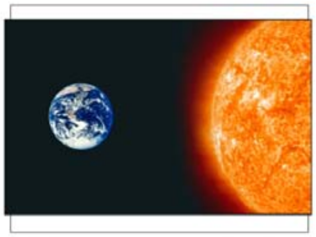
the farther you get from the equator, the more humans there are that have stockier frames and shorter arms and legs. Why do you think that is?



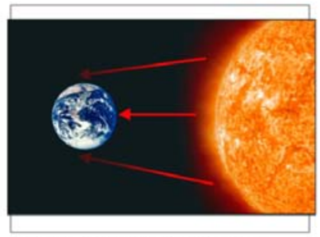
You know it has something to do with SA/V ratio. So, do the humans with longer arms and legs and smaller torsos have a higher or lower SA/V ratio?



Higher, right? And the stockier humans have a lower SA/V ratio. Can you think of an environmental factor, near the equator, that might have selected for this trait?

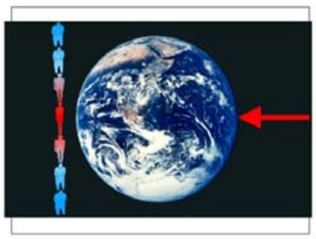


Well, the temperatures are generally much hotter near the equator. And the farther you get from the equator, the colder it gets.

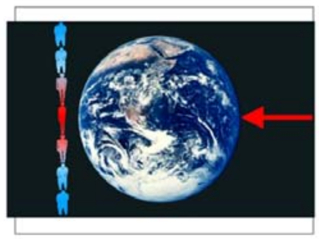


So the environmental factor is the climate, which selects for humans with higher or lower SA/V ratio, depending on where they are relative to the equator.

People with a higher SA/V ratio are genetically more adapted to to release heat. This is beneficial in hotter climates nearer the equator.

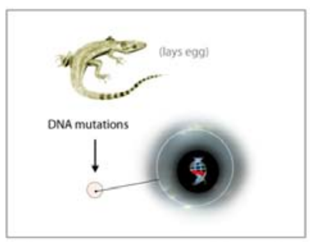


While people with a lower SA/V ratio are genetically more adapted to retain heat. This is beneficial in colder climates farther from the equator.

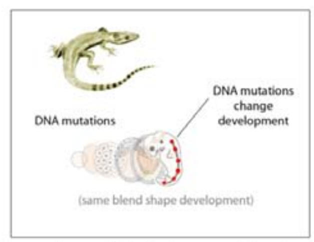


Even with modern dwellings, transportation, air conditioning and technology we can observe the effects of evolution, due to climate, on the entire human population.

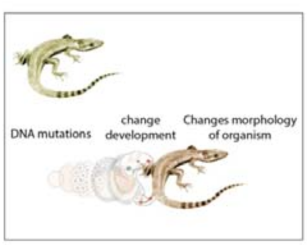
What does embryology have to do with evolution?



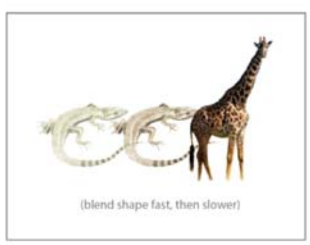
We know that DNA mutations in the germ-line cells, that is the egg and sperm,



cause changes in the development of the offspring



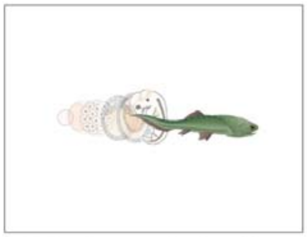
and this changes the morphology, or form and structure, of the adult organism.



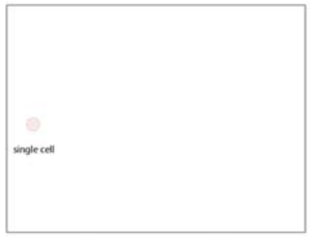
and over hundreds of millions of years the changes in morphology can gradually become very great.

How does this show relationships between the species?

But how does this show relationships between the species?

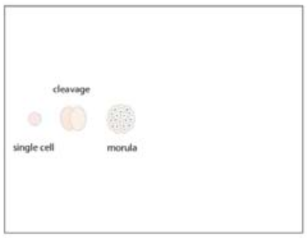


Well, did you know our embryology still has a lot in common with our recent relatives: like all vertebrates for instance. We all go through very similar stages of development.

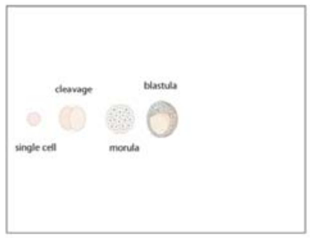


We see the following pattern in all fish, amphibians, reptiles and mammals (including humans). First there comes a fertilized egg which starts off as a single cell.

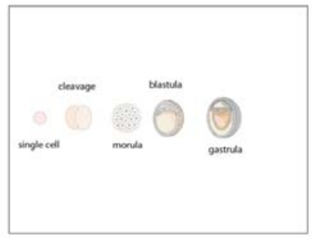
That cell divides to form two cells in the cleavage stage,



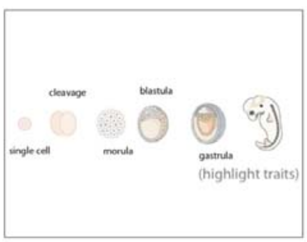
and then many cells in a stage called a morula.



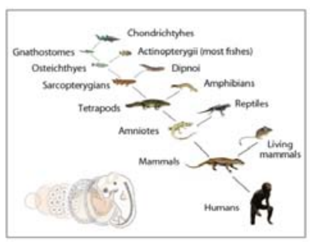
This ball of cells forms a cavity, becoming hollow, and goes through a stage called a blastula.



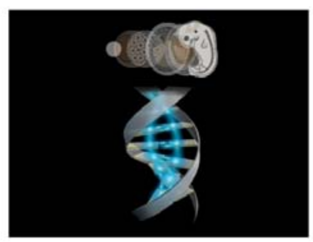
The blastula develops a little hole, which becomes either the mouth or anus, and forms 3 layers of tissue (called endoderm, mesoderm and ectoderm), thereby becoming a gastrula.



And then this develops into a little guy with a head, eyes, pharyngeal arches (we'll talk about those later), 4 limbs and a notochord.

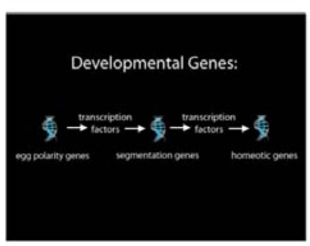


So, how is it that our development has so much in common with all these other species?



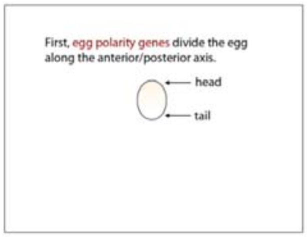
The answer is that the specific genes, in our DNA, which control development, are essentially identical to the genes in these other species.

We still have a lot of the same genes with the same developmental functions. These genes include egg polarity genes, segmentation genes, and homeotic genes, or hox genes.

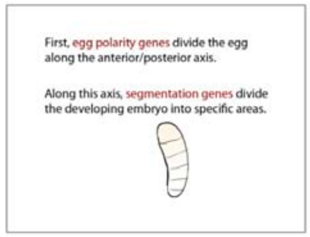


Basically they encode transcription factors which *transcribe* the next set of genes in the genetic cascade.

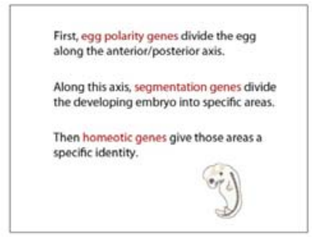
This genetic cascade is just like the domino effect.



First, egg polarity genes divide the egg along the anterior/posterior axis. This tells the egg where it will form a head and where it will form a tail.



Along this axis, segmentation genes divide the developing embryo into specific areas, or *segments*.



And then homeotic genes, called hox genes for short, give those areas a specific identity.

So, these developmental genes, in general, are very "conserved" in nature, meaning they don't mutate very much at all because when there is a mutation in one of these genes

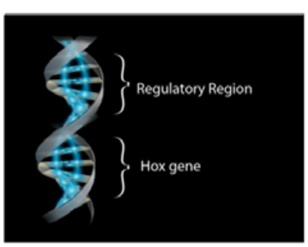
it affects this critical early development, which affects everything after that in the genetic cascade, and almost always results in an unsuccessful organism.

But the question remains, what part of DNA does create successful mutations? If not the very conserved egg polarity, segmentation, or hox genes, then what?

Well, this is what is currently being researched on the frontiers of evolutionary developmental science, called "evo-devo."

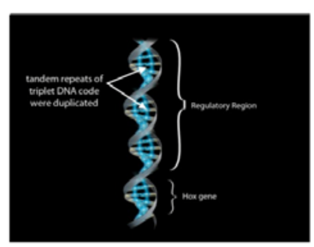
While conducting research at UTSW Medical Center in Dallas, evolutionary biologist Dr. Trey Fondon, discovered one possibility for how, or where, DNA mutates.

He studied many species of dog skulls and the variation in their morphology. He scanned the skulls with a 3d laser and found mathematical relationships in their shapes.

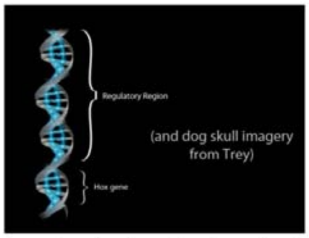


Ultimately, what he found in their DNA, were mutations in the regulatory regions just before, or upstream, from the hox genes controlling the skull morphology.

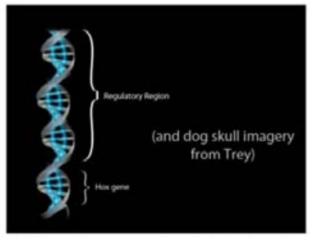
That's the place where all the transcription factors bind to DNA to transcribe it into mRNA and make developmental proteins for that hox gene.



The mutations he found were tandem repeats of triplet DNA code. This would allow for more or less transcription of developmental protein, which would affect skull morphology.



So over time, what changed was the number of tandem repeats of DNA code in the regulatory region upstream to the hox genes that controlled skull development.



Evolution almost never takes the simplest path, but that's what makes it so fascinating!

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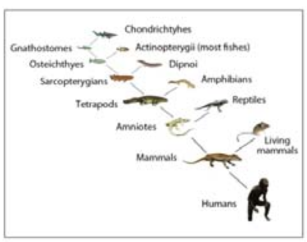
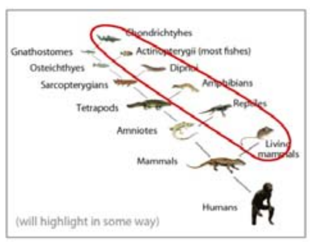
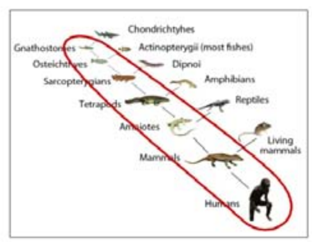
And there's so much more out there left to discover about how genes mutate and affect evolution.



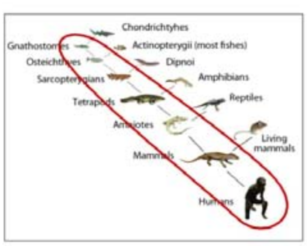
Meet your extended family tree for the last 400 million years.



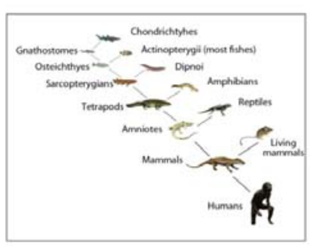
At these nodes are all the living species, that you can go observe today.



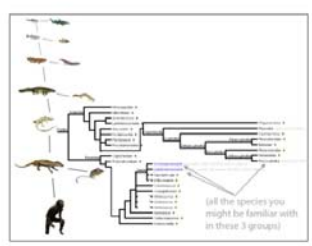
And at these nodes are representations of our common ancestors with these species.



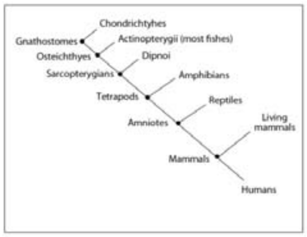
Every year, as we uncover more fossils and gain better technologies science is improving our understanding of what these ancestor species looked like. So these are visual estimates which



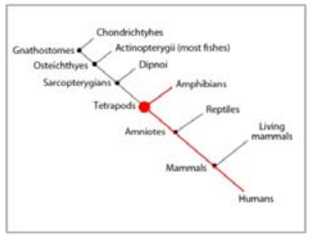
are becoming more definite over time. Also keep in mind that this is an incredibly simplified version of a phylogenetic tree. If we were to zoom in on just one of these branches we



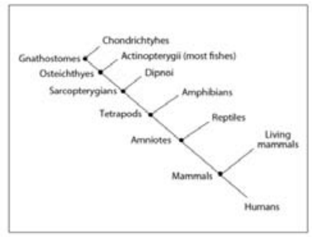
would see many smaller branches of species. And these 2 taxa contain all the crocodiles, dinosaurs, birds, lizards and snakes, so maybe you can just imagine how many branches there are



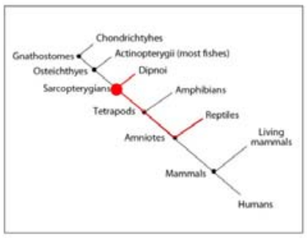
extending from just these 2 groups. Phylogenetic trees are often just represented like this, to simplify matters. So, where would you find our most recent common ancestor with Amphib



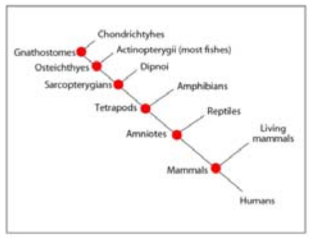
ians? The node representing Tetrapods is correct. Your genetic link to a frog or salamander was a four-limbed Tetrapod with air breathing lungs.



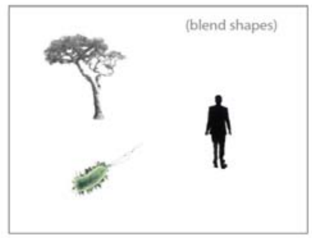
Now can you find the most recent common ancestor of Reptiles and Dipnoi?



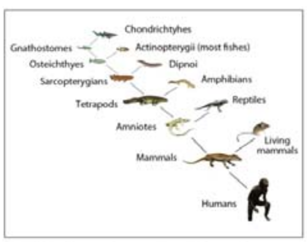
A Sarcopterygian fish was the common ancestor. It was also our ancestor.



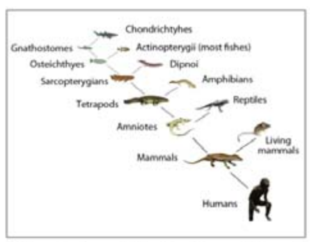
And because this represents a part of our lineage, it means that humans are also Mammals, Amniotes, Tetrapods, Sarcopterygians, Osteichthyes, and Gnathostomes.



But we are also so much more. Our DNA is a shared trait that relates us to all life, like trees and even bacteria.

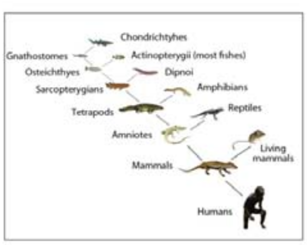


Which leads to the question, what is this so called "phylogenetic tree" based on? In other words, how do we know that the puzzle pieces fit together just like this?

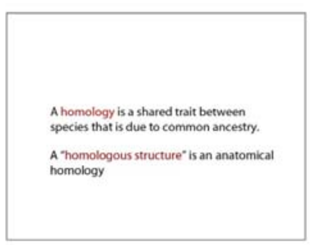


Well, a phylogenetic tree like this one is based on something called homologies.

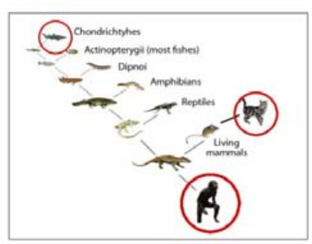
A homology is a shared trait between species that is due to common ancestry. Sometimes biologists refer to homologies as "synapomorphies."



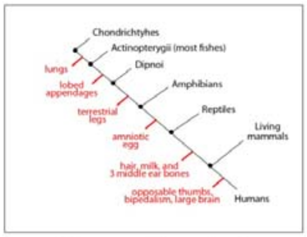
Traditionally, these phylogenetic trees were constructed based on anatomy and physiology, or structure and function.



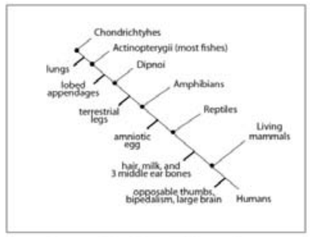
When a homology is structural, we call it a homologous structure. There is long history of anatomists who have compared all the little structures of a vast number of species.



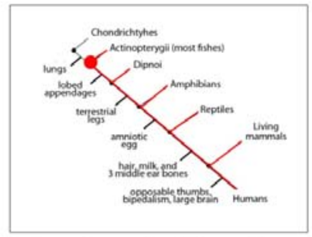
For instance, they can relate all the little nerves and blood vessels and bones in your body to all the little nerves and blood vessels and bones in a cat's body, or even a shark's body.



We can label our tree with some homologous structures like this. These are certainly not all the homologous structures, but just a few to give you an idea of how this works.

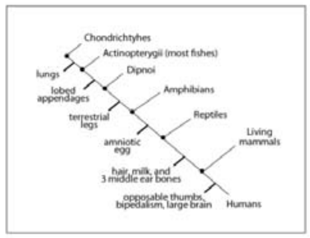


Now, when we label this with homologous structures, it means that every group after has that structure, or something homologous to that structure.

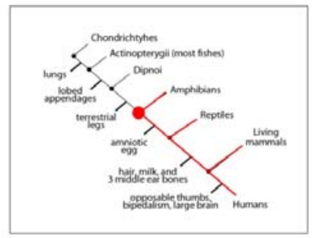


For instance lungs evolved with most fishes, so we can see that all Osteichthyans have lungs or structures that evolved from lungs.

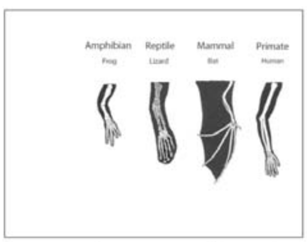
This means that all mammals, reptiles, and amphibians have lungs. But did you know almost all fish also have lungs, or swim bladders which evolved from lungs? It's true.



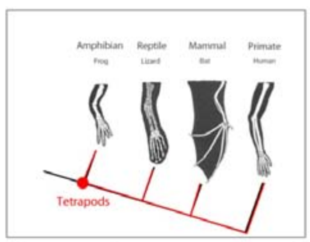
So, looking at the homologous structures on this phylogenetic tree, which group or groups have terrestrial legs?



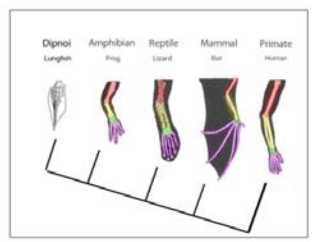
Yes, all tetrapods originally had legs that evolved to walk on land. That includes mammals, reptiles, and amphibians.



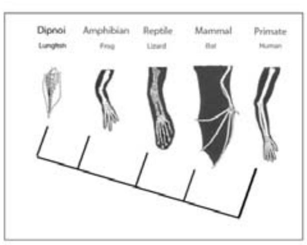
So we can say that your arms and legs are "homologous" to the arms and legs of any amphibian, reptile, or mammal.



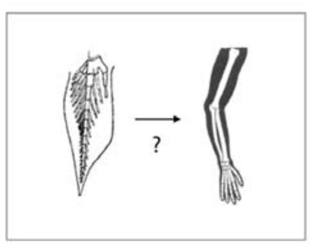
These are homologous structures; our ancestral tetrapod evolved legs that walked on land and amphibians, reptiles and mammals continued to evolve those legs.



Do you see how in all these limbs there is a very similar arrangement of bones? But then what about this fish fin? Pretty different arrangement right?

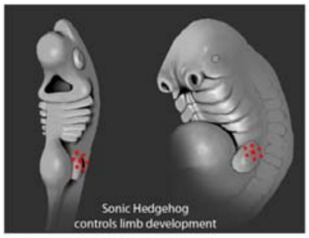


We do know, however, that our tetrapod limbs evolved from fish fins. But *how* do we know this?

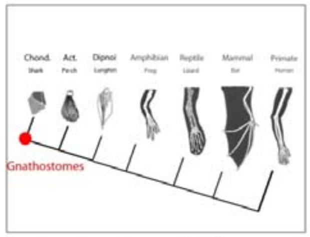


How do we know this when both the structure and function of fish fins are different than the structure and function of our arms and legs?

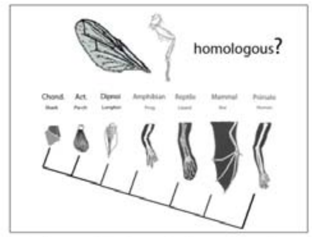
This is where current DNA research enters the picture. Remember those hox genes from the previous chapter, the ones that control those critical stages of embryological development?



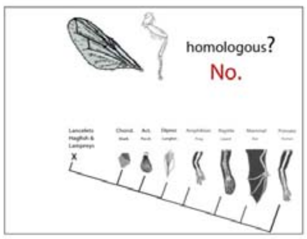
Well it just so happens that these hox genes regulate another gene called Sonic Hedgehog (named after the video game), which controls development of both fish fins and our arms and



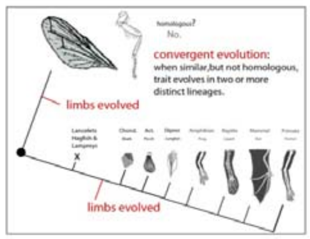
legs.So we know that even shark fins are genetically homologous to our arms and legs, which makes them homologous structures.So all "Gnathostomes," which are jawed vertebrates, and



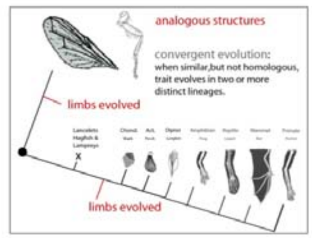
include everything from sharks to mammals, have homologous limbs. OK, so what about insect legs or wings? Are they homologous to all of these other homologous structures.



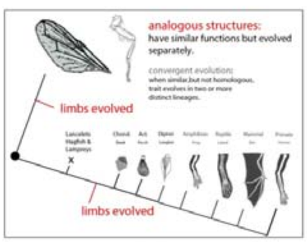
Actually, no. We can trace our phylogenetic lineage back to when our aquatic ancestors had no fins... *no limbs at all*. But our common ancestor with arthropods, including all insects,



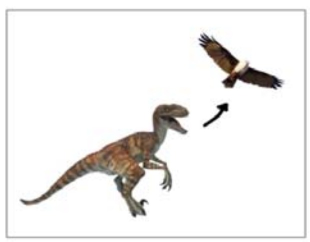
lived millions of years before this. So, the insects developed their limbs independently from ours in a process known as "convergent evolution":



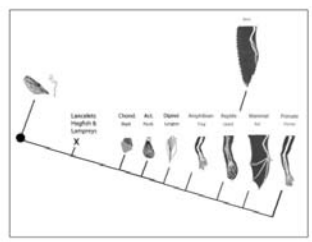
that's when a similar, but not homologous, trait evolves in two or more distinct lineages. And we call that trait an "analogous structure."



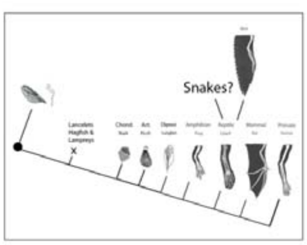
These are structures which have similar functions but evolved separately. Therefore, insect limbs and vertebrate limbs are called "analogous structures."



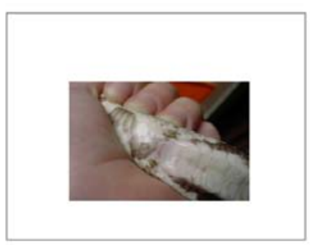
Now, I said all reptiles have limbs which are homologous to our limbs, right? And that includes birds because they are actually reptiles that evolved from dinosaurs.



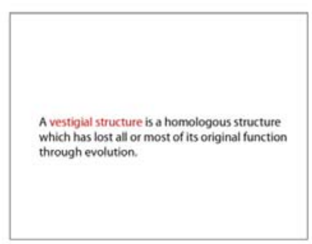
That's right... phylogenetically speaking, the dinosaurs are still roaming... and er, flying over... the planet. And their wings are analogous to insect wings but homologous to our arms.



But how about snakes? They're reptiles right? Where are the homologous limbs? They don't appear to have ANY limbs... or do they?

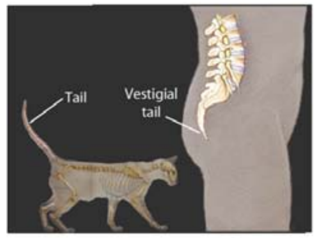


In truth, some snakes, like boas and pythons, do still develop little hind limbs when they're embryos, and the limbs remain as vestigial structures in the adult.



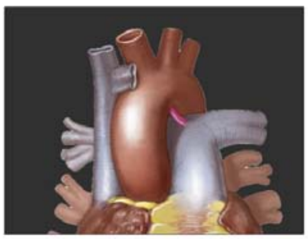
Now, a vestigial structure is a homologous structure which has lost all or most of its original function through evolution. So do humans have any vestigial structures?

Yeah, lots of 'em. First of all you're probably stitting on one right now. That little nubbin of a bone called a "tail bone" you got back there is homologous to the tails of all our vertebrate



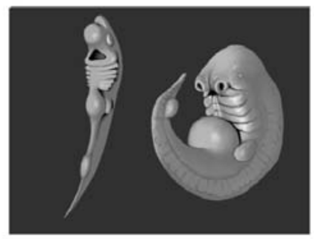
cousins, even the ones swimming in the ocean. But it's not much use to us any more, kinda like those limbs on snakes, so we call it a vestigial structure.

You even have vestigial blood vessels. Here's one in your heart, called the ductus arteriousus. It was useful for delivering blood in our fish ancestors, but for human adults... not so much.

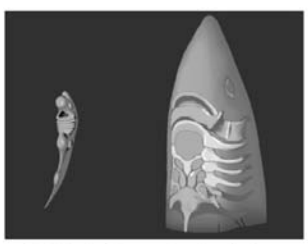


It closes up during our development and becomes, well, a vestigial structure.

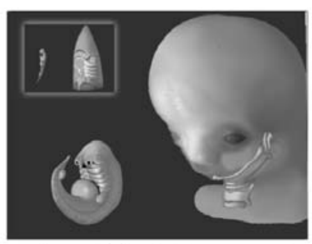
There's one more very fascinating human homology which you should know about: the pharyngeal arches.



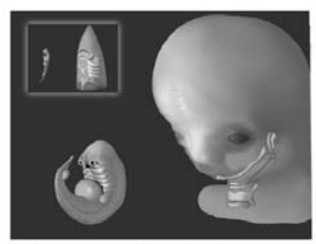
The pharyngeal arches look kinda like little gills, right? Here's a fish embryo during the same stage of development



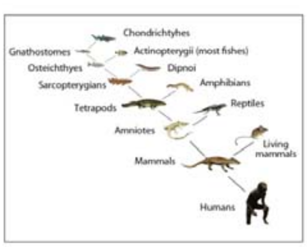
In adult fish the pharyngeal arches develop into jaws and gills, but since our development has evolved in another direction, gills not being so adaptive to breathing air on land,



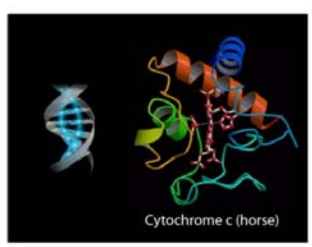
our pharyngeal arches develop into jaws and various structures in your neck. So, these bones and cartilages in your neck and the bones in fish gills are homologous structures.



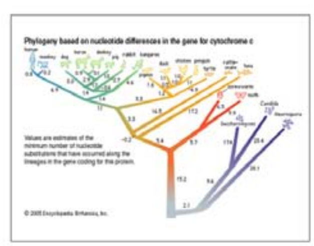
Our lower jaw, which forms from the 1st pharyngeal arch, is homologous also.



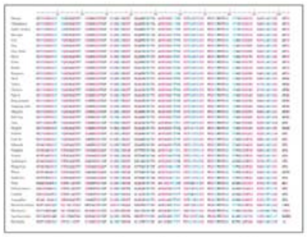
So, phylogenetic trees like this were traditionally figured out on the basis of all the homologous and vestigial structures between the groups.



But homologies between species don't have to be an anatomical structure. In fact, today by using *genetic homologies*, like DNA and protein similarities between species,



we are able to assemble even more accurate phlyogenetic trees. We have so much information on DNA sequences and protein structure and function that scientists now put all of this



information into a huge database, and let powerful computer programs run algorithms to construct the most accurate phylogenetic tree between species.

This is a field in biology called bioinformatics. It's where biology and math and computer science converge, and it's at the forefront of evolutionary scientific research.

APPENDIX D
Formative Evaluation

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

Do you think your students would connect with this content?

Would you be interested and enthused about teaching it, and using this as a discussion aid?

Make clear: Mutation (change) (accepted) fits into an environment. The mutant must pair with another same mutant then reproduce.

Are there any parts that you would rather me leave out completely?

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution... the list goes on)?

Will you use this when it's done?

You would make a great teacher.
- Voice.
- Pace
- Creativity

Feel free to share any other ideas or concerns:

Be real clear about the definition of Evolution.

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

Visuals & future interactivity

Do you think your students would connect with this content?

Yes - but some parts are beyond the scope of what I teach.

Would you be interested and enthused about teaching it, and using this as a discussion aid?

Yes.

Are there any parts that you would rather me leave out completely?

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution... the list goes on)?

Will you use this when it's done?

Feel free to share any other ideas or concerns:

Look forward to seeing finished product!

contact Pam Owen Tx Museum of Natural history

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

Do you think your students would connect with this content?

possibly

Would you be interested and enthused about teaching it, and using this as a discussion aid?

yes

Are there any parts that you would rather me leave out completely?

No

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution... the list goes on)?

possibly as add on choices to extend
sh

Will you use this when it's done?

yes

Feel free to share any other ideas or concerns:

Roxanne [illegible]

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

Evo-devo, the questions and answers are very informative. The vocabulary words.

Do you think your students would connect with this content?

Yes, this is long past due for today's students

Would you be interested and enthused about teaching it, and using this as a discussion aid?

Yes, this information is great! It gives students a "more" in your face" approach to learning this material. Especially in this "video age" we are living in today.

Are there any parts that you would rather me leave out completely?

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution... the list goes on)?

The parts that you covered is the most challenging to most students.

Will you use this when it's done?

Of course!

Feel free to share any other ideas or concerns:

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

The connection of evolution throughout history. Excited about animations with linkage.

Do you think your students would connect with this content?

Yes, needs a little mathematically connection w/ SA/V ratio.

Would you be interested and enthused about teaching it, and using this as a discussion aid?

Yes, I would use this as a great tool for Exit TAKS review for Juniors + Seniors that struggle w/ retention of concepts needed for exam

Are there any parts that you would rather me leave out completely?

NO

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution… the list goes on)?

might break down evolution down to even more basic common elements in organisms that link them together

Will you use this when it's done? Yes, definitely

Feel free to share any other ideas or concerns:

need a glossary for ESL students

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

· evo-devo
- students always are curious to know how we might be related to other species this is a great introduction and tool for the lesson

Do you think your students would connect with this content?

Yes, the idea of where we come from is still important and peaks the curiosity

Would you be interested and enthused about teaching it, and using this as a discussion aid?

Yes.

Are there any parts that you would rather me leave out completely?

no

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution… the list goes on)?

→ the Hardy-Weinberg principle is taught in AP Biology
→ malaria and sickle cell trait focus on the genetic disease and survival against

Will you use this when it's done?

yes

Feel free to share any other ideas or concerns.

the information is detailed but not over the top to where high school students can follow

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

Do you think your students would connect with this content?

YES IT IS A GREAT VISUAL REPRESENTATION FOR THE STUDENTS TO HELP THEM UNDERSTAND THE CONCEPTS

Would you be interested and enthused about teaching it, and using this as a discussion aid?

VERY MUCH SO

Are there any parts that you would rather me leave out completely?

EVERYTHING

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution… the list goes on)?

Will you use this when it's done?

YES TO TEACH ? TRAIN OTHER TEACHERS. I DO NOT TEACH EVOLUTION.

Feel free to share any other ideas or concerns:

Mechanisms' Natural Selection

* Visually define surface area and give mathematical examples so students can understand the calculation.
* Or graphs use numerical data
* Try to include another species that students can relate to such as a squirrel or rabbit,

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

Graphics used to explain, extend info. while building on prior knowledge of students.

Do you think your students would connect with this content?

Yes, definately my students will connect with the content about fossil record, Natural Selection and speciation.

Would you be interested and enthused about teaching it, and using this as a discussion aid?

Yes, I am very excited about your handout very basic, simple but informative, interesting and engaging.

Are there any parts that you would rather me leave out completely? No, I will not leave out anything.

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution... the list goes on)?

Genetic drift, gene flow, Hardy Weinberg principle including co-evolution.

Will you use this when it's done? Yes, Yes, definately. I love it

This is complicated for students to understand because of misconceptions & complexity of topic

Feel free to share any other ideas or concerns:

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

The SA/N tables and how it affects natural selection
Homologous structure tree

Do you think your students would connect with this content?

For the most part yes some above my students

Would you be interested and enthused about teaching it, and using this as a discussion aid?

I teach 7th grade and much is beyond what we do but I would use it to reinforce what they have learned + intro deeper topics. I may even use some in 7th for Evolution / Adaptation and in fossil record Geologic time scale

Are there any parts that you would rather me leave out completely?

no

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution... the list goes on)?

I do a lab on the peppered moth so that would be nice

Will you use this when it's done?

I would like to

Feel free to share any other ideas or concerns:

Very good, understandable, great reading voice

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic? Evo Devo

Do you think your students would connect with this content? Yes

Would you be interested and enthused about teaching it, and using this as a discussion aid? Yes

Are there any parts that you would rather me leave out completely? No

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution... the list goes on)?

Peppered Moth
Systematic coverage of Darwin
Hardy Weinberg Principle

Will you use this when it's done? Yes

Feel free to share any other ideas or concerns:

Reduce & simplify the $\frac{SA}{V}$ portion.

"over" →

Possible daily Lesson Cycle (Evolution)

1. Review previous day's material
2. Introduce & run animation for the day.
3. Discuss animation
4. Model hands on activities or lab for the day.
5. Hands on or lab time
6. Review hands on or lab activities

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

I liked the mix of real images, cartoons, graphs, & charts.

Do you think your students would connect with this content?

Great job with making deep/difficult subjects understandable —good level.

Would you be interested and enthused about teaching it, and using this as a discussion aid?

yes — I like that we can pause & discuss w/ class.

Are there any parts that you would rather me leave out completely?

no — everything was linked well & even revisited

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution... the list goes on)?

I think will both be tested on new Biology end-of-course test.

Will you use this when it's done?

yes — would love to just have the CD even w/o the rest of the suitcase.

Feel free to share any other ideas or concerns:

Allow teachers to teach which segments they want — some teachers are on block schedule & have longer class periods.

maybe check the new TEKS for Biology (now are more specific than before)

my plan would be
to show a segment
then discuss w/ class
& take notes
then move on to next segment

Cjacobsen @ mckinneyrsd.net

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

Do you think your students would connect with this content?

Would you be interested and enthused about teaching it, and using this as a discussion aid?

Are there any parts that you would rather me leave out completely?

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution… the list goes on)?

Will you use this when it's done?

Feel free to share any other ideas or concerns:

I like not having the math.
(Math) turns off many students.
Your presentation says give me
more.

Biology What grade ?

Great Morphology (Definition)
(a/morula) sounds like 1-word.
I don't

? Vocabulary at end.
Definition + your Visual

~~Not Covered~~ Developed ;

Vestigal Structures
- Would like to have
seen the word as
you pronounced it.

Most video's get so advanced only the
most gifted have a hard time following.

Please share your thoughts on my animatic for evolution. Eventually (this spring), it will be a full-fledged animation, but your critique on my **content** and **general flow of ideas** right now will help direct the final outcome for this project. Thank you.

What do you think are the most interesting parts in the animatic?

comparing embryos' development

Do you think your students would connect with this content? mostly but right now it's higher level than Freshman Biology - maybe Pre AP to AP level

Would you be interested and enthused about teaching it, and using this as a discussion aid? yes if it's in a good form esp. for freshman level

Are there any parts that you would rather me leave out completely? Don't get "argumentative" about whether evolution occurs or not. Just be matter-of-fact about natural selection - it occurs so address that. Also add about artificial selection - maybe follow dogs or other organisms along.

Is there anything that you think should definitely be added in terms of content for this animation (i.e., genetic drift, gene flow, Hardy Weinberg principle, malaria and sickle cell trait, peppered moth, a more systematic coverage of Darwinism, sexual selection, co-evolution... the list goes on)?

- pesticides and antibiotics

DNA homology - what most recent discoveries have been made on sequences (& also protein) eg: Chimp to human

Will you use this when it's done? definitely consider it

Feel free to share any other ideas or concerns: (1) Should get with Pam Owens (Owens) @ U.T.-Austin's (Texas Museum of Natural History) - she's involved in education of evolution and could give you some great ideas for this kit!

(2)

(2) could start with how dogs evolved through human intervention but still have ancestry (shared) with wolves. Still interbreed - can look at their traits as they were developed - hunting, herding, etc -

(3) can then look at dog genome homology to other organisms - since you brought in dog skulls

(4) don't use the human as the "top of the pyramid" - give the wrong impression that evolution is "goal oriented"

(5) more evidence for evolution needs to be added

(6) need more animations, not so much text, more figures, evolutions

(7) watch analogy - evolution is random but not chaotic - the fireworks analogy didn't work for me -

(8) and evolution isn't "selecting for more and more surface" → its the environment that selects the traits resulting in evolution.

(9) Don't express evolution as "goal-oriented" its just adaptation to the environment

(10) emphasize the genetic mutations

STARS

Inservice: Science Suitcases

Evaluation Form

Thank you for attending this inservice. We hope that the experience has been a useful one. Your input is extremely important to us as we strive to improve the STARS Program. Please take a moment to give us some feedback on the following topics.

Name (optional) Rudy Shipp School Boswell H.S.

- How did you hear about this event?
  - ☐ STARS Newsletter
  - ☒ STARS Calendar
  - ☒ STARS Web Page
  - ☐ Email
  - ☐ Another Teacher
  - ☐ Lead Science Teacher
  - ☐ Science Supervisor
  - ☐ Other ____________
- Grade(s) Taught 9-12 • Subject(s) Taught Science
- Years Teaching Experience 25 • How many previous STARS events have you attended? many all of them
- Why did you decide to attend this symposium? (check all that apply)
  - ☒ Topic sounded interesting
  - ☒ Needed professional development hours
  - ☒ Wanted to increase science knowledge base
  - ☒ Looking for some new teaching ideas
  - ☐ Other ____________

See Back of Page for Ordering Free DVD of Today's Presentations.

- Please rate each of today's presentations with the understanding that these presentations are geared for teacher content professional development and would need modification(s) for use in the classroom. Please place an **(X)** next to the appropriate box.

	Strongly disagree	Disagree	Undecided	Agree	Strongly Agree	
The presentation was appropriate in depth.				X		Dr. Wright
The presentation was clear.				X		Dr. Wright
The presenter kept your interest.				X		Dr. Wright
There is a strong level of relevance to the classroom.			X			Dr. Wright
I gained knowledge from the presentation.				X		Dr. Wright
I intend to recommend this to other teachers.				X		Dr. Wright

• Please comment on today's presentations and activities.

I enjoyed the preview of the evolution Suitcase,

• In what ways do you plan to use the information presented today in your classroom? What was most useful/interesting? What was least useful/interesting?

I am adding a new lab on natural selection, Division plane control in Plants, upcoming evolution Suitcase

• What are some topics that you would like to see covered at future symposia? Please check all that apply.

- [x] Mental Disorders/ Neurological Diseases
- [ ] Metabolic Diseases
- [ ] Cardiovascular Disease/Stroke
- [x] Body Systems
- [ ] Pathogens/Microbes
- [x] Genetics/DNA/Mutations
- [ ] Biochemistry
- [ ] Cellular Processes
- [ ] Other__________

• In what ways can we improve the Basic Science Symposia or the STARS Program in general?

- [ ] Discussion Panels
- [ ] Breakout Sessions
- [x] Interactive Activities
- [ ] Lab Visits
- [x] Demonstrations
- [ ] Other__________

Request additional information: Please check the boxes that apply and make sure your name and school are written below.

- [x] DVD of today's presentation.
- [ ] Virtual Instrument CD
- [ ] Science Suitcases (portable labs)
- [ ] Summer Research Program
- [ ] Other__________
- [ ] STARS Calendar
- [ ] STARS Newsletter
- [ ] Student Medical Tours
- [ ] Exploring Post

• If you would like additional information or have any other requests, please fill in the information below.

Name Randy Shipp

School Boswell HS

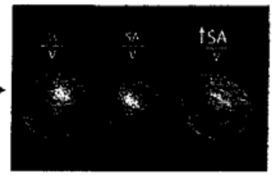
School Phone (817) 237-3314 setting new extension

E-mail rshipp@ems-isd.net

May we use your comments in our future publications? [x] Yes [ ] No

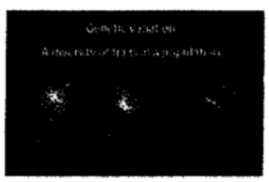
RS

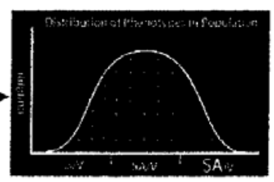
Mechanisms: Natural Selection and Speciation



Let's say we have a population of microscopic organisms, and they are multicellular. When we look more closely at their trait for surface area to volume ratio, we discover that there are 3 different types, or 3 different "phenotypes" to be more exact. So let's discuss the different types. One has a low surface area to volume ratio. In other words, the outer surface is about as small as it can get for this volume. The type beside it has the same volume, but because the outer surface has expanded, and folded in a little bit, it has more surface area. Therefore it has more surface area per volume. The last one, with a deep invagination, has the most surface area per volume, and therefore the largest surface area to volume ratio.

Comments: wauld like more of an introduction before you start into SA/V ratio. What is the point of explaining this : how is this relevant to a teenager's life?

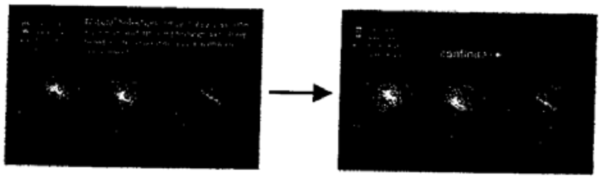




And because our population has this "diversity" of traits, we say it has genetic variation. Look around your classroom, it's a population. Does anyone look exactly the same? Unless your class has identical twins, probably not. So the population of your classroom has genetic variation, just like this one. This variation can be plotted on a distribution curve, so we can see that most of our population has an average SA/V ratio. But few individuals have a very low or a very high SA/V ratio. So, now that we've analyzed our 3 phenotypes for this trait, and placed them on a distribution curve, let's see what happens with selective pressures from an environment.

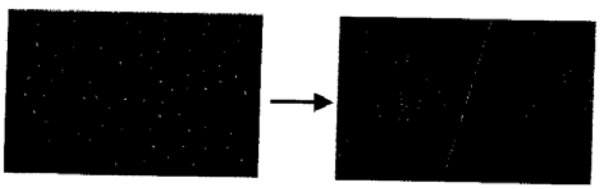
Comments:

Mechanisms: Natural Selection and Speciation



(The Natural Selection Menu part).

Comments:

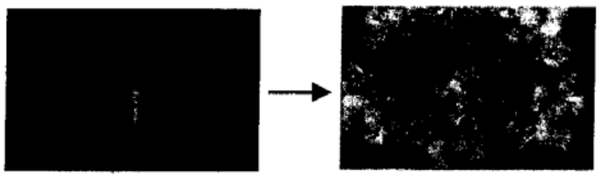


Now we've seen how different environments can select for different individuals in a population. But what happens if a population splits into 2 by occupying different environments? Let's say one group gets carried off by water currents, so that they are now geographically isolated from the other group. They reproduce, and with each generation, random mutations in DNA cause little developmental changes in the offspring that set them slightly apart from their parents. Because the two groups are now in different environments, they have different selective pressures. As you have seen, these pressures select different individuals. Then those reproduce, and over millions of years of random mutation and natural selection, many species can evolve from what started as one population of organisms.

Comments:

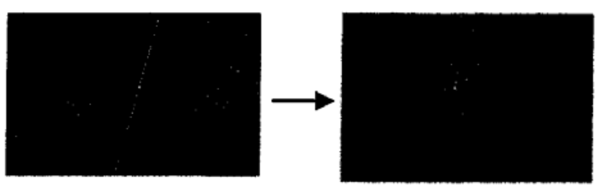
I'm not sure the students would understand the graphics here. ~~Et~~ Using a more creature-like graphic that changes slowly might be easier to understand. ???

Mechanisms: Natural Selection and Speciation



Comments:

In this way, evolution is sort of like a fireworks display. In fact, it's like one very long, messed up firework. Let's call our rocket here, the first generation. When it reproduces, it's like an explosion of DNA with little random mutations in all directions. This would be the 2nd generation. But the wind has picked up, and there's a little moisture in the air, so some of the embers diffuse and fade away. That's just natural selection. However, some of them create new explosions of DNA, resulting in the 3rd generation, which has different shapes and colors that set it apart from the preceding generation. That is what evolution is like: one big, continuous, out of control, fireworks display.

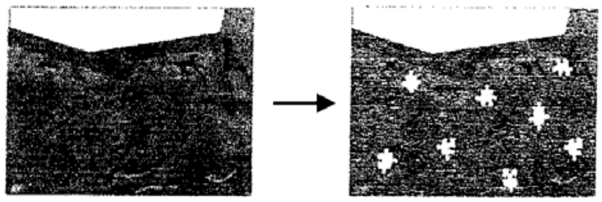


Comments:

I like the connection to humans. I would probably use this when I first introduce SA/V ratios when introducing cells/cell size.

In our lineage, one of these populations of little multicellular, microscopic organisms, gradually formed a gut. And what does a gut do in terms of surface area to volume ratio? Well a gut can catch and hold even more food, right? So, we can say that it increases the SA/V ratio to maximize the absorption of nutrients. Over millions of years, one of these populations of multicellular organisms with a gut, evolved into little worms, with longer guts. So, let's see the human gut in comparison to this worm gut. Now, why do you think our digestive tract has all those twists and turns and loops and compartments? Well, aside from more specialized digestion, it REALLY increases the SA/V ratio, right?! It really increases the amount of nutrients you can get from food. But that's not the only way your gut has evolved to increase SA/V ratio. On the tissue level, it has all these all these little bumps and folds. So, what do you think is the function of these little bumps and folds? Well, these would increase absorption by increasing SA/V ratio., right? If we zoom in, we see smaller bumps and folds, and this also increases absorption by increasing SA/V ratio. In fact, each individual cell on your digestive surface, also has even smaller bumps and folds, which also increase SA/V ratio! The surface area of your digestive tract is about the size of a tennis court. But evolution of SA/V ratio is not limited to your digestive tract. Many of the tissues in your body have evolved to increase SA/V ratio to increase absorption or connectivity, or some other function. Again, think of this as evolution's way of selecting for more and more surface crammed into a limited volume.

The Fossil Record

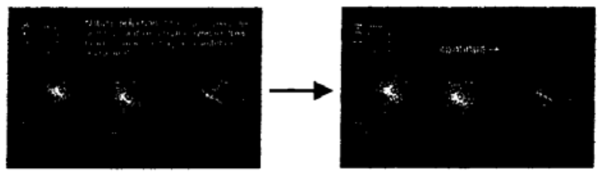


Comments:

Now, tectonic shifts (think massive earthquakes, volcanic eruptions, continental drift) have in specific areas, disrupted the layers, but geologists can still discern the pattern of rocks and, remember, they can use radiometric dating to confirm the identity of the layer. This is how scientists are able to create vast and intricate geological maps, which evolutionary biologists can then use to find certain fossils. For instance, if they are searching for dinosaur fossils they will know in which layer to look. However, if they were looking for human fossils they wouldn't find any in this layer because the rocks are too old and humans hadn't evolved yet. Rather, they would know to look in newer rocks to find human fossils. In a sense, the entire field of Evolution is like a giant jigsaw puzzle. We've put enough pieces together to know it's there, but there are many pieces that have yet to be found.

like this analogy

Mechanisms: Natural Selection and Speciation



(The Natural Selection Menu part).

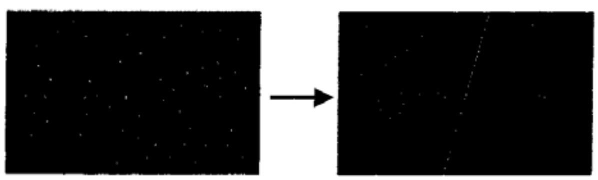
I like to use lots of examples of different curves - this is good as another ex

Comments:

I like this idea. I do explain cell size SA/V ratio for cubes and then changing shape to rectangle w) same volume but greater SA I have animation which shows changes for cubes.

} suggest experiments done before (diffusion/agar cubes)

I like different scenario options

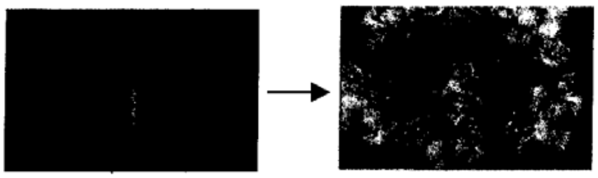


Now we've seen how different environments can select for different individuals in a population. But what happens if a population splits into 2 by occupying different environments? Let's say one group gets carried off by water currents, so that they are now geographically isolated from the other group. They reproduce, and with each generation, random mutations in DNA cause little developmental changes in the offspring that set them slightly apart from their parents. Because the two groups are now in different environments, they have different selective pressures. As you have seen, these pressures select different individuals. Then those reproduce, and over millions of years of random mutation and natural selection, many species can evolve from what started as one population of organisms.

Comments:

α different colors to disting. diff pop

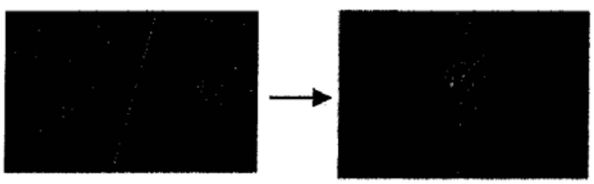
Mechanisms: Natural Selection and Speciation



Comments:

analogy OK

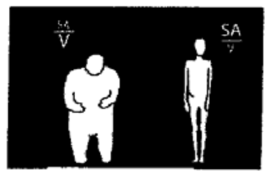
In this way, evolution is sort of like a fireworks display. In fact, it's like one very long, messed up firework. Let's call our rocket here, the first generation. When it reproduces, it's like an explosion of DNA with little random mutations in all directions. This would be the 2nd generation. But the wind has picked up, and there's a little moisture in the air, so some of the embers diffuse and fade away. That's just natural selection. However, some of them create new explosions of DNA, resulting in the 3rd generation, which has different shapes and colors that set it apart from the preceding generation. That is what evolution is like: one big, continuous, out of control, fireworks display.



Comments:

In our lineage, one of these populations of little multicellular, microscopic organisms, gradually formed a gut. And what does a gut do in terms of surface area to volume ratio? Well a gut can catch and hold even more food, right? So, we can say that it increases the SA/V ratio to maximize the absorption of nutrients. Over millions of years, one of these populations of multicellular organisms with a gut, evolved into little worms, with longer guts. So, let's see the human gut in comparison to this worm gut. Now, why do you think our digestive tract has all those twists and turns and loops and compartments? Well, aside from more specialized digestion, it REALLY increases the SA/V ratio, right?! It really increases the amount of nutrients you can get from food. But that's not the only way your gut has evolved to increase SA/V ratio. On the tissue level, it has all these all these little bumps and folds. So, what do you think is the function of these little bumps and folds? Well, these would increase absorption by increasing SA/V ratio., right? If we zoom in, we see smaller bumps and folds, and this also increases absorption by increasing SA/V ratio. In fact, each individual cell on your digestive surface, also has even smaller bumps and folds, which also increase SA/V ratio! The surface area of your digestive tract is about the size of a tennis court. But evolution of SA/V ratio is not limited to your digestive tract. Many of the tissues in your body have evolved to increase SA/V ratio to increase absorption or connectivity, or some other function. Again, think of this as evolution's way of selecting for more and more surface crammed into a limited volume.

Mechanisms: Natural Selection and Speciation



And we also see SA/V ratio showing the macro effects of evolution on the Earth's geographical distribution of humans. Did you know that the average human has a higher SA/V ratio the closer you get to the equator? It's true. Over thousands of years, humans have adapted to different environments. Humans nearer the equator generally have longer arms and legs and smaller torsos and frames. Whereas, the farther you get from the equator, the more humans there are that have stockier frames and shorter arms and legs. Why do you think that is? You know it has something to do with SA/V ratio. So, do the humans with longer arms and legs and smaller torsos have a higher or lower SA/V ratio? Higher, right? And the stockier humans have a lower SA/V ratio. Can you think of an environmental factor, near the equator, that might have selected for this trait?

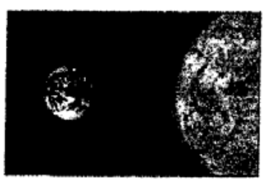
Comments:

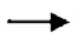
show examples of similar organisms expressing same traits

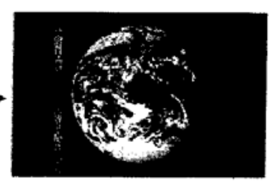
arctic - ears, nose, body morph

equator " "

pause for student answer







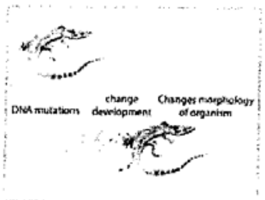
Well, the temperatures are generally much hotter near the equator. And the farther you get from the equator, the colder it gets. So the environmental factor is the climate, which selects for humans with higher or lower SA/V ratio, depending on where they are relative to the equator. People with a higher SA/V ratio are genetically more adapted to to release heat. This is beneficial in hotter climates nearer the equator. People with a higher SA/V ratio are genetically more adapted to to release heat. This is benefical in hotter climates nearer the equator. While people with a lower SA/V ratio are genetically more adapted to retain heat. This is beneficial in colder climates farther from the equator. Even with modern dwellings, transportation, air conditioning and technology we can observe the effects of evolution, due to climate, on the entire human population.

Comments:

suggest experiments before this module.

temperature exchange

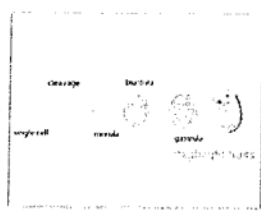
Evo-devo



What does embryology have to do with evolution? We know that DNA mutations in the germ-line cells, that is the egg and sperm, cause changes in the development of the offspring and this changes the morphology, or form and structure, of the adult organism. And over hundreds of millions of years the changes in morphology can gradually become very great.

Comments:

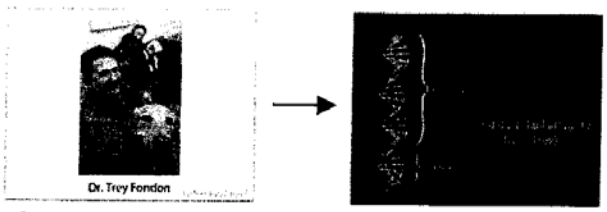
Might want to explain what embryology is, before starting.



But how does this show relationships between the species? Well, did you know our embryology still has a lot in common with our recent relatives: like all vertebrates for instance. We all go through very similar stages of development. We see the following pattern in all fish, amphibians, reptiles and mammals (including humans). First there comes a fertilized egg which starts off as a single cell. That cell divides to form two cells in the cleavage stage, and then many cells in a stage called a morula. This ball of cells forms a cavity, becoming hollow, and goes through a stage called a blastula. The blastula develops a little hole, which becomes either the mouth or anus, and forms 3 layers of tissue (called endoderm, mesoderm and ectoderm), thereby becoming a gastrula. And then this develops into a little guy with a head, eyes, pharyngeal arches (we'll talk about those later), 4 limbs and a notochord.

Comments:

Evo-devo



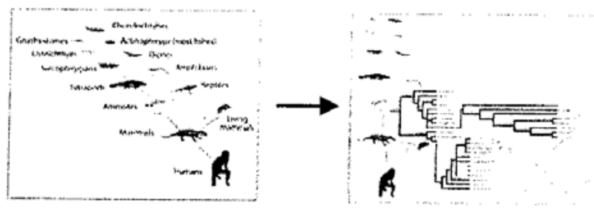
But the question remains, what part of DNA does create successful mutations? If not the very conserved egg polarity, segmentation, or hox genes, then what? Well, this is what is currently being researched on the frontiers of evolutionary developmental science, called "evo-devo." While conducting research at UTSW Medical Center in Dallas, evolutionary biologist Dr. Trey Fondon, discovered one possibility for how, or where, DNA mutates. He studied many species of dog skulls and the variation in their morphology. He scanned the skulls with a 3d laser and found mathematical relationships in their shapes. Ultimately, what he found in their DNA, were mutations in the regulatory regions just before, or upstream, from the hox genes controlling the skull morphology. That's the place where all the transcription factors bind to DNA to transcribe it into mRNA and make developmental proteins for that hox gene. The mutations he found were tandem repeats of triplet DNA code. This would allow for more or less transcription of developmental protein, which would affect skull morphology. So over time, what changed was the number of tandem repeats of DNA code in the regulatory region upstream to the hox genes that controlled skull development. Evolution almost never takes the simplest path, but that's what makes it so fascinating! And there's so much more out there left to discover about how genes mutate and affect evolution.

Comments:

Explain morphology

My 9th graders would get lost w/ this info but I like including the latest research. Is there any way to simplify this but have a place to click for "more explanation"??

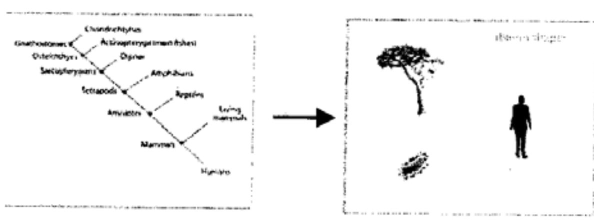
Phylogeny and Homology



Meet your extended family tree for the last 400 million years. At these nodes are all the living species, that you can go observe today. And at these nodes are representations of our common ancestors with these species. Every year, as we uncover more fossils and gain better technologies science is improving our understanding of what these ancestor species looked like. So these are visual estimates which are becoming more definite over time. Also keep in mind that this is an incredibly simplified version of a phylogenetic tree. If we were to zoom in on just one of these branches we would see many smaller branches of species. And these 2 taxa contain all the crocodiles, dinosaurs, birds, lizards and snakes, so maybe you can just imagine how many branches there are extending from just these 2 groups.

Comments:

I like how you show that these trees are much more complex



Phylogenetic trees are often just represented like this, to simplify matters. So, where would you find our most recent common ancestor with Amphibians? The node representing Tetrapods is correct. Your genetic link to a frog or salamander was a four-limbed Tetrapod with air breathing lungs. Now can you find the most recent common ancestor of Reptiles and Dipnoi? A Sarcopterygian fish was the common ancestor. It was also our ancestor. And because this represents a part of our lineage, it means that humans are also Mammals, Amniotes, Tetrapods, Sarcopterygians, Osteichthyes, and Gnathostomes. But we are also so much more. Our DNA is a shared trait that relates us to all life, like trees and even bacteria.

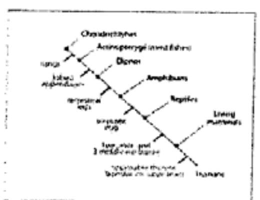
Comments:

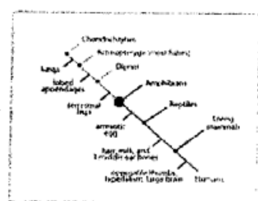
I like the questions of how to read tree. This is TAKS type questioning.

Phylogeny and Homology

Comments:

Which leads to the question, what is this so called "phylogenetic tree" based on? In other words, how do we know that the puzzle pieces fit together just like this? Well, a phylogenetic tree like this one is based on something called homologies. A homology is a shared trait between species that is due to common ancestry. Sometimes biologists refer to homologies as "synapomorphies." Traditionally, these phylogenetic trees were constructed based on anatomy and physiology, or structure and function. When a homology is structural, we call it a homologous structure. There is long history of anatomists who have compared all the little structures of a vast number of species. For instance, they can relate all the little nerves and blood vessels and bones in your body to all the little nerves and blood vessels and bones in a cat's body, or even a shark's body.



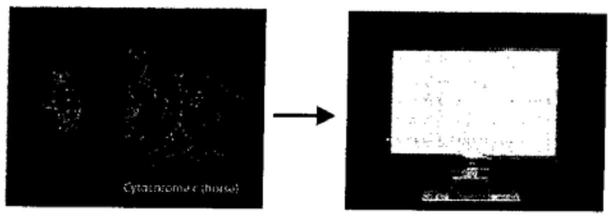


Comments:

Where is this label on the tree? Confusing.

We can label our tree with some homologous structures like this. These are certainly not all the homologous structures, but just a few to give you an idea of how this works. Now, when we label this with homologous structures, it means that every group after has that structure, or something homologous to that structure. For instance lungs evolved with most fishes, so we can see that all Osteichthyans have lungs or structures that evolved from lungs. This means that all mammals, reptiles, and amphibians have lungs. But did you know almost all fish also have lungs, or swim bladders which evolved from lungs? It's true. So, looking at the homologous structures on this phylogenetic tree, which group or groups have terrestrial legs? Yes, all tetrapods originally had legs that evolved to walk on land. That includes mammals, reptiles, and amphibians.

Phylogeny and Homology



Comments:

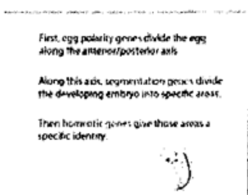
Love the connection to technology.

So, phylogenetic trees like this were traditionally figured out on the basis of all the homologous and vestigial structures between the groups. But homologies between species don't have to be an anatomical structure. In fact, today by using *genetic homologies*, like DNA and protein similarities between species, we are able to assemble even more accurate phlyogenetic trees. We have so much information on DNA sequences and protein structure and function that scientists now put all of this information into a huge database, and let powerful computer programs run algorithms to construct the most accurate phylogenetic tree between species. This is a field in biology called bioinformatics. It's where biology and math and computer science converge, and it's at the forefront of evolutionary scientific research.

Evo-devo

Comments:

So, how is it that our development has so much in common with all these other species? The answer is that the specific genes, in our DNA, which control development, are essentially identical to the genes in these other species. We still have a lot of the same genes with the same developmental functions. These genes include egg polarity genes, segmentation genes, and homeotic genes, or hox genes. Basically they encode transcription factors which *transcribe* the next set of genes in the genetic cascade. This genetic cascade is just like the domino effect.



Comments:

I like this

First, egg polarity genes divide the egg along the anterior/posterior axis. This tells the egg where it will form a head and where it will form a tail. Along this axis, segmentation genes divide the developing embryo into specific areas, or *segments*. And then homeotic genes, called hox genes for short, give those areas a specific identity. So, these developmental genes, in general, are very "conserved" in nature, meaning they don't mutate very much at all because when there is a mutation in one of these genes it affects this critical early development, which affects everything after that in the genetic cascade, and almost always results in an unsuccessful organism.

Evo-devo

Dr. Trey Fondon

Comments:

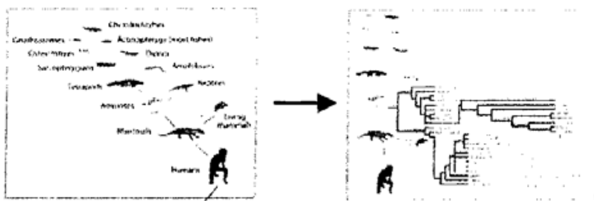
But the question remains, what part of DNA does create successful mutations? If not the very conserved egg polarity, segmentation, or hox genes, then what? Well, this is what is currently being researched on the frontiers of evolutionary developmental science, called "evo-devo." While conducting research at UTSW Medical Center in Dallas, evolutionary biologist Dr. Trey Fondon, discovered one possibility for how, or where, DNA mutates. He studied many species of dog skulls and the variation in their morphology. He scanned the skulls with a 3d laser and found mathematical relationships in their shapes. Ultimately, what he found in their DNA, were mutations in the regulatory regions just before, or upstream, from the hox genes controlling the skull morphology. That's the place where all the transcription factors bind to DNA to transcribe it into mRNA and make developmental proteins for that hox gene. The mutations he found were tandem * repeats of triplet DNA code. This would allow for more or less transcription of developmental protein, which would affect skull morphology. So over time, what changed was the number of tandem repeats of DNA code in the regulatory region upstream to the hox genes that controlled skull development. Evolution almost never takes the simplest path, but that's what makes it so fascinating! And there's so much more out there left to discover about how genes mutate and affect evolution.

did you see TV shows on development of cats dogs – showed variations in genes for different breeds & tied it into tandem repeats

National Geo or Animal Planet

I may have taped – rleitner@ursulinedallas.org 469-232-1869

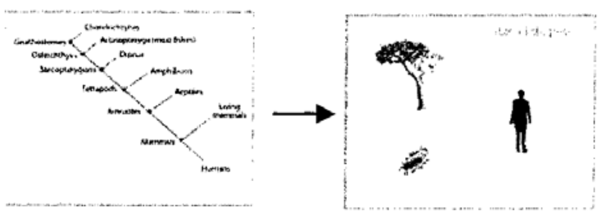
Phylogeny and Homology



Comments:

maybe use
human sitting at computer

Meet your extended family tree for the last 400 million years. At these nodes are all the living species, that you can go observe today. And at these nodes are representations of our common ancestors with these species. Every year, as we uncover more fossils and gain better technologies science is improving our understanding of what these ancestor species looked like. So these are visual estimates which are becoming more definite over time. Also keep in mind that this is an incredibly simplified version of a phylogenetic tree. If we were to zoom in on just one of these branches we would see many smaller branches of species. And these 2 taxa contain all the crocodiles, dinosaurs, birds, lizards and snakes, so maybe you can just imagine how many branches there are extending from just these 2 groups.



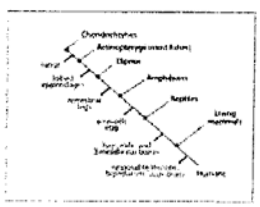
Comments:

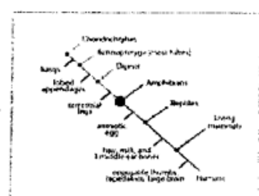
Phylogenetic trees are often just represented like this, to simplify matters. So, where would you find our most recent common ancestor with Amphibians? The node representing Tetrapods is correct. Your genetic link to a frog or salamander was a four-limbed Tetrapod with air breathing lungs. Now can you find the most recent common ancestor of Reptiles and Dipnoi? A Sarcopterygian fish was the common ancestor. It was also our ancestor. And because this represents a part of our lineage, it means that humans are also Mammals, Amniotes, Tetrapods, Sarcopterygians, Osteichthyes, and Gnathostomes. But we are also so much more. Our DNA is a shared trait that relates us to all life, like trees and even bacteria.

Phylogeny and Homology

Comments:

Which leads to the question, what is this so called "phylogenetic tree" based on? In other words, how do we know that the puzzle pieces fit together just like this? Well, a phylogenetic tree like this one is based on something called homologies. A homology is a shared trait between species that is due to common ancestry. Sometimes biologists refer to homologies as "synapomorphies." Traditionally, these phylogenetic trees were constructed based on anatomy and physiology, or structure and function. When a homology is structural, we call it a homologous structure. There is long history of anatomists who have compared all the little structures of a vast number of species. For instance, they can relate all the little nerves and blood vessels and bones in your body to all the little nerves and blood vessels and bones in a cat's body, or even a shark's body.



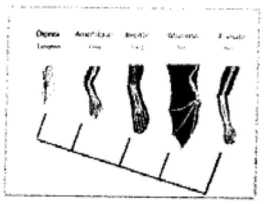


Comments:

Would need some explanation

We can label our tree with some homologous structures like this. These are certainly not all the homologous structures, but just a few to give you an idea of how this works. Now, when we label this with homologous structures, it means that every group after has that structure, or something homologous to that structure. For instance lungs evolved with most fishes, so we can see that all Osteichthyans have lungs or structures that evolved from lungs. This means that all mammals, reptiles, and amphibians have lungs. But did you know almost all fish also have lungs, or swim bladders which evolved from * lungs? It's true. So, looking at the homologous structures on this phylogenetic tree, which group or groups have terrestrial legs? Yes, all tetrapods originally had legs that evolved to walk on land. That includes mammals, reptiles, and amphibians.

Phylogeny and Homology



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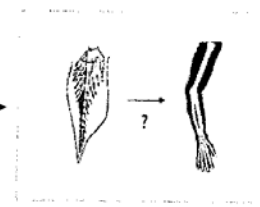
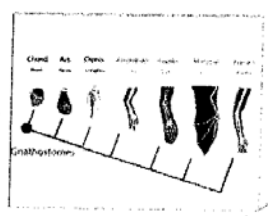


Comments:

So we can say that your arms and legs are "homologous" to the arms and legs of any amphibian, reptile, or mammal. These are homologous structures; our ancestral tetrapod evolved legs that walked on land and amphibians, reptiles and mammals continued to evolve those legs. Do you see how in all these limbs there is a very similar arrangement of bones? But then what about this fish fin? Pretty different arrangement right? We do know, however, that our tetrapod limbs evolved from fish fins. But *how* do we know this? How do we know this when both the structure and function of fish fins are different than the structure and function of our arms and legs?

→



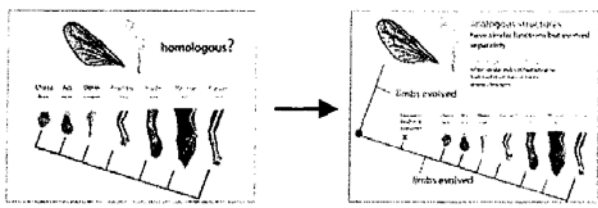
Comments:

This is where current DNA research enters the picture. Remember those hox genes from the previous chapter, the ones that control those critical stages of embryological development? Well it just so happens that these hox genes regulate another gene called Sonic Hedgehog (named after the video game), which controls development of both fish fins and our arms and legs. So we know that even shark fins are genetically homologous to our arms and legs, which makes them homologous structures.So all "Gnathostomes," which are jawed vertebrates, and include everything from sharks to mammals, have homologous limbs.

saw this on TV.

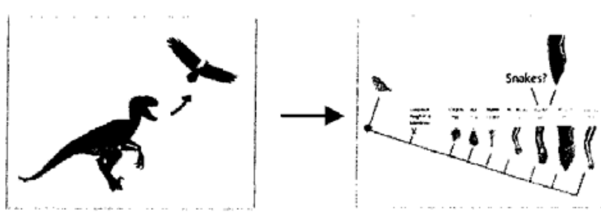
Animal Planet ?
Wild & Freaky
Animals w/ abnormalities such as cyclops, etc.
diff btwn conjoined/parasitic twins and problems w/ genes.

Phylogeny and Homology



Comments:

OK, so what about insect legs or wings? Are they homologous to all of these other homologous structures? Actually, no. We can trace our phylogenetic lineage back to when our aquatic ancestors had no fins... *no limbs at all*. But our common ancestor with arthropods, including all insects, lived millions of years before this. So, the insects developed their limbs independently from ours in a process known as "convergent evolution": that's when a similar, but not homologous, trait evolves in two or more distinct lineages. And we call that trait an "analogous structure." These are structures which have similar functions but evolved separately. Therefore, insect limbs and vertebrate limbs are called "analogous structures."

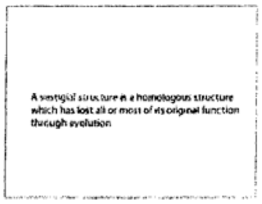


Comments:

liked this – have activities

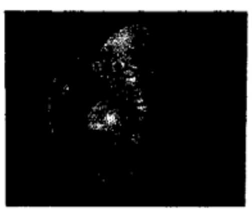
Now, I said all reptiles have limbs which are homologous to our limbs, right? And that includes birds because they are actually reptiles that evolved from dinosaurs. That's right... phylogenetically speaking, the dinosaurs are still roaming... and er, flying over... the planet. And their wings are analogous to insect wings but homologous to our arms.

Phylogeny and Homology



Comments:

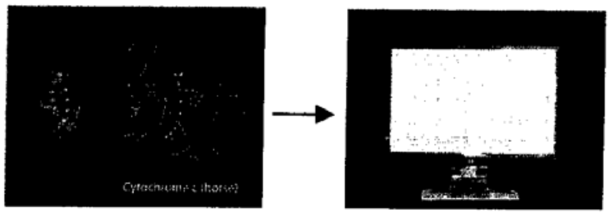
But how about snakes? They're reptiles right? Where are the homologous limbs? They don't appear to have ANY limbs... or do they? In truth, some snakes, like boas and pythons, do still develop little hind limbs when they're embryos, and the limbs remain as vestigial structures in the adult. Now, a vestigial structure is a homologous structure which has lost all or most of its original function through evolution. So do humans have any vestigial structures? Yeah, lots of 'em. First of all you're probably stitting on one right now. That little nubbin of a bone called a "tail bone" you got back there is homologous to the tails of all our vertebrate cous ins, even the ones swimming in the ocean. But it's not much use to us any more, kinda like those limbs on snakes, so we call it a vestigial structure. You even have vestigial blood vessels. Here's one in your heart, called the ductus arteriousus. It was useful for delivering blood in our fish ancestors, but for human adults... not so much. It closes up during our development and becomes, well, a vestigial structure.



Comments: really liked this

There's one more very fascinating human homology which you should know about: the pharyngeal arches. The pharyngeal arches look kinda like little gills, right? Here's a fish embryo during the same stage of development In adult fish the pharyngeal arches develop into jaws and gills, but since our development has evolved in an other direction, gills not being so adaptive to breathing air on land, our pharyngeal arches develop into jaws and various structures in your neck. So, these bones and cartilages in your neck and the bones in fish gills are homologous structures. Our lower jaw, which forms from the 1st pharyngeal arch, is homologous also.

Phylogeny and Homology



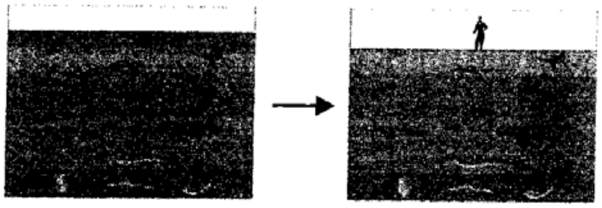
So, phylogenetic trees like this were traditionally figured out on the basis of all the homologous and vestigial structures between the groups. But homologies between species don't have to be an anatomical structure. In fact, today by using *genetic homologies*, like DNA and protein similarities between species, we are able to assemble even more accurate phlyogenetic trees. We have so much information on DNA sequences and protein structure and function that scientists now put all of this information into a huge database, and let powerful computer programs run algorithms to construct the most accurate phylogenetic tree between species. This is a field in biology called bioinformatics. It's where biology and math and computer science converge, and it's at the forefront of evolutionary scientific research.

Comments:

provide suggested references/ activities in this area for extension for upper level students

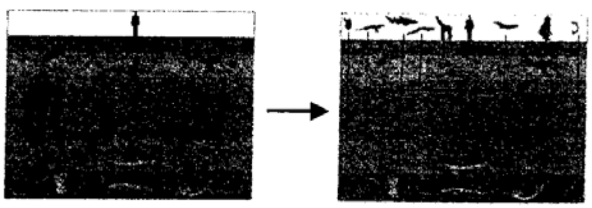
This has possibilities for reaching and challenging a wide range of students/classes

The Fossil Record



And just like the rocks in the Earth's surface, fossils are arranged in corresponding layers. In the oldest rocks on the bottom, we find only the life forms without a head. On top of that we find everything with a head. On top of that we find everything with a head, jaws, and paired apendages. On top of that we find everything with a head, jaws, and paired apendages that walk on land. On top of that we find everything with a head, jaws, paired apendages that walk on land, and hair. And on top of that we find everything with a head, jaws, paired apendages that walk on land with 2 legs, hair, and a well developed brain.

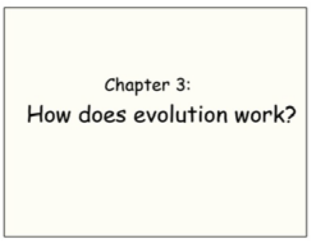
Comments:



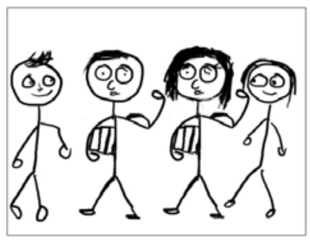
But in case you're feeling on top of it all, keep in mind that these ancestral species split into millions of other lineages, which evolved into all the species alive today. So, we are not "more evolved" than other living species. Just like us, they have been evolving for a very long time and they are equally adapted to their respective environments. Instead, think of these other living species as our very distant cousins.

Comments: I like the analogy: making the point that humans aren't really "on top"

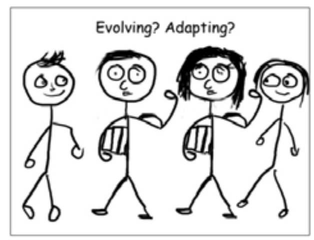
APPENDIX E
Giraffe Storyboard



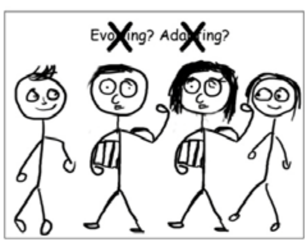
So, how does Evolution work?



First of all, Evolution works on populations, not individuals. So if you work out and get really fit, socialize and make a bunch of friends, and study really hard and get very smart, are you

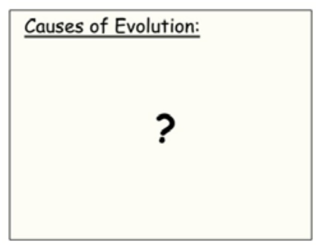


evolving? Are you "adapting" to your environment? You might become a better person, but

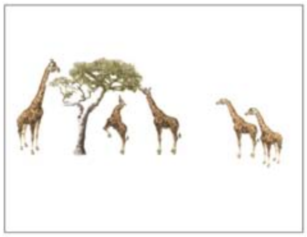


in terms of Evolution, the answer is no because you, an individual, do not evolve or adapt. Populations evolve and populations adapt over generations.

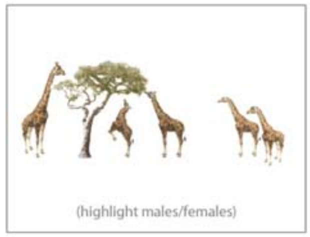
Now, a population is a localized group of individuals that belong to the same biological species. This means they can interbreed and produce fertile offspring.



But how do populations evolve and adapt? Well there are a few ways.

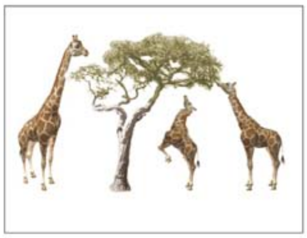


Let's say we have a population of giraffes,

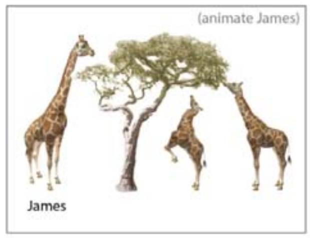


with some males and some females.

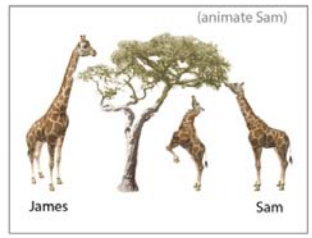
The females are watching the males eat leaves off a tree. And in this activity, we can see some variation in traits.



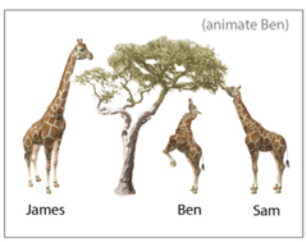
Specifically, there's variation in neck length. In fact, we see 3 different phenotypes of neck length in the males.



James has a very long neck and can easily reach the nutrient rich leaves on the tree tops.

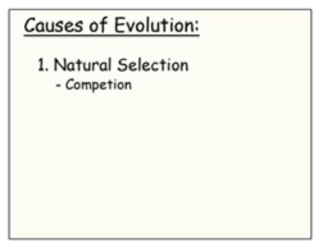


Sam has an average length neck and can get just enough leaves to get by.

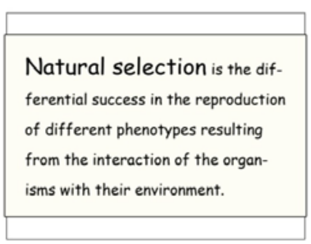


Ben, however, has a very short neck and can barely get a leaf.

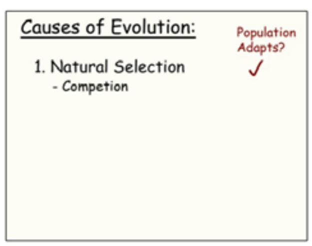
This means, that in this environment, James is the *fittest* individual for getting enough nutritious leaves to live long enough to reproduce.



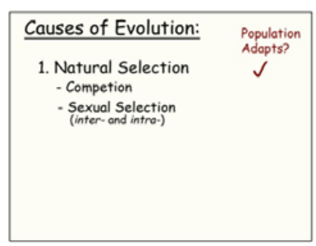
So, this kind of competition (in this case, for food) is one environmental factor in something called natural selection.



Natural selection is the differential success in the reproduction of different phenotypes (like the 3 giraffes) resulting from the interaction of the organisms with their environment.

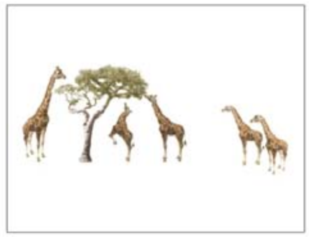


Now natural selection causes the population to adapt, because the next generation will likely look more like James, with longer necks.



Another type of natural selection is called sexual selection.

Sexual selection is natural selection for mating success.

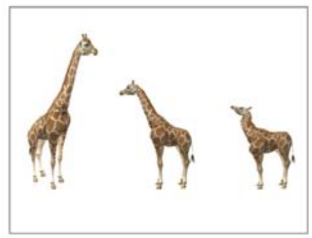


There's *inter*sexual selection, where members of one sex are more choosy for members of the opposite sex.

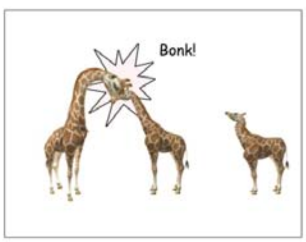
Patricia: "Girl, look at that neck!"

Becky: "Mmmm...hmmm. James is SO fine. He can just have my babies."

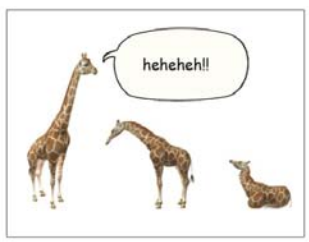
James: "Thas right."

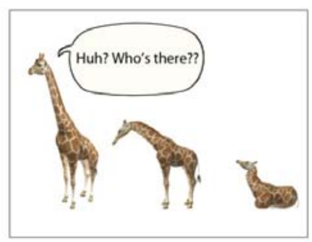


And then there's *intra*sexual selection, or competition among members of one sex.

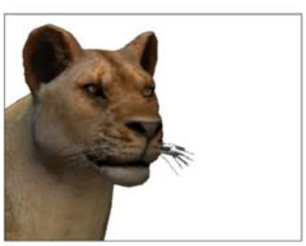


James: "No 'necking' with the ladies! Got it?! They're mine!!"



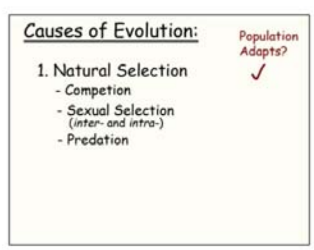


But, not all factors in an environment favor the reproductive success of one particular phenotype.



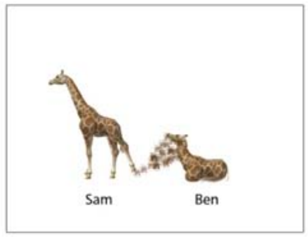
Predator: "Yeah, your neck looks the best to me too, James. And I can see it a mile away."

(gutteral noises)



Predation is another factor in natural selection, and often, in nature, it can go against sexual selection.

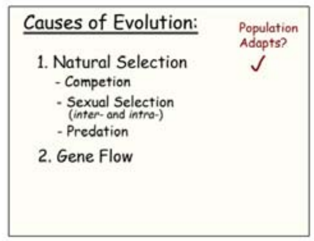
Patricia: "OK, I guess Sam will have to do."



(pft pft pft)

While Sam's babies might not have the long necks that James' babies would've had, they'll be less noticeable to predators. And at least they'll have more sex appeal than Ben's babies.

So, with predation, this is how the population might adapt. Natural Selection is a balancing of many different environmental factors with many different physical traits of organisms.

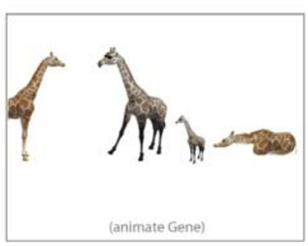


But natural selection is just one way populations evolve.

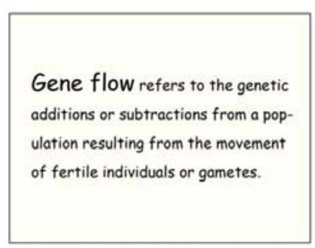
Patricia: "I don't know Becky, Sam's OK, but..."

Becky: "Uh... hold your estrous Patricia! Who is THAT?!"

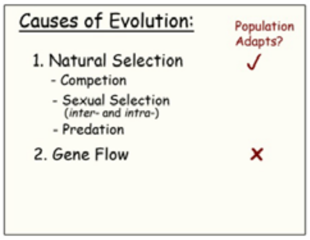
Gene: "Who me? The name's Gene. I'm from the *other* population, and I came to spread my genes, with a little bit uh...mmm...



Gene: "gene flow."

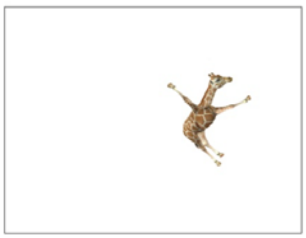


Gene flow refers to the genetic additions or subtractions from a population resulting from the movement of fertile individuals or gametes.

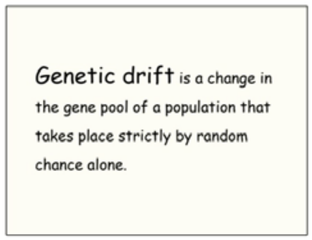


Gene flow is another way a population can evolve. But gene flow alone rarely causes a population to adapt.

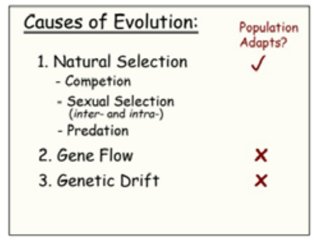
But wait, let's not forget about genetic drift.



Ben: "AAAAAHHAHAHAH!!! YES!!! YES!!!"



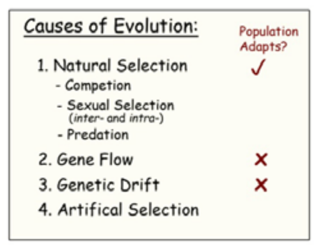
Genetic drift is a change in the gene pool of a population that takes place strictly by random chance alone. Also unlike natural selection, it does not cause a population to adapt.



Ben: "THANK YOU, GENETIC DRIFT!!!" The next generation will NOT be more adapted to meteors falling on them. That was just a random event that changed our population's gene pool.

Therefore, it evolves, without adapting. Patricia: "I think we just got bottlenecked."

Becky: "Yeah, and by the looks of it, we're headed for extinction."

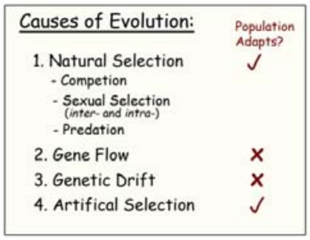


Oh, I almost forgot. There's one more cause for evolution, and it's something that farmers and ranchers and animal breeders do for a living.

Artificial Selection is the selective breeding of domesticated plants and animals to encourage the occurence of desirable traits.

In other words, in artifical selection we're the environment and we select the individuals who will make it to the next generation.

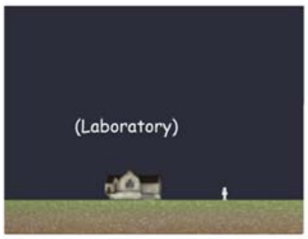
You see these individuals when you cruise the produce section at the grocery store or your local pet shop.



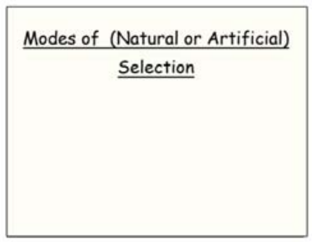
But do populations which evolve through artificial selection adapt? Yeah sure, they adapt to us and the environments we create.

Take your little puppy and put him out in the Alaskan arctic and he probably won't fit in so well.

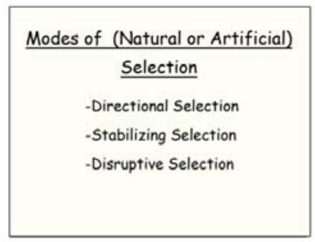
Plop him on a sofa in front of a warm fireplace, however, and he will seem perfectly adapted.
so yeah



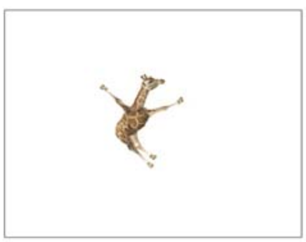
We'll come back to the giraffes in a little bit, but for now, let's go into the laboratory so we can manipulate the environment to observe changes in a population under the microscope.



Populations can adapt in different ways to different environments, depending on which phenotype is selected.



So, in general, there are 3 different modes of selection. There's directional selection, stabilizing selection and disruptive selection.

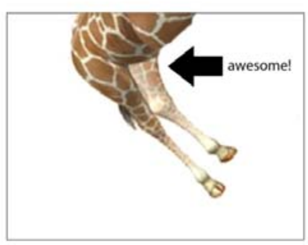


So... back to our population of giraffes.

Becky: "I'm not mating with that. Ben vs. extinction? The choice is clear."

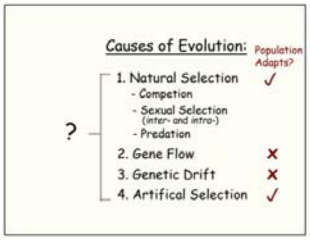
Patricia: "Alright, I guess I'll take one for the team."

Patricia: "Alright, dude. Let's go... into the forest where no one can see."

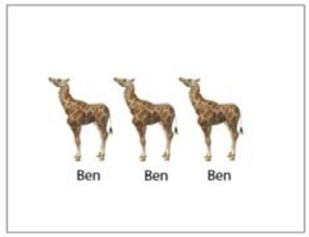


Little did Patricia and Becky know, and you wouldn't know it from looking at him, but Ben had a few germ cells tucked away that were carrying some really awesome mutations.

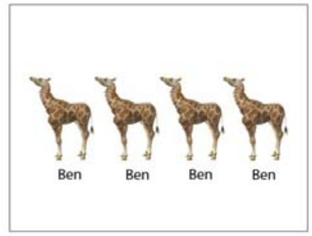
Well, to be honest these sperm were more like the golden gods of Mount Testicula. In fact, you might call them super sperm!



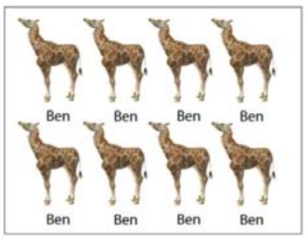
You see, while there are many causes of evolution, there is one cause which rules them all. So what is it that all 4 of these mechanisms need in order to work?



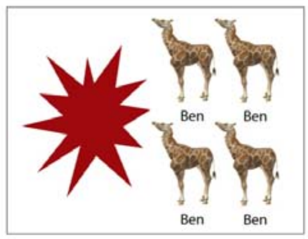
Let's think about this. What if we had started out with just a population of only "Bens?" When they compete, get sexually rejected or eaten by predators,



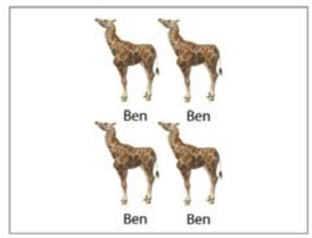
who, if anyone, will survive to mate and reproduce? Ben, right? But he can only reproduce with more Bens (which is kind of problematic).



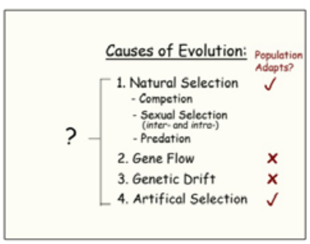
And if more Bens show up from a neighboring population, there won't be much Gene flow.



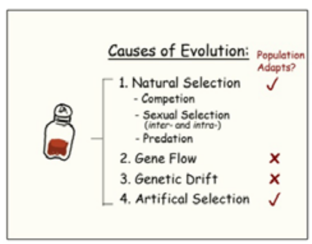
Nor will genetic drift have any real effect if some of the Bens survive whatever random thing happens.



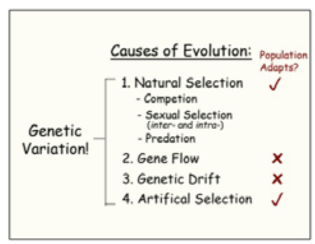
And if we wanted to artificially select to breed giraffes from this population, well, you got your choice of Ben... or Ben.



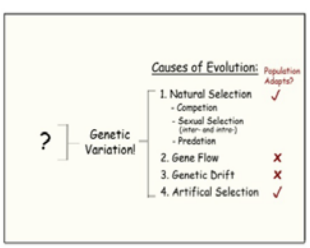
We need *something* to get these mechanisms of evolution to cause... well... evolution. What is it?!



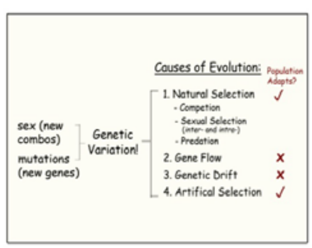
The answer of course, is paprika. Paprika is the cause of all.... wait, did I say paprika? I mean cilantro... no, ginger... or was it garlic? No, it's a spice... spice in general?... the "spice of life."



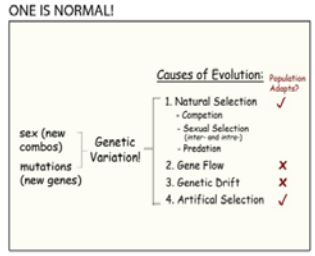
Wait a minute, what *is* the "spice of life?" GENETIC VARIATION!!! THAT'S IT!!! THAT'S THE SECRET TO EVERY LIVING THING!!! The little differences that make us all unique! NO ONE... NO ONE IS NORMAL!



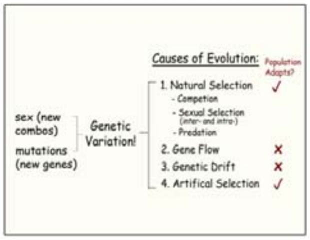
OK, ahem. Now... what causes this genetic variation?



Well, your variation comes in 2 different *varieties*. You got new *combinations* of genes and new *genes*.



In other words, sex, which recombines existing genes into new genetic flavors, and mutation, which are little changes in DNA that create new alleles and new genes.

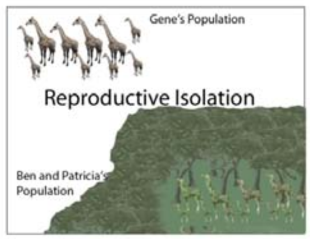


So, sexual *recombination* and mutation create variation, which allow these mechanisms of evolution to work.

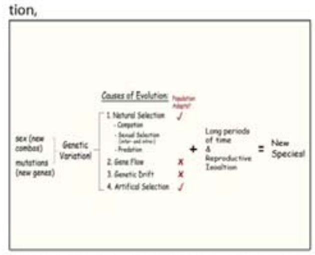
Now, here in the forest, some of Ben's sperm, with very rare but awesome mutations, will recombine genetically with Patricia's eggs, to make some really fit offspring.

Well, these new guys take off through natural selection, and over many generations they adapt to the forest. With each new generation they get new mutations and sexual recombination,

which leads to more variation, which allows natural selection and genetic drift to cause evolution. We're not around so there's no artificial selection.

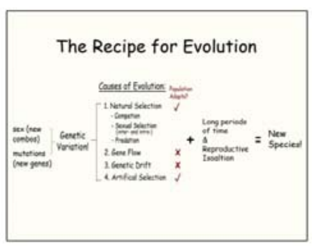


And Ben and Patricia's population is *reproductively isolated* from other giraffe populations, such as Gene's. Meaning, no gene flow and they're not mating with giraffes from these other populations.

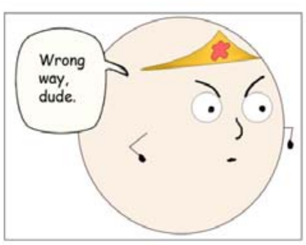


When evolution works like this over long periods of time (a matter of hundreds of thousands to millions of years), coupled with reproductive isolation, you get new species.

Gene progeny: "Mmm... you just ain't goin' with our flow no more."



And if you can understand just this much by the time you get to college, you'll be



(chasing after)

(dancing)

APPENDIX F
Teacher Guide

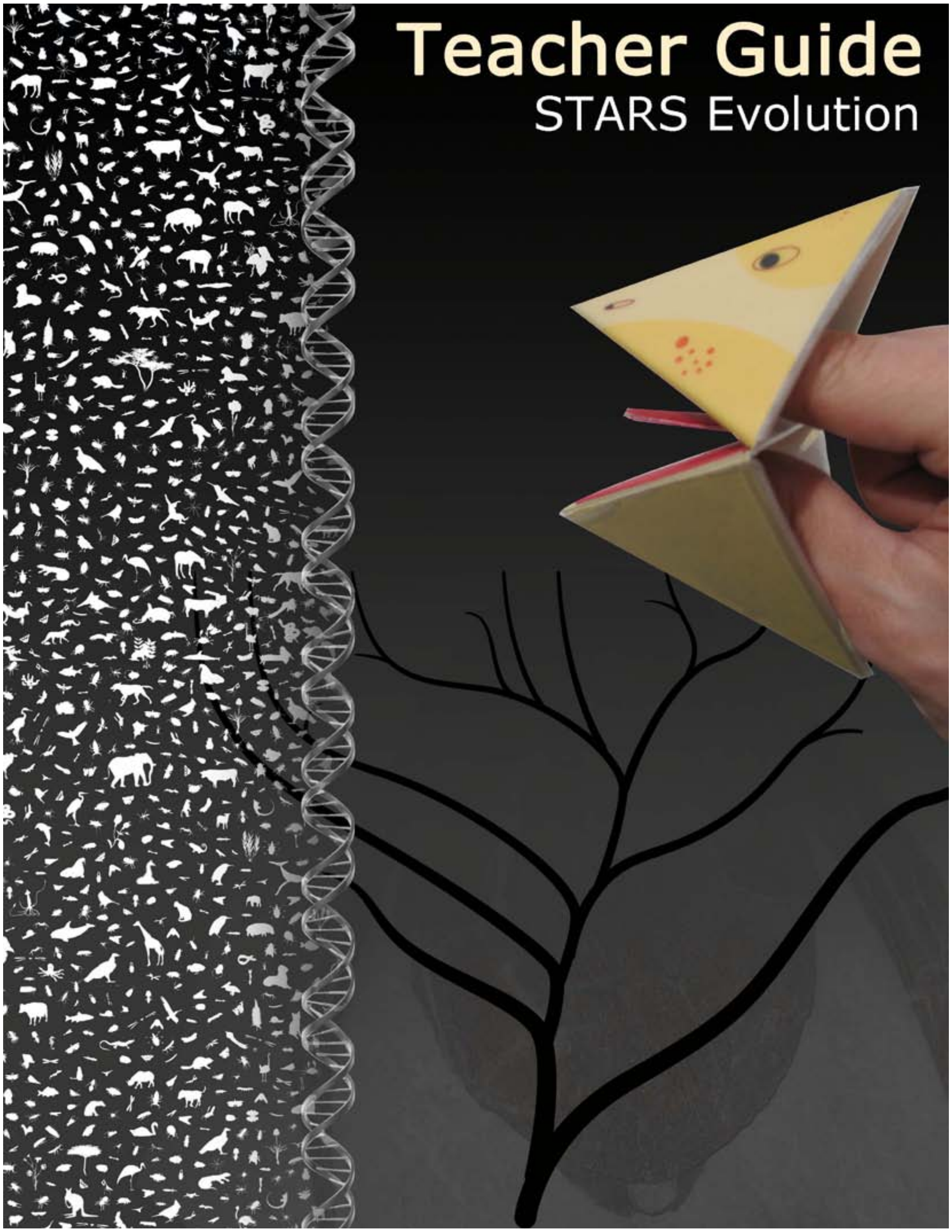
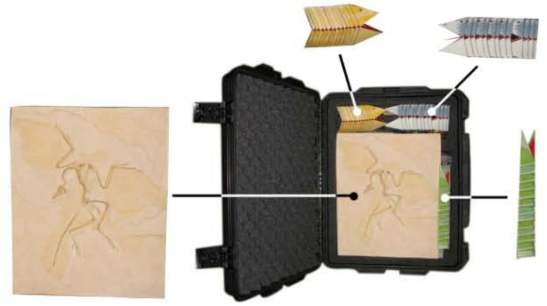
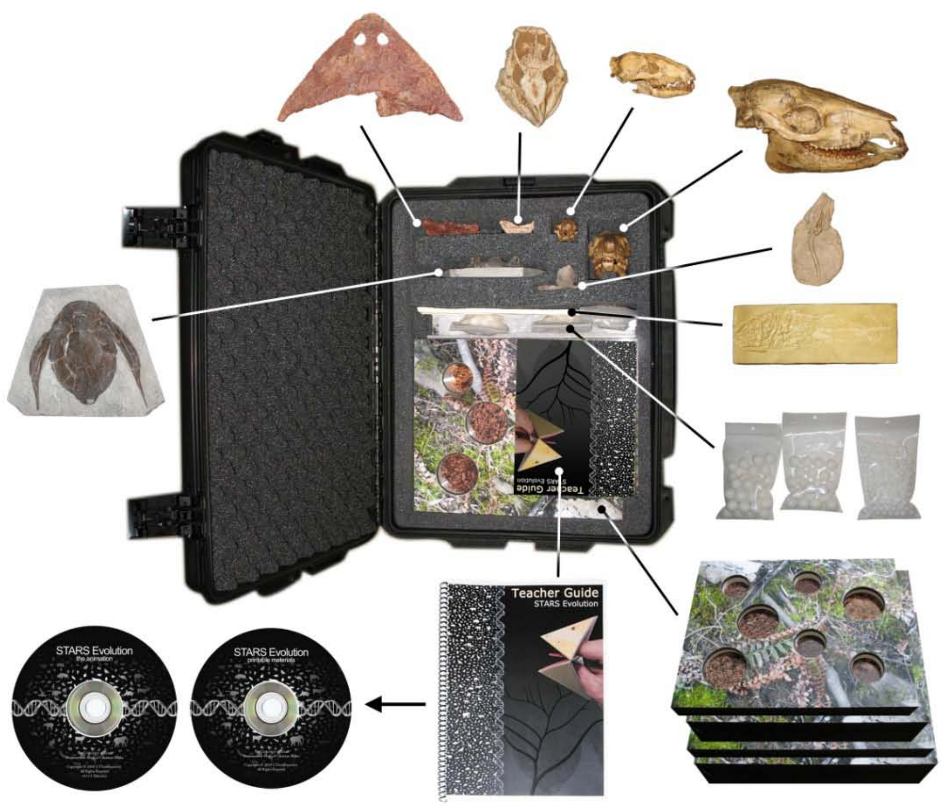


Table of Contents

Suitcase Materials



1 Teacher Guide
1 Animation DVD
1 Printable Materials CD
8 Fossil Casts
4 Game Boards
3 Bags of Food
39 Beak Finger Puppets
(13 of each type)



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Proposed Schedule

Day 1: Watch Chapter 1: Introduction
(3:41 minutes)

Watch Chapter 2: The Fossil Record
(4:42 minutes)

Watch Chapter 3: Mechanisms
(19:28 minutes)

Play *Beak Niche*

Day 2: Watch Chapter 4: Embryology
(4:42 minutes)

Watch Chapter 5: Phylogeny
(8:40 minutes)

Do the Fossil Lab

Animation

The animation script and the end of chapter quizzes are available for you and your students. If needed, the students can follow along with the script while watching the animation, and then take the quizzes at the end of each chapter. Following the script, is an answer key to the questions.

Also available are two student worksheets. The *Evolution Concepts* worksheet has the basic terminology found throughout the entire animation; and the students should use this to write down definitions. The *Recipe for Evolution* worksheet is a flow chart designed specifically to accompany Chapter 3: Mechanisms; so when the class watches this section, the students should fill out this worksheet.

Animation Script

Chapter 1: Introduction (3:44 minutes)

If you were assigned the task to collect individuals from every living species on Earth, how would you do it? Well, for starters, don't quit your day job. Or you might want to consider staying in school, because this task would be completely impossible. Not just for you alone, but if every person on the planet worked in unison to gather members from every living species, the task would still not get done. Why is this?

Not only do we not know all species on Earth, we have absolutely no idea *how many* species there are on Earth. We don't even have a good estimate. Every time a team of biologists goes into, say a tropical jungle, they wind up cataloguing hundreds of new species of insects. This happens every year. But those are organisms that we can see with the naked eye. What about all the microorganisms out there? Viruses?! We still haven't decided if they are within the confines of life. They have their own entire taxonomic system! Scientists have discovered about 2 million living species, but their estimates for the total number of species living on Earth range anywhere from 3 -100 million. So, where did all these species come from? They didn't just pop into existence out of nowhere, at least we've never seen that happen.

This is what we DO know: DNA is a shared trait of all life and, within a population, not only do gene frequencies change, but DNA recombines and mutates from generation to generation. Interestingly enough, this is the very definition of <u>Evolution</u>: that is, change in the genetic material (DNA) of a population of organisms from one generation to the next. *This is a fact.* There is no scientific debate on whether or not Evolution exists. It does exist: genetic change in a population from generation to generation does occur.

We also know why Evolution doesn't expand populations limitlessly in all directions; Evolution works through mechanisms, such as Natural Selection. More on that later... But, does evolution cause new species to arise from older species? Again, this is what we do know: the fossil record, DNA and protein analysis, comparative embryology, and all the homologies (or shared traits between species) show that new species do arise from older species. Of course, this can take thousands, sometimes millions, of years in a process called speciation.

Evolution is the cause for all the variation of life on Earth. Without it there would be no reason for you to have Biology class. Biology would be meaningless. In fact, the class wouldn't even exist. There wouldn't be chairs, or desks, or walls. This very animation would cease to be, along with my voice, because... *you* would not exist, either.

Chapter 1 Quiz (correct answers are in red)

1. (TRUE OR **FALSE**) We've known for a long time exactly how many species there are on Earth.

2. All of the following are based on empirical observations which support evolution, except:
   A. The Fossil Record
   B. DNA and protein analysis
   C. Comparative Embryology
   D. All the shared traits between species.
   E. One's personal religious faith.

3. Evolution is
   A. the same thing as Natural Selection.
   B. a theoretical fringe science of Biology.
   C. kind of interesting, but not that useful.
   D. the change in the genetic material of a population of organisms from one generation to the next.
   E. adapting to your environment to become the superior organism.

4. (TRUE or **FALSE**) Evolution is "just a theory," and there are other theories out there which can explain the same biological phenomena.

Chapter 2: The Fossil Record (4:42 minutes)

So, where did we get this idea of Evolution? Charles Darwin gave us an explanation for how evolution works, but where did HE first get the idea? Well, you're standing on it.

The Earth's surface is composed of layers of rock. And some of that is sedimentary rock, in other words, rock formed from sediment. Now, if you had to guess, which layer do you think would be the oldest layer in this sedimentary rock? Well, it's the layer on the bottom. Think of a sand bottle, in which you pour one color of sand that settles to the bottom. We're depositing "sediment" here. Then you add another color of sand, which settles on top of the first color. In general, this is how the sedimentary rock of the Earth's surface is arranged, with older layers on the bottom and newer layers on top.

The data which support this concept is gathered using a technology called radiometric dating (radioactive carbon dating is one such technique). If they take a sample of rock from one of these layers... there will be radioactive atoms in that sample, which have been releasing particles over time. This is called decay. And using the rate of decay, scientists can measure the amount of certain elements to deduce the age of the rock sample. Radiometric dating has shown that the Earth is about 4 ½ billion years old, and in sedimentary rock, the oldest layers are generally on the bottom, with the newer layers on top.

And just like the rocks in the Earth's surface, certain fossils are found in corresponding layers. If we focus on the tiny branch of Evolution that is our own vertebrate lineage, this is what we find in the fossil record. In the oldest rocks on the bottom, we find only life forms without a head. On top of that we find everything with a head. On top of that we find everything with a head, jaws, and paired appendages. On top of that we find everything with a head, jaws, and paired apendages that walk on land. On top of that we find everything with a head, jaws, paired apendages that walk on land, and hair. And on top of that we find everything with a head, jaws, paired apendages that walk on land with 2 legs, hair, and a well developed brain.

This fossil record supports evolution because it shows how adaptations expand upon preexisting structures over time. This is NOT how things were *destined* to evolve; it's just how they *did* evolve. Evolution is not goal oriented. So in case you're feeling on top of it all, keep in mind that these ancestral species split into millions of other lineages, which evolved into all the species alive today. Now Evolution does not support the idea that any species is "superior" to any other species. So, we are not like the highest rung of a ladder. There's no ladder and there's no chain of being. We are only one tiny little branch on an ever expanding tree of life. Instead, you can think of these other living species as our very distant cousins, who are equally adapted to their respective environments.

Now, tectonic shifts (think massive earthquakes, volcanic eruptions, continental drift) have, in specific areas, disrupted the layers. But geologists can still discern the pattern of rocks. And remember, they can use radiometric dating to confirm the identity of the layer. This is how scientists are able to create vast and intricate geological maps, which evolutionary biologists can then use to find certain fossils. For instance, if they are searching for dinosaur fossils they will know in which layer to look. However, if they were looking for human fossils they wouldn't find any in this layer because the rocks are too old, and humans had not evolved yet. Rather, they would know to look in newer rocks to find human fossils.

In a sense, the entire field of Evolution is like a giant jigsaw puzzle. We've put enough pieces together to know it's there, but there are many pieces that have yet to be found.

Chapter 2 Quiz (correct answers in red)

1. Fossils are
    A. randomly scattered in the Earth's surface.
    B. in layers, with the newer fossils beneath the older fossils.
    C. **in layers, just like the rocks in the Earth's surface, with the newer fossils on top of the older fossils.**
    D. in layers of no chronological significance.

2. Which of these statements is true about the Earth's surface?
    A. The older layers of sedimentary rock are generally under the newer layers.
    B. The newer layers of sedimentary rock are generally under the older layers.
    C. It's been disrupted by tectonic shifts so much that we cannot discern its history.
    D. It's been disrupted by tectonic shifts, but geologists can still discern the pattern of rocks and their history.
    E. **Both A and D are true.**
    F. Both A and C are true.
    G. Both B and C are true.

3. Radiometric dating
    A. uses the compounds of radioactive atoms to prove the existence of fossils.
    B. has shown that the Earth is about 4.5 billion years old
    C. uses the rate of decay in certain radioactive atoms to determine the age of a rock sample.
    D. Both A and B are true.
    E. **Both B and C are true.**
    F. Both A and C are true.

4. (TRUE or **FALSE**) In the fossil record, mammals can be found in any geological layer.

5. In the fossil record
    A. organisms with heads are not found below a certain geological layer.
    B. organisms with jaws are not found below a certain geological layer.
    C. organisms with hair are not found below a certain geological layer.
    D. **All of the above are true.**
    E. None of the above are true.

6. (**<u>TRUE</u>** or FALSE) Some organisms without heads evolved after the first organisms with heads.

7. (TRUE or **<u>FALSE</u>**) Humans are the superior species on the planet because they are so intelligent. In a sense, they are the highest rung on the evolutionary ladder.

8. In the fossil record
   A. creatures with hair evolved before the first creatures with jaws.
   B. creatures with jaws evolved before the first creatures that walked on land.
   C. creatures that walked on land evolved before the first creatures evolved with heads.
   D. creatures with jaws evolved after the first creatures with heads.
   E. B, C and D are correct.
   F. <u>B and D are correct.</u>
   G. None of the above are correct.

Chapter 3: Mechanisms (19:28 minutes)

So, how does Evolution work? First of all, Evolution works on populations, not individuals. So if you work out and get really fit, socialize and make a bunch of friends, and study really hard and get very smart, are you "evolving"? Are you "adapting" to your environment? You might maximize your genetic potential to become a sharper, better looking giraffe. But in terms of Evolution, the answer is no because you, an individual, do not evolve or adapt. *Populations evolve and populations adapt over generations.*

Now, a <u>population</u> is a localized group of individuals that belong to the same biological species. This means they can interbreed and produce fertile offspring. Also, populations are kind of a relative concept (meaning it depends on what you're looking at and how closely you're zooming in). You might be comparing 2 giraffe populations within one region in Africa. Or, you could be comparing all the giraffes in that region with all the giraffes in another region. Or, you might even be observing all the interbreeding giraffes in Africa, and comparing them to a population of an entirely different species, like: the population of *Homo sapiens* in your city, country or planet.

But how do populations evolve and adapt? Well there are a few ways. Let's say we have a population of giraffes, with some males and some females. The females are watching the males eat leaves off a tree. And in this activity, we can see some variation in traits. Specifically, there's variation in neck length. In fact, we see 3 different phenotypes of neck length in the males. James has a very long neck and can easily reach the nutrient rich leaves on the tree tops. Sam has an average length neck and can get just enough leaves to get by. Ben, however, has a very short neck and can barely get a leaf. This means, that in this environment, James is the fittest individual for getting enough nutritious leaves to live long enough to reproduce. So, this kind of competition (in this case, for food) is one environmental factor in something called natural selection.

Natural selection is the differential success in the reproduction of different phenotypes (like the 3 giraffes) resulting from the interaction of the organisms with their environment. Now natural selection causes the population to *adapt*, because the next generation will likely look more like James, with longer necks. Another type of natural selection is called sexual selection. Sexual selection is natural selection for mating success. There's intersexual selection, where members of one sex are choosy for members of the opposite sex. And then there's intrasexual selection, or competition among members of one sex.

But, not all factors in an environment favor the reproductive success of one particular phenotype. Predation is another factor in natural selection, and often in nature, it can go against sexual selection. While Sam's babies might not have the long necks that James' babies would've had, they'll be less noticeable to predators. And at least they'll have more sex appeal than Ben's babies. So, with predation, this is how the population might adapt. Natural Selection is a balancing of many different environmental factors with many different physical traits of organisms. But natural selection is just one way populations evolve.

Gene flow refers to the genetic additions or subtractions from a population resulting from the movement of fertile individuals or gametes. Gene flow is another way a population can evolve. But gene flow alone rarely causes a population to adapt. But wait, let's not forget about genetic drift.

Genetic drift is a change in the gene pool of a population that takes place strictly by random chance alone. So in the case of meteor shower… (kaboom!). Also unlike natural selection, it does not cause a population to adapt. The next generation will NOT be more adapted to meteors falling on them. That was just a random event that changed our population's gene pool.

Oh, I almost forgot. There's one more cause for evolution, and it's something that farmers and ranchers and animal breeders do for a living. Artificial Selection is the selective breeding of domesticated plants and animals to encourage the occurrence of desirable traits. In other words, in artificial selection we are the environment and we select the individuals who will make it to the next generation. You see these individuals when you cruise the produce section at the grocery store or your local pet shop. But do populations which evolve through artificial selection adapt? Take your little puppy and put him out in the Alaskan arctic and he probably won't fit in so well. Plop him on a sofa in front of a warm fireplace, however, and he will seem perfectly adapted. So yeah, sure, they adapt to us and the environments we create.

We'll come back to the giraffes in a little bit, but for now, let's go into the laboratory so we can manipulate the environment to observe changes in a population under the microscope.

Chapter 3 Quiz, Part 1 (correct answers are in red)

1. Evolution works on
   A. individuals
   B. communities
   C. ecosystems
   D. populations

2. A population is a localized group of individuals that
   A. belong to the same species.
   B. belong to different species.
   C. can interbreed and produce fertile offspring.
   D. do not migrate and are not part of any other group.
   E. Both B and C are correct.
   F. Both A and C are correct.
   G. None of the above are correct.

3. Natural selection is the differential success in the _______ of different phenotypes resulting from the interaction of the organisms with their ________.
   A. competition, species
   B. attraction, sexual selection
   C. avoidance of predators, population
   D. reproduction, environment

4. Two rams butting heads for the female sheep (ewes) is an example of
   A. intersexual selection.
   B. intrasexual selection.
   C. primitive male bonding.
   D. true love.

5. Sexual "choosiness" for members of the opposite sex is
   - **A. <u>intersexual selection.</u>**
   - B. intrasexual selection.
   - C. good fashion sense.
   - D. completely random.

6. Natural selection might involve all the following, except:
   - A. competition for food
   - B. predation
   - C. sexual selection
   - **D. <u>genetic drift</u>**

7. A few fertile members of one population move to another population. This is an example of
   - A. heterozygous advantage
   - B. genetic drift
   - **C. <u>gene flow</u>**
   - D. the founder effect

8. Genetic drift causes evolution strictly by
   - A. meteor showers
   - **B. <u>random chance</u>**
   - C. surprise
   - D. adaptation

9. Which of these causes a population to adapt?
   - A. genetic drift
   - **B. <u>natural selection</u>**
   - C. gene flow
   - D. all of the above

10. An example of artificial selection is
    - A. humans breeding dogs from wolves.
    - B. bacteria having antibiotic resistance.
    - C. humans growing Gala apples to eat.
    - **D. <u>both A and C</u>**

In the lab…

Let's say we have a population of microscopic, multicellular organisms. When we look more closely at their trait for surface area to volume ratio, we discover that there are 3 different phenotypes. So let's discuss the different types. One has a low SA/V ratio. In other words, the outer surface is about as small as it can get for this volume. The type beside it has the same surface area, but its volume has decreased, so it has a higher SA/V ratio. The last one, with a deep invagination, has the most surface area per volume, and therefore the largest SA/V ratio. And because our population has this *variation* of traits, we say it has *genetic variation*. Look around your classroom; it's a population. Does anyone look exactly the same? (Unless your class has identical twins, probably not) So the population of your classroom has genetic variation, just like this one. This variation can be plotted on a distribution curve, so we can see that most of our population has an average SA/V ratio. But few individuals have a very low or a very high SA/V ratio. So, now that we've analyzed our 3 phenotypes for this trait, and placed them on a distribution curve, let's see what happens with selective pressures from an environment. Choose an environment. You can release food, biotoxin, both food and biotoxin at the same time, or a predator.

The food is a positive, life-sustaining environmental factor for our population. Which type seems to be the most adapted to getting food? The one with the highest SA/V ratio will have a higher chance of getting enough food because of its larger SA. So, which type would likely be the most successful in reproducing offspring in this environment? Yes, the type that is most adapted to getting food will have a better chance of living long enough and having the energy to reproduce more, and more successfully. Now what do you think will happen to our distribution curve in the next generation? It shifts more towards the individuals with the highest SA/V ratio because they were the best at getting food, and therefore could reproduce more. This is a kind of natural selection called <u>directional selection</u>. In this case the "direction" is towards the phenotype with the highest SA/V ratio.

The biotoxin is a harmful molecule produced by another organism in this environment. If an individual in our population gets too much biotoxin, it will die. So, what organism is most susceptible to the biotoxin? The one with the highest SA/V ratio will likely be most affected by the biotoxin. But which one will be the most reproductively successful? Well, since the one with the lowest SA/V ratio receives less, it is safest from the biotoxin. Therefore, in this environment, it is more likely to survive to reproduce. So, in the next generation there will be more individuals with a lower SA/V ratio. So, what happens to our distribution curve in the next generation? It shifts towards the individuals with the lowest SA/V ratio to reflect that there are more of them being reproduced in this environment. This kind of natural selection is called directional selection. In this case, the "direction" is towards the type with the lowest SA/V ratio.

Releasing both the food and biotoxin, a positive and negative stimulus, respectively, at the same time, will create a more complex environment. So, what type is the most adaptive to this environment? It's hard to say, and in real life there are often an incredible number of environmental factors, each balancing the benefits and costs of an individual's traits. But perhaps we find that the type with the average SA/V ratio gets just enough food and avoids the biotoxin just enough to survive, so that in this environment, we find it to be the most reproductively successful. But what do you think will happen to our distribution curve in the next generation? In this environment, our distribution curve will spike in the middle and be reduced on both sides, showing that in the next generation our population will have even more individuals with an average SA/V ratio. This type of natural selection is called stabilizing selection. Think of this as selecting for the most "stabile" or "balanced" set of traits, in between the 2 extremes.

The predator is a hydra that has adapted to feed on our population. While the hydra can devour any of the phenotypes, it is specifically adapted to eat the most numerous phenotype, which are the ones with the average SA/V ratio. So, which phenotype will show the least reproductive success in this environment? The one in the middle right? Because that's the type the predator is most adapted to eat. And what do you suppose might happen to our distribution curve in the next generation? Well, the individuals with an average SA/V ratio will decrease and the 2 phenotypes at the extremes will reproduce more. So, our curve would look something like this. This is a kind of natural selection called disruptive selection. So, the predator apparently "disrupted" our nice singular curve into 2 smaller curves.

Back to the giraffes...

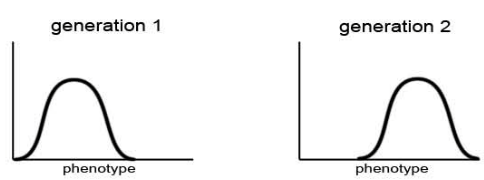
So... back to our population of giraffes. Little did Patricia and Becky know, and you wouldn't know it from looking at him, but Ben had a few germ cells tucked away that were carrying some really awesome mutations. In fact, you might call them super sperm! You see, while there are many causes of Evolution, there is one cause which rules them all. So what is it that all 4 of these mechanisms need in order to work? Let's think about this. What if we had started out with just a population of only Bens? When they compete, get sexually rejected or eaten by predators, who, if anyone, will survive to mate and reproduce? Ben, right? But he can only reproduce with more Bens (which is kind of problematic). And if more Bens show up from a neighboring population, there won't be much *gene flow*. Nor will *genetic drift* have any real effect if some of the Bens survive whatever random thing happens. And if we wanted to artificially select to breed giraffes from this population, well, you got your choice of Ben... or

Ben. We need something to get these mechanisms of Evolution to cause… well… Evolution. What is it?! The answer is genetic variation. Now… what causes this genetic variation? Well, your variation comes in 2 different varieties. You got new combinations of genes and new genes… in other words, sex, which recombines existing genes into new genetic flavors, and mutation, which are little changes in DNA that create new alleles and new genes. So, sexual recombination and mutation create variation, which allow these mechanisms of evolution to work.

Now, here in the forest, some of Ben's sperm, with very rare but awesome mutations, will recombine genetically with Patricia's eggs, to make some really fit offspring. Well, these new guys take off through natural selection, and over many generations they adapt to the forest. With each new generation they get new mutations and sexual recombination, which leads to more variation, which allows natural selection and genetic drift to cause Evolution. We're not around so there's no artificial selection. And Ben and Patricia's population is reproductively isolated from other giraffe populations, such as Gene's. Meaning, no *gene flow* and they're not mating with giraffes from these other populations. When evolution works like this over long periods of time (a matter of hundreds of thousands to millions of years), coupled with reproductive isolation, you get new species. And if you can understand just this much by the time you get to college, you'll be… (awesome).

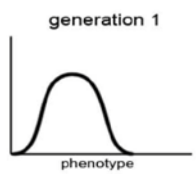
Chapter 3 Quiz, Part 2 (correct answers are in red)

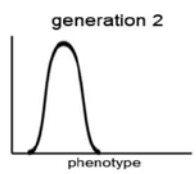
11. The mode of natural selection represented in the population distribution curves below is



A) directional selection
B) stabilizing selection
C) disruptive selection

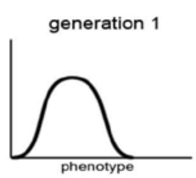
12. The mode of natural selection represented in the population distribution curves below is

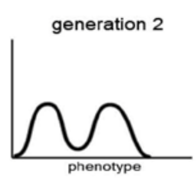




A) directional selection
B) stabilizing selection
C) disruptive selection

13. The mode of natural selection represented in the population distribution curves below is





A) directional selection
B) stabilizing selection
C) disruptive selection

14. The mechanisms of natural selection, gene flow and genetic drift are dependent on a population's ________, to cause evolution.
   a. genetic substitution
   b. **genetic variation**
   c. dominant phenotype
   d. adaptation

15. Genetic variation in a population is generated by
    a. mutation
    b. sexual recombination
    c. adaptation
    d. natural selection
    e. **Both A and B are true.**
    f. None of the above are true.

16. For a new species to evolve, a population needs
    a. genetic drift
    b. gene flow
    c. adaptation
    d. **reproductive isolation**

Chapter 4: Embryology (4:42 minutes)

Embryology is the science which studies the development of embryos, from the fertilization of the ovum to the fetus stage. What does embryology have to do with Evolution? We know that DNA mutations in the germ-line cells (that is, the egg and sperm) cause changes in the development of the offspring. And this changes the morphology, or form and structure, of the adult organism. And over hundreds of millions of years the changes in morphology can gradually become very great. But how does this idea show relationships between the species?

Well, did you know our embryology still has a lot in common with our recent relatives? Like all vertebrates, for instance, go through very similar stages of development. We see the following pattern in all fish, amphibians, reptiles and mammals (including humans). First there comes a fertilized egg which starts off as a *single cell*. That cell divides to form two cells in the *cleavage stage*, and then many cells in a stage called a *morula*. This ball of cells forms a cavity, becoming hollow, and goes through a stage called a *blastula*. The blastula develops a little hole, which in all vertebrates becomes the anus, and forms 3 layers of tissue (called endoderm, mesoderm and ectoderm), thereby becoming a *gastrula*. And then this develops into a little guy with a head, eyes, pharyngeal arches (we'll talk about those later), 4 limbs and a notochord.

So, how is it that our development has so much in common with all these other species? The answer is that the specific genes, in our DNA, which control development, are essentially identical to the genes in these other species. We still have a lot of the same genes with the same developmental functions. These genes include egg polarity genes, segmentation genes, and homeotic genes (or Hox genes). Basically they encode transcription factors which transcribe the next set of genes in the genetic cascade. This genetic cascade is just like the domino effect.

First, egg polarity genes divide the egg along the anterior/posterior axis. This tells the egg where it will form a head and where it will form a tail. Along this axis, segmentation genes divide the developing embryo into specific areas, or segments. And then homeotic genes, called Hox genes for short, give those areas a specific identity.

So, these developmental genes, in general, are very "conserved" in nature, meaning they don't mutate very much at all. Because when there is a mutation in one of these genes, it affects this critical early development, which affects everything after that in the genetic cascade, and almost always results in an unsuccessful organism.

But the question remains, what part of DNA does create successful mutations? If not the very conserved egg polarity, segmentation, or hox genes, then what? Well, this is what is currently being researched on the frontiers of evolutionary developmental science, called "evo-devo." While conducting research at UTSW Medical Center in Dallas, evolutionary biologist Dr. Trey Fondon, discovered one possibility for how, or where, DNA mutates. He studied many breeds of dog skulls and the variation in their morphology. He scanned the skulls with a 3d laser and found mathematical relationships in their shapes. The mutations he found in their DNA were tandem repeats of triplet DNA code upstream from the Hox genes controlling the skull morphology. This would allow for more or less transcription of the developmental protein, which would affect skull morphology. Evolution almost never takes the simplest path, but that's what makes it so fascinating. And there's so much more out there left to discover about how genes mutate and affect Evolution.

Chapter 4 Quiz (correct answers are in red)

1. Mutations in the ______ cells change ________, which changes _______ in the adult organism .
   A. somatic, morphology, development
   B. germ, embryological development, morphology
   C. stem, ontogeny, phylogeny
   D. single, recombination, selection

2. (**TRUE** or FALSE) All vertebrates (mammals, reptiles, amphibians and fish) go through very similar stages of embryological development.

3. Species have similarities in development with other species because of the conservation of similar developmental
   A. embryos.
   B. cells.
   C. **genes.**
   D. patterns.

4. Developmental genes include all the following, except:
   A. homeotic genes
   B. egg polarity genes
   C. segmentation genes
   D. **m-transcoder genes**

5. Hox genes are very conserved among the species because
   A. **they are responsible for critical stages in embryological development.**
   B. they mutate more than other genes.
   C. they are the "genetic blueprint" for all the higher species.
   D. they determine where the single cell embryo will form a head and where it will for a tail.

6. Current research has shown that the evolution in dog skull morphology has occurred mostly because of
   A. translocations in maternal effect genes.
   B. duplications in segmentation genes.
   C. **tandem repeat mutations of triplet DNA code in cis-regulatory regions.**
   D. embryological conservation.

Chapter 5: Phylogeny (8:40 minutes)

Phylogeny is the evolutionary history of a species or group of related species. Meet your extended family tree for the last 400 million years. At these nodes are all the living species that you can go observe today. And at these nodes are representations of our common ancestors with these species. Every year, as we uncover more fossils and gain better technologies science is improving our understanding of what these ancestor species looked like. So these are visual estimates which are becoming more definite over time. Also keep in mind that this is an incredibly simplified version of a phylogenetic tree. If we were to zoom in on just one of these branches we would see many smaller branches of species.

Phylogenetic trees are often just represented like this, to simplify matters. So, where would you find our most recent common ancestor with Amphibians? The node representing Tetrapods is correct. Your genetic link to a frog or salamander was a four-limbed Tetrapod with air breathing lungs. Now can you find the most recent common ancestor of all Chondrichthyes and all Reptiles? A fish with jaws and paired fins was the common ancestor between these two groups. It was a Gnathostome, and this fish was also our ancestor. And because this represents a part of our lineage, it means that humans are also Mammals, Amniotes, Tetrapods, Gnathostomes, Craniates, and Deuterostomes. But we are also so much more. Our DNA is a shared trait that relates us to all life, like trees and even bacteria.

Which leads to the question, what is this so called "phylogenetic tree" based on? In other words, how do we know that the puzzle pieces fit together just like this? Well, a phylogenetic tree like this one is based on something called homologies. A homology is a shared trait between species that is due to common ancestry. Sometimes biologists refer to homologies as "synapomorphies." When a homology is structural we call it a homologous structure.

We can label our tree with some homologous structures like this. These are certainly not all the homologous structures, but just a few to give you an idea of how this works. Now, when we label this with homologous structures, it means that every group after has that structure, or something homologous to that structure. So, looking at the homologous structures on this phylogenetic tree, which group or groups have terrestrial legs? Yes, all tetrapods originally had legs that evolved to walk on land. That includes mammals, reptiles, and amphibians.

So we can say that your arms and legs are "homologous" to the arms and legs of any amphibian, reptile, or mammal. These are homologous structures; our ancestral tetrapod evolved legs that walked on land and amphibians, reptiles and mammals continued to evolve those legs. Do you see how in all these limbs there is a very similar arrangement of bones? But then what about this fish fin? Pretty different arrangement right? We do know, however, that our tetrapod limbs evolved from fish fins. But how do we know this? How do we know this when both the structure and function of fish fins are different than the structure and function of our arms and legs?

This is where current DNA research enters the picture. Remember those hox genes from the previous chapter, the ones that control those critical stages of embryological development? Well it just so happens that these hox genes regulate another gene called Sonic Hedgehog (named after the video game), which controls development of both fish fins and our arms and legs. So we know that even shark fins are genetically homologous to our arms and legs, which makes them homologous structures. So all "Gnathostomes," which are jawed vertebrates and include everything from sharks to mammals, have homologous limbs.

OK, so what about insect legs or wings? Are they homologous to all of these other homologous structures? Actually, no. We can trace our phylogenetic lineage back to when our aquatic ancestors had no fins... no limbs at all. But our common ancestor with arthropods, including all insects, lived millions of years before this. So, the insects developed their limbs independently from ours in a process known as convergent evolution: that's when a similar, but not homologous, trait evolves in two or more distinct lineages. And we call that trait an analogous structure. These are structures which have similar functions but evolved separately. Therefore, insect limbs and vertebrate limbs are called analogous structures.

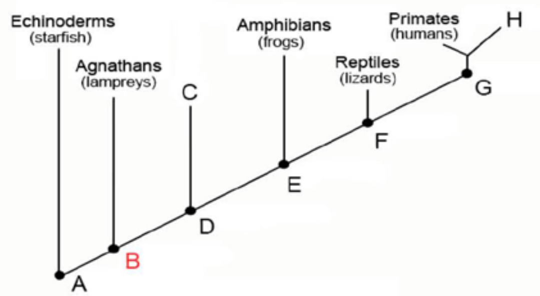
Now, I said all reptiles have limbs which are homologous to our limbs, right? And that includes birds because they are actually reptiles that evolved from dinosaurs. That's right. Phylogenetically speaking, the dinosaurs are still roaming... and er, flying over... the planet. And their wings are analogous to insect wings but homologous to our arms. But how about snakes, they're reptiles right? Where are the homologous limbs? They don't appear to have ANY limbs... or do they? In truth, some snakes, like boas and pythons, do still develop little hind limbs when they're embryos, and the limbs remain as vestigial structures in the adult.

Now, a vestigial structure is a homologous structure which has lost all or most of its original function through Evolution. So do humans have any vestigial structures? Yeah, lots of them. First of all you're probably sitting on one right now. That little nubbin of a bone called a "tailbone" you got back there is homologous to the tails of all our vertebrate cousins, even the ones swimming in the ocean. But it's not much use to us any more, kind of like those limbs on snakes, so we call it a vestigial structure. You even have vestigial blood vessels. Here's one in your heart, called the ductus arteriosus. It was useful for delivering blood in our fish ancestors, but for human adults... not so much. It closes up during our development and becomes, well, a vestigial structure.

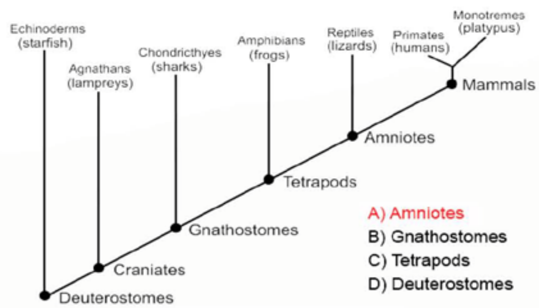
There's one more very fascinating human homology which you should know about: the pharyngeal arches. The pharyngeal arches look kind of like little gills, right? Here's a fish embryo during the same stage of development. In adult fish the pharyngeal arches develop into jaws and gills. But since our development has evolved in another direction, gills not being so adaptive to breathing air on land, our pharyngeal arches develop into jaws and various structures in your neck. So, these bones and cartilages in your neck and the bones and cartilages in fish gills are homologous structures. Our lower jaw, which forms from the 1st pharyngeal arch, is homologous also.

Chapter 5 Quiz (correct answers are in red)

1. Where would you find the most recent common ancestor of Agnathans and Primates?

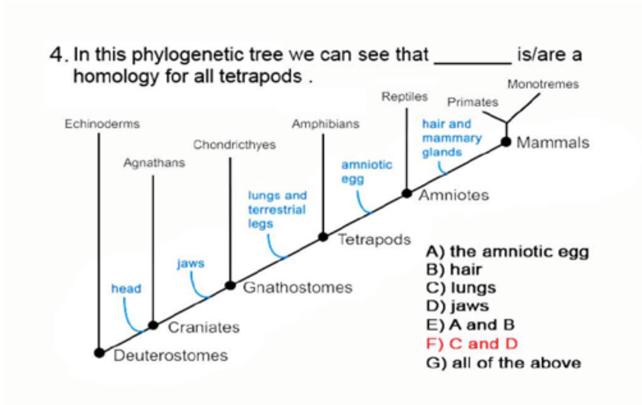


2. Amphibians are all of the following, except:



A) Amniotes
B) Gnathostomes
C) Tetrapods
D) Deuterostomes

3. A homology is a ______ between species that is due to _______.
   A. branch, random chance
   B. relationship, natural selection
   C. **<u>shared trait, common ancestry</u>**
   D. convergence, environmental pressures



5. Your arms are homologous to the forelimbs of all ________.
   A. Reptiles
   B. Primates
   C. Mammals
   D. Amphibians
   E. <u>All of the above</u>
   F. None of the above

6. (**<u>TRUE</u>** or FALSE) Shark fins are homologous to our limbs.

7. Bird wings are analogous to _______.
   A. human arms
   B. bat wings
   C. vestigial snake limbs
   D. <u>insect wings</u>

8. The evolution of bat wings and insect wings is an example of ________.
   A. homologous evolution
   B. <u>convergent evolution</u>
   C. speciation
   D. divergent radiation

9. One example of a vestigial structure in your body is your _______.
   A. lungs
   B. limbs
   C. jaws
   D. tailbone
   E. ribs
   F. brain

10. (**TRUE** or FALSE) Your jaws, earbones, and various bones and cartilages in your neck are homolgous to the fish gill arches.

Evolution Concepts

Evolution:

* Population:

* Natural Selection:

* Sexual Selection:

* Gene Flow:

* Genetic Drift:

* Artificial Selection:

Embryology:

Phylogeny:

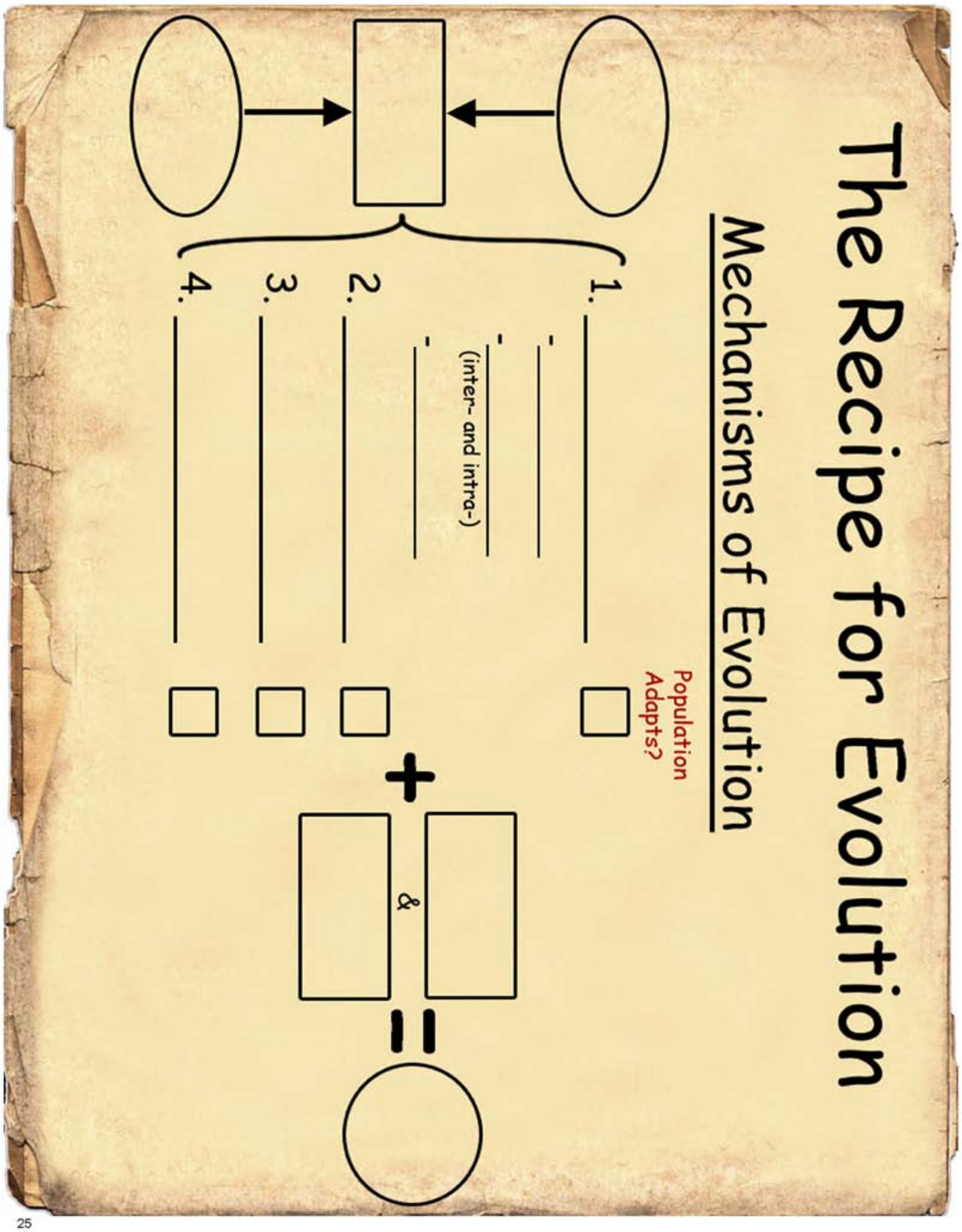
* Homology:

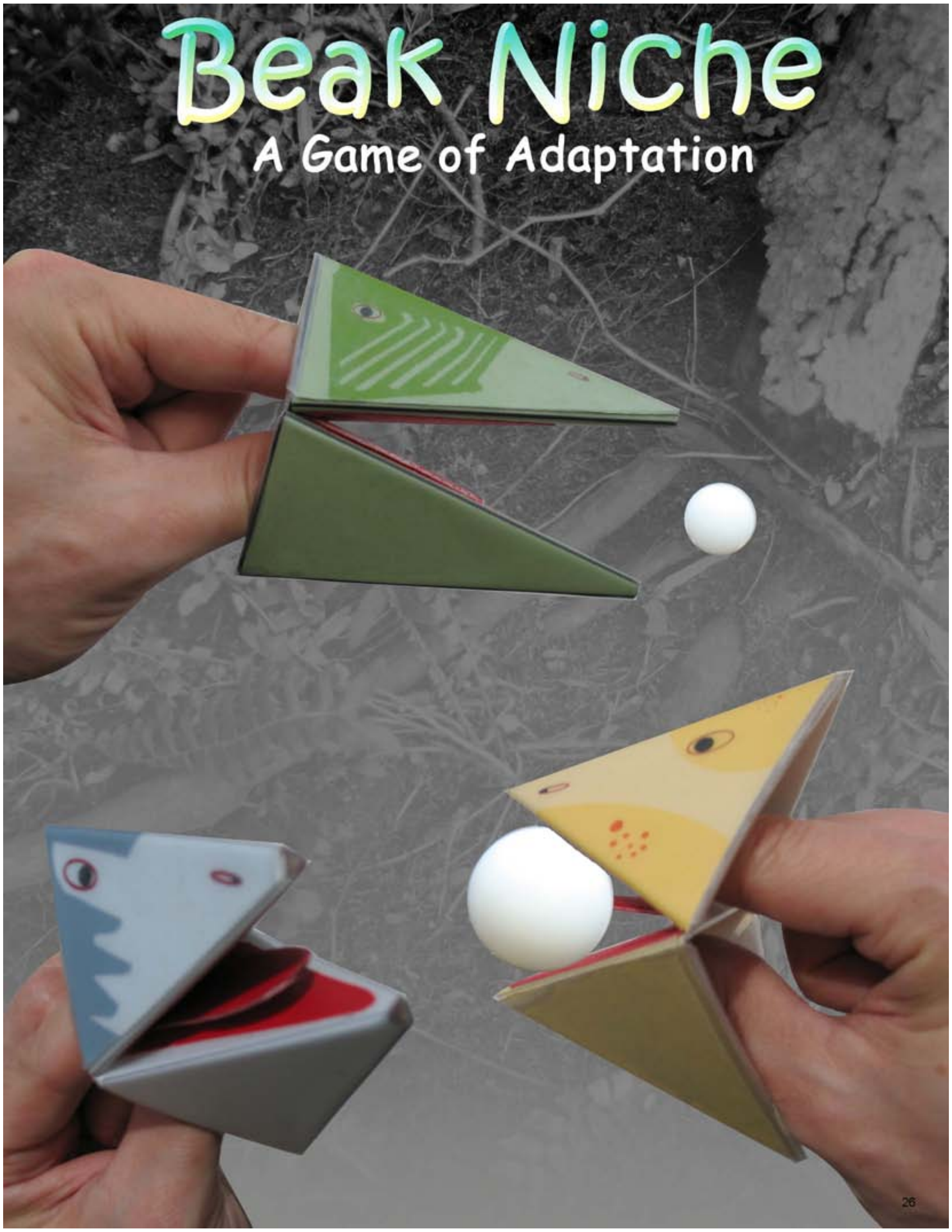
* Convergent Evolution:

* Analogous Structure:

* Vestigial Structure:

* Define AND give an example


The Recipe for Evolution
Mechanisms of Evolution
Population Adapts?
1.
(inter- and intra-)
2.
3.
4.
&
25


Beak Niche
A Game of Adaptation
26

Lesson Plan for *Beak Niche*

Learning Objectives

1. The student will understand the concept of population.

2. The student will understand what genetic variation is and its effect on observable traits in a species.

3. The student will know the process of natural selection, which works, through the environment, on populations with genetic variation.

4. The student will understand how an individual's fitness is dependent on the environment. If the environment changes, so might fitness.

5. The student will understand how natural selection causes a population to adapt differently to different environments.

6. The student will understand the effect of gene flow on a population.

7. The student will understand the effect of genetic drift on a population.

8. The student will know why variation is important to a population's survival (i.e. because the environment can change).

Scenario

The game is designed to reinforce the concepts illustrated in Chapter 3: Mechanisms, in the animation. So, after watching this chapter, the class will pretend to be a population of birds competing for food in two different environments. There is a shallow-hole environment with big seeds and a deep-hole environment with small seeds. The population has "genetic variation" as indicated by the 3 different phenotypes: a green long beak bird with a slick mouth surface, a blue medium beak bird with an average mouth surface, and a yellow short beak bird with a rough mouth surface.

Logistics and Points of Discussion during the game

Conceptually, the game mimics what you would find in nature; that is, it's based on probability. There are environments with selective pressures and individuals in populations with varying degrees of fitness, so it is very likely that (A) the populations will evolve and (B) the mechanism for that evolution will be natural selection. As in nature, the dice are heavily loaded for this scenario. Also, as in nature, the game does not produce black and white results; it is not absolute. It is possible your population may not evolve. And it is possible your population may evolve, but more through genetic drift, and not natural selection (i.e. if the group with the least fitness somehow manages to be the most reproductively successful - it would be genetic drift as a result of that particular sample – it is possible, but very unlikely). The point of the game is to have some physical object to use to review these concepts and see how they relate.

1. Set up both environments and have 6 students at each environment.
2. Each of the 12 students at an environment will get a phenotype. Start off with 2 of each phenotype at each environment.
3. The teacher will explain to the class that they are a population of birds and ask the class if they remember, from the animation, the definition of a population.
4. The teacher will ask the class how they know their population has genetic variation (the answer is that there are different phenotypes).
5. The students will now take turns (one at a time) trying to get as much food as possible. They each get two, 10-second turns. Record the food score on the board for each player, and replace the food after each turn.
6. After they compete for food, the teacher will explain that if they got enough food they can support reproductive offspring.
7. The teacher tallies the food score on the board and determines the number of offspring each individual gets:

0 food = 0 offspring
1-6 food = 1 offspring
7-13 food = 2 offspring
14-20 food = 3 offspring
21-25 food = 4 offspring

8. Those 12 students replace the food, sit down and the new generation gets up. They get the same phenotype as their parent. If the class is small they can recycle students.

9. If needed, the teacher can explain that, while this is a very simplified version of genetics, it's useful in this demonstration to quickly show a basic selective inheritance of traits.

10. The new generation will repeat the game. The teacher can repeat this as much as necessary to demonstrate how different environments, with different selective pressures can cause populations to evolve and adapt differently.

11. The teacher will ask the students if their population is adapting to the environment. If they didn't already go extinct, the answer will likely be yes, in both environments.

12. The teacher will also ask the students, "For which traits are the environments selecting?" (answer: beak length and mouth surface)

13. At some point, the teacher will tell two random students from each environment, in one generation, to migrate to the other environment. The teacher will ask, "What just happened? Remember from the animation?" (The answer is gene flow). "Does this cause the population to adapt? (Most likely it does not).

14. Then play the game again.

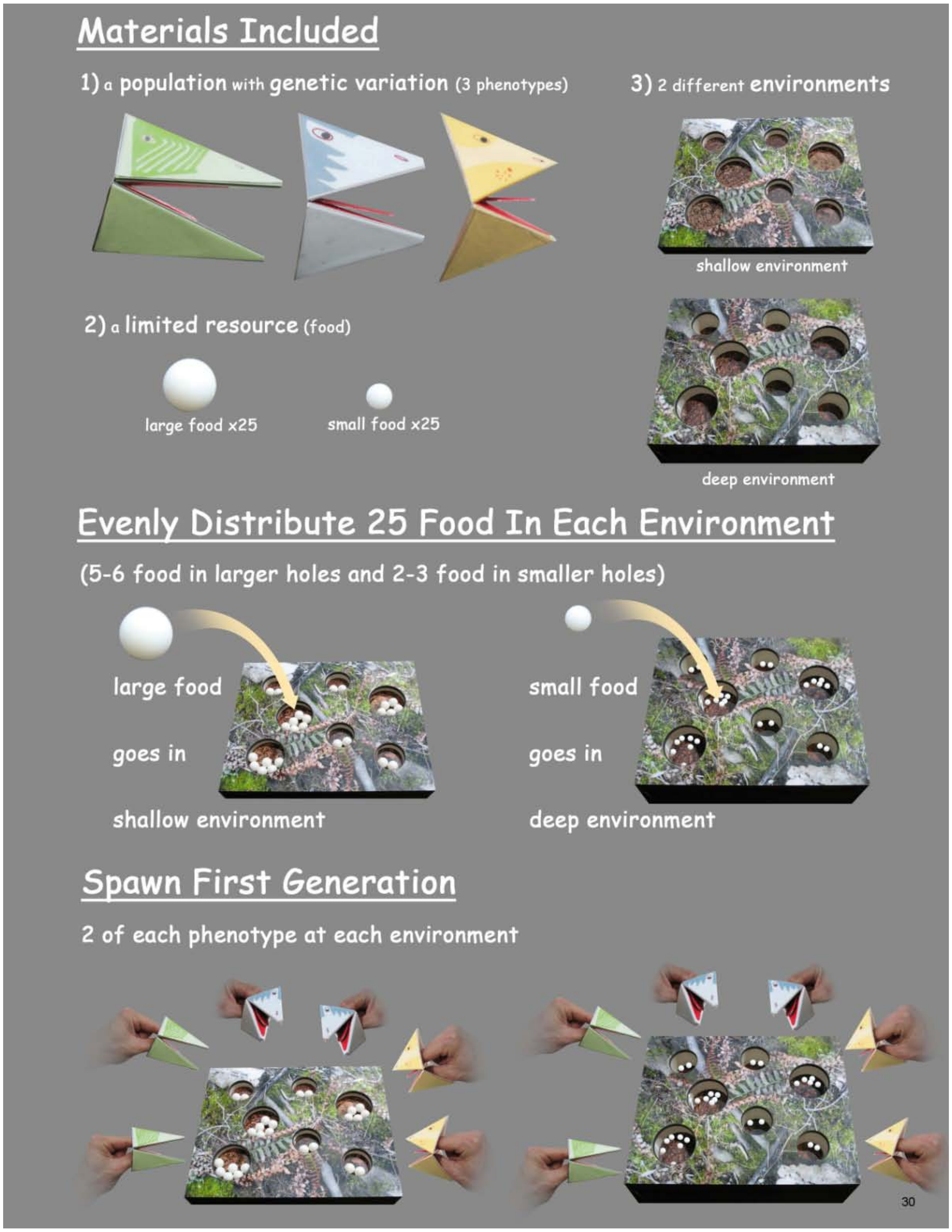
15. Now, after competing, instead of tabulating offspring in one environment, the teacher explains how a number of human corporations, motivated solely by profit, begin a vast wave of deforestation, obliterating an entire ecosystem. All the students at that environment sit down. No offspring for them. The teacher will ask, "What just happened? Remember something like this from the animation? Something very random, and not usually part of the natural environment, causes what??" (answer: genetic drift). "Did it cause the population to adapt?" (answer: no, they all died)

16. Play the game again, only for the other environment.

17. Now the teacher will switch the environments, and asks "So what happens if the environment changes?"

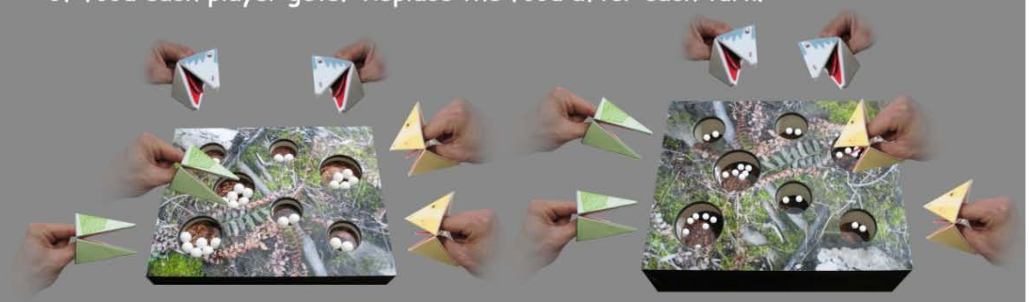
18. Play again.

19. The teacher will ask, "So why do you think genetic variation is so important for a healthy population?" (answer: because the environment can change)


Materials Included
1) a population with genetic variation (3 phenotypes)
3) 2 different environments
shallow environment
2) a limited resource (food)
large food x25
small food x25
deep environment
Evenly Distribute 25 Food In Each Environment
(5-6 food in larger holes and 2-3 food in smaller holes)
large food
goes in
shallow environment
small food
goes in
deep environment
Spawn First Generation
2 of each phenotype at each environment
30

First Generation Compete!

Take turns competing for food one-at-a-time. Each individual gets two, 10-second turns to gather as much food as possible. Keep track of the amount of food each player gets. Replace the food after each turn.



No Cheating, Please!

You must get the food in your mouth.

"Scooping" does not count. Replace any food that flies out by accident.

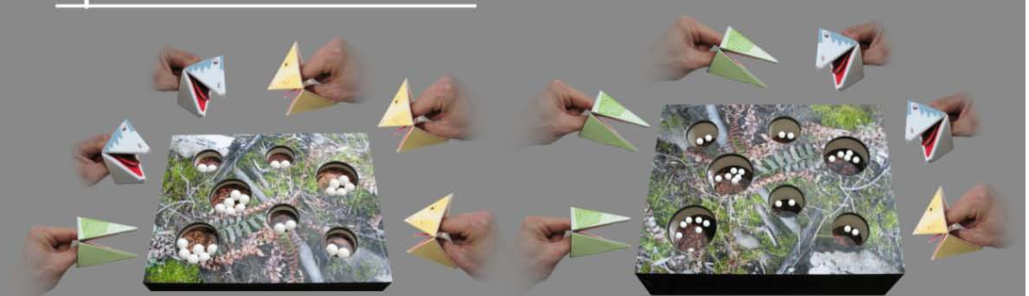
Reproduce!

The total amount of food you aquired in both turns determines the number of offspring you can support.

Tally the results for each individual.

0 food	= 0 offspring
1-6 food	= 1 offspring
7-13 food	= 2 offspring
14-20 food	= 3 offspring
21-25 food	= 4 offspring

Spawn Next Generation



Repeat!

Fossil Lab (Teacher Version with Answers)

Lesson Plan for Fossil Lab

Learning Objectives

1. The student will gain hands-on experience working with fossil casts and replicas.
2. The student will understand the phylogenetic tree, which is based on homologies.
3. The student will understand homologies and how they show common ancestry between species.
4. The student will use deductive reasoning to discover how these fossil species evolved and how they are all related.

Instructions

1. After watching the video, place the fossils on a table (the fossils are numbered).
2. Have the students come up with a hypothetical phylogenetic tree, based on what they think shows the relationships between the species. Allow the students to pick up and observe the fossil casts.
3. After forming their hypothesis, have the students read the descriptions of the species and then match them to the fossils.
4. Go over the correct answers with the class.
5. Then have the students fill out the blanks with the correct species in the phylogenetic tree worksheet, and place the listed homologies in the appropriate spots on the tree.
6. Have the students complete the post-lab questions.
7. Have the students evaluate their hypothetical tree and make changes to correct it, if needed.


1


2


3

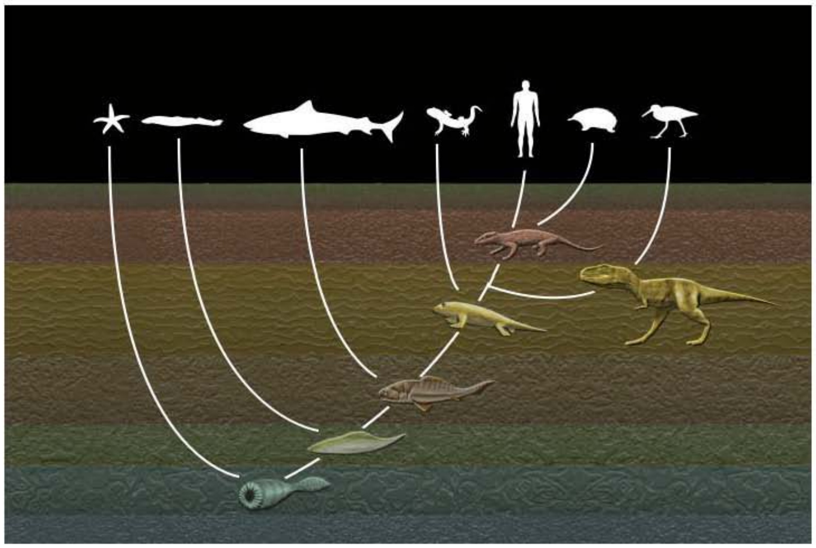

4


5

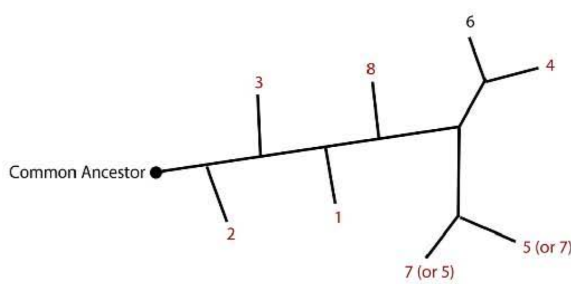

6


7


8



Hypothetical Tree (take a guess and fill in the blanks with the number labels on the species)



Now observe the fossils and images, and match the description to the correct number of the fossil.

Species descriptions:

1) Coccoderma barvaricum

This Sarcopterygian ("fleshy-finned") Coelacanth fish, with both pectoral and pelvic fins, was found in rocks dated 155 million years old. Older Sarcopterygians had similar fleshy fins which evolved into the terrestrial limbs of Tetrapods.

2) *Actinocrinites gibsons*

This Deuterostome with radial symmetry was discovered in rocks dated at 340 million years old.

3) Bothriolepis canadensis

This ancient fish, known as a Placoderm ("armored fish") had an extensive dermal skeleton, an adaptation that functioned as a protective armor, and well-developed spine-like pectoral fins. Placoderms are some of the earliest known Gnathostomes (jawed vertebrates).

4) Hesperocyon gregarious

This early Canidae species, found in rocks dated over 30 million years old, was an early ancestor to dogs and it climbed trees. Like modern canid species, it had prominent canine teeth.

5) Archaeopteryx lithographica

This reptile is regarded as an intermediate species between dinosaurs and modern birds. It was found in rocks dated at 150 million years old.

6) Mesohippus bairdi

This tiny horse species stood only 60cm, and was found in rocks dated about 30 million years ago. Like the modern horse, it had an interdental region, or space between the front and back teeth.

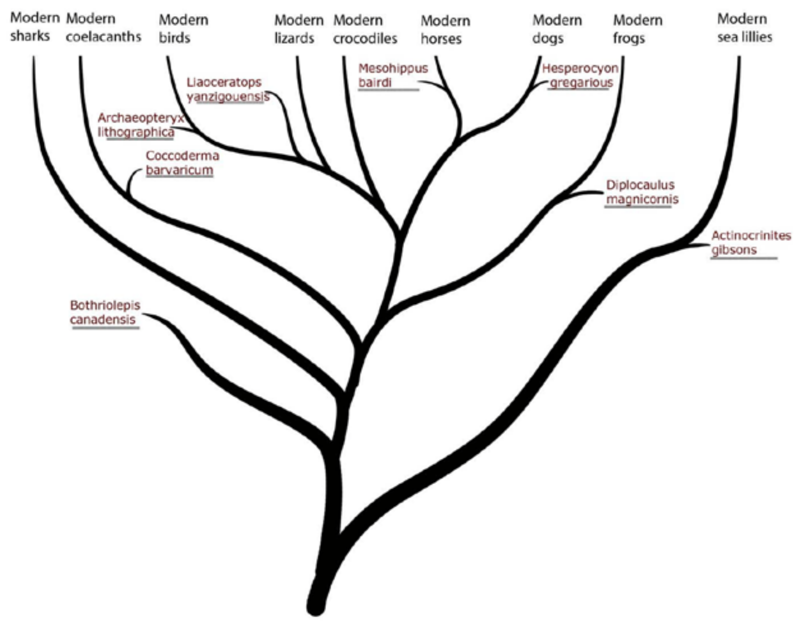
7) Liaoceratops yanzigouensis

This newly discovered dinosaur species was found in 130 million year old rocks. While being relatively close in relation to the familiar Triceratops, Liaoceratops was in fact a very tiny dinosaur, stood about one foot off the ground, and weighed about 7lbs.

8) Diplocaulus magnicornis

This amphibian species was found in rocks over 250 million years old. Like other early Tetrapods, it had a flattened skull with eyes on top of its head.

Now fill in the in the blanks with the correct species on the phylogenetic tree.



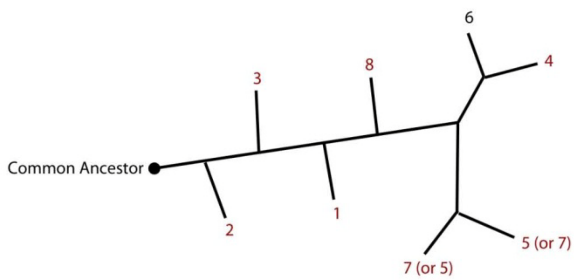
1) After you place the species on the tree, label it with the following homologies: terrestrial limbs (for walking on land), wings, specialized teeth (hint: look at the skulls!), radial symmetry, hair, jaws. fleshy fins, paired fins

2) Label the most recent common ancestor of frogs and dogs with the name Tetrapods.

3) Label the most recent common ancestor of crocodiles and all jawed fishes with the name Gnathostomes.

4) Label the most recent common ancestor of all mammals and all reptiles with the name Amniotes. Also add the homology of the amniotic egg in the correct spot.

Was your hypothesis correct? Make any necessary corrections.



Student Handouts

(available on Printable Materials CD)

Animation Script

Chapter 1: Introduction

If you were assigned the task to collect individuals from every living species on Earth, how would you do it? Well, for starters, don't quit your day job. Or you might want to consider staying in school, because this task would be completely impossible. Not just for you alone, but if every person on the planet worked in unison to gather members from every living species, the task would still not get done. Why is this?

Not only do we not know all species on Earth, we have absolutely no idea *how many* species there are on Earth. We don't even have a good estimate. Every time a team of biologists goes into, say a tropical jungle, they wind up cataloguing hundreds of new species of insects. This happens every year. But those are organisms that we can see with the naked eye. What about all the microorganisms out there? Viruses?! We still haven't decided if they are within the confines of life. They have their own entire taxonomic system! Scientists have discovered about 2 million living species, but their estimates for the total number of species living on Earth range anywhere from 3 -100 million. So, where did all these species come from? They didn't just pop into existence out of nowhere, at least we've never seen that happen.

This is what we DO know: DNA is a shared trait of all life and, within a population, not only do gene frequencies change, but DNA recombines and mutates from generation to generation. Interestingly enough, this is the very definition of <u>Evolution</u>: that is, change in the genetic material (DNA) of a population of organisms from one generation to the next. *This is a fact.* There is no scientific debate on whether or not Evolution exists. It does exist: genetic change in a population from generation to generation does occur.

We also know why Evolution doesn't expand populations limitlessly in all directions; Evolution works through mechanisms, such as Natural Selection. More on that later... But, does evolution cause new species to arise from older species? Again, this is what we do know: the fossil record, DNA and protein analysis, comparative embryology, and all the homologies (or shared traits between species) show that new species do arise from older species. Of course, this can take thousands, sometimes millions, of years in a process called speciation.

Evolution is the cause for all the variation of life on Earth. Without it there would be no reason for you to have Biology class. Biology would be meaningless. In fact, the class wouldn't even exist. There wouldn't be chairs, or desks, or walls. This very animation would cease to be, along with my voice, because... *you* would not exist, either.

Chapter 2: The Fossil Record

So, where did we get this idea of Evolution? Charles Darwin gave us an explanation for how evolution works, but where did HE first get the idea? Well, you're standing on it.

The Earth's surface is composed of layers of rock. And some of that is sedimentary rock, in other words, rock formed from sediment. Now, if you had to guess, which layer do you think would be the oldest layer in this sedimentary rock? Well, it's the layer on the bottom. Think of a sand bottle, in which you pour one color of sand that settles to the bottom. We're depositing "sediment" here. Then you add another color of sand, which settles on top of the first color. In general, this is how the sedimentary rock of the Earth's surface is arranged, with older layers on the bottom and newer layers on top.

The data which support this concept is gathered using a technology called radiometric dating (radioactive carbon dating is one such technique). If they take a sample of rock from one of these layers… there will be radioactive atoms in that sample, which have been releasing particles over time. This is called decay. And using the rate of decay, scientists can measure the amount of certain elements to deduce the age of the rock sample. Radiometric dating has shown that the Earth is about 4 ½ billion years old, and in sedimentary rock, the oldest layers are generally on the bottom, with the newer layers on top.

And just like the rocks in the Earth's surface, certain fossils are found in corresponding layers. If we focus on the tiny branch of Evolution that is our own vertebrate lineage, this is what we find in the fossil record. In the oldest rocks on the bottom, we find only life forms without a head. On top of that we find everything with a head. On top of that we find everything with a head, jaws, and paired appendages. On top of that we find everything with a head, jaws, and paired apendages that walk on land. On top of that we find everything with a head, jaws, paired apendages that walk on land, and hair. And on top of that we find everything with a head, jaws, paired apendages that walk on land with 2 legs, hair, and a well developed brain.

This fossil record supports evolution because it shows how adaptations expand upon preexisting structures over time. This is NOT how things were *destined* to evolve; it's just how they *did* evolve. Evolution is not goal oriented. So in case you're feeling on top of it all, keep in mind that these ancestral species split into millions of other lineages, which evolved into all the species alive today. Now Evolution does not support the idea that any species is "superior" to any other species. So, we are not like the highest rung of a ladder. There's no ladder and there's no chain of being. We are only one tiny little branch on an ever expanding tree of life. Instead, you can think of these other living species as our very distant cousins, who are equally adapted to their respective environments.

Now, tectonic shifts (think massive earthquakes, volcanic eruptions, continental drift) have, in specific areas, disrupted the layers. But geologists can still discern the pattern of rocks. And remember, they can use radiometric dating to confirm the identity of the layer. This is how scientists are able to create vast and intricate geological maps, which evolutionary biologists can then use to find certain fossils. For instance, if they are searching for dinosaur fossils they will know in which layer to look. However, if they were looking for human fossils they wouldn't find any in this layer because the rocks are too old, and humans had not evolved yet. Rather, they would know to look in newer rocks to find human fossils.

In a sense, the entire field of Evolution is like a giant jigsaw puzzle. We've put enough pieces together to know it's there, but there are many pieces that have yet to be found.

Chapter 3: Mechanisms

So, how does Evolution work? First of all, Evolution works on populations, not individuals. So if you work out and get really fit, socialize and make a bunch of friends, and study really hard and get very smart, are you "evolving"? Are you "adapting" to your environment? You might maximize your genetic potential to become a sharper, better looking giraffe. But in terms of Evolution, the answer is no because you, an individual, do not evolve or adapt. *Populations evolve and populations adapt over generations.*

Now, a population is a localized group of individuals that belong to the same biological species. This means they can interbreed and produce fertile offspring. Also, populations are kind of a relative concept (meaning it depends on what you're looking at and how closely you're zooming in). You might be comparing 2 giraffe populations within one region in Africa. Or, you could be comparing all the giraffes in that region with all the giraffes in another region. Or, you might even be observing all the interbreeding giraffes in Africa, and comparing them to a population of an entirely different species, like: the population of *Homo sapiens* in your city, country or planet.

But how do populations evolve and adapt? Well there are a few ways. Let's say we have a population of giraffes, with some males and some females. The females are watching the males eat leaves off a tree. And in this activity, we can see some variation in traits. Specifically, there's variation in neck length. In fact, we see 3 different phenotypes of neck length in the males. James has a very long neck and can easily reach the nutrient rich leaves on the tree tops. Sam has an average length neck and can get just enough leaves to get by. Ben, however, has a very short neck and can barely get a leaf. This means, that in this environment, James is the fittest individual for getting enough nutritious leaves to live long enough to reproduce. So,

this kind of competition (in this case, for food) is one environmental factor in something called natural selection.

Natural selection is the differential success in the reproduction of different phenotypes (like the 3 giraffes) resulting from the interaction of the organisms with their environment. Now natural selection causes the population to ***adapt***, because the next generation will likely look more like James, with longer necks. Another type of natural selection is called sexual selection. Sexual selection is natural selection for mating success. There's intersexual selection, where members of one sex are choosy for members of the opposite sex. And then there's intrasexual selection, or competition among members of one sex.

But, not all factors in an environment favor the reproductive success of one particular phenotype. Predation is another factor in natural selection, and often in nature, it can go against sexual selection. While Sam's babies might not have the long necks that James' babies would've had, they'll be less noticeable to predators. And at least they'll have more sex appeal than Ben's babies. So, with predation, this is how the population might adapt. Natural Selection is a balancing of many different environmental factors with many different physical traits of organisms. But natural selection is just one way populations evolve.

Gene flow refers to the genetic additions or subtractions from a population resulting from the movement of fertile individuals or gametes. Gene flow is another way a population can evolve. But gene flow alone rarely causes a population to adapt. But wait, let's not forget about genetic drift.

Genetic drift is a change in the gene pool of a population that takes place strictly by random chance alone. So in the case of meteor shower… (kaboom!). Also unlike natural selection, it does not cause a population to adapt. The next generation will NOT be more adapted to meteors falling on them. That was just a random event that changed our population's gene pool.

Oh, I almost forgot. There's one more cause for evolution, and it's something that farmers and ranchers and animal breeders do for a living. Artificial Selection is the selective breeding of domesticated plants and animals to encourage the occurrence of desirable traits. In other words, in artificial selection we are the environment and we select the individuals who will make it to the next generation. You see these individuals when you cruise the produce section at the grocery store or your local pet shop. But do populations which evolve through artificial selection adapt? Take your little puppy and put him out in the Alaskan arctic and he probably won't fit in so well. Plop him on a sofa in front of a warm fireplace, however, and he will seem perfectly adapted. So yeah, sure, they adapt to us and the environments we create.

We'll come back to the giraffes in a little bit, but for now, let's go into the laboratory so we can manipulate the environment to observe changes in a population under the microscope.

In the lab...

Let's say we have a population of microscopic, multicellular organisms. When we look more closely at their trait for surface area to volume ratio, we discover that there are 3 different phenotypes. So let's discuss the different types. One has a low SA/V ratio. In other words, the outer surface is about as small as it can get for this volume. The type beside it has the same surface area, but its volume has decreased, so it has a higher SA/V ratio. The last one, with a deep invagination, has the most surface area per volume, and therefore the largest SA/V ratio. And because our population has this *variation* of traits, we say it has *genetic variation*. Look around your classroom; it's a population. Does anyone look exactly the same? (Unless your class has identical twins, probably not) So the population of your classroom has genetic variation, just like this one. This variation can be plotted on a distribution curve, so we can see that most of our population has an average SA/V ratio. But few individuals have a very low or a very high SA/V ratio. So, now that we've analyzed our 3 phenotypes for this trait, and placed them on a distribution curve, let's see what happens with selective pressures from an environment. Choose an environment. You can release food, biotoxin, both food and biotoxin at the same time, or a predator.

The food is a positive, life-sustaining environmental factor for our population. Which type seems to be the most adapted to getting food? The one with the highest SA/V ratio will have a higher chance of getting enough food because of its larger SA. So, which type would likely be the most successful in reproducing offspring in this environment? Yes, the type that is most adapted to getting food will have a better chance of living long enough and having the energy to reproduce more, and more successfully. Now what do you think will happen to our distribution curve in the next generation? It shifts more towards the individuals with the highest SA/V ratio because they were the best at getting food, and therefore could reproduce more. This is a kind of natural selection called directional selection. In this case the "direction" is towards the phenotype with the highest SA/V ratio.

The biotoxin is a harmful molecule produced by another organism in this environment. If an individual in our population gets too much biotoxin, it will die. So, what organism is most susceptible to the biotoxin? The one with the highest SA/V ratio will likely be most affected by the biotoxin. But which one will be the most reproductively successful? Well, since the one with the lowest SA/V ratio receives less, it is safest from the biotoxin. Therefore, in this environment, it is more likely to survive to reproduce. So, in the next generation there will be more individuals with a lower SA/V ratio. So, what happens to our distribution curve in the next

generation? It shifts towards the individuals with the lowest SA/V ratio to reflect that there are more of them being reproduced in this environment. This kind of natural selection is called directional selection. In this case, the "direction" is towards the type with the lowest SA/V ratio.

Releasing both the food and biotoxin, a positive and negative stimulus, respectively, at the same time, will create a more complex environment. So, what type is the most adaptive to this environment? It's hard to say, and in real life there are often an incredible number of environmental factors, each balancing the benefits and costs of an individual's traits. But perhaps we find that the type with the average SA/V ratio gets just enough food and avoids the biotoxin just enough to survive, so that in this environment, we find it to be the most reproductively successful. But what do you think will happen to our distribution curve in the next generation? In this environment, our distribution curve will spike in the middle and be reduced on both sides, showing that in the next generation our population will have even more individuals with an average SA/V ratio. This type of natural selection is called stabilizing selection. Think of this as selecting for the most "stabile" or "balanced" set of traits, in between the 2 extremes.

The predator is a hydra that has adapted to feed on our population. While the hydra can devour any of the phenotypes, it is specifically adapted to eat the most numerous phenotype, which are the ones with the average SA/V ratio. So, which phenotype will show the least reproductive success in this environment? The one in the middle right? Because that's the type the predator is most adapted to eat. And what do you suppose might happen to our distribution curve in the next generation? Well, the individuals with an average SA/V ratio will decrease and the 2 phenotypes at the extremes will reproduce more. So, our curve would look something like this. This is a kind of natural selection called disruptive selection. So, the predator apparently "disrupted" our nice singular curve into 2 smaller curves.

Back to the giraffes…

So… back to our population of giraffes. Little did Patricia and Becky know, and you wouldn't know it from looking at him, but Ben had a few germ cells tucked away that were carrying some really awesome mutations. In fact, you might call them super sperm! You see, while there are many causes of Evolution, there is one cause which rules them all. So what is it that all 4 of these mechanisms need in order to work? Let's think about this. What if we had started out with just a population of only Bens? When they compete, get sexually rejected or eaten by predators, who, if anyone, will survive to mate and reproduce? Ben, right? But he can only reproduce with more Bens (which is kind of problematic). And if more Bens show up from a neighboring population, there won't be much *gene flow*. Nor will *genetic drift* have any real

effect if some of the Bens survive whatever random thing happens. And if we wanted to artificially select to breed giraffes from this population, well, you got your choice of Ben... or Ben. We need something to get these mechanisms of Evolution to cause... well... Evolution. What is it?! The answer is genetic variation. Now... what causes this genetic variation? Well, your variation comes in 2 different varieties. You got new combinations of genes and new genes... in other words, sex, which recombines existing genes into new genetic flavors, and mutation, which are little changes in DNA that create new alleles and new genes. So, sexual recombination and mutation create variation, which allow these mechanisms of evolution to work.

Now, here in the forest, some of Ben's sperm, with very rare but awesome mutations, will recombine genetically with Patricia's eggs, to make some really fit offspring. Well, these new guys take off through natural selection, and over many generations they adapt to the forest. With each new generation they get new mutations and sexual recombination, which leads to more variation, which allows natural selection and genetic drift to cause Evolution. We're not around so there's no artificial selection. And Ben and Patricia's population is reproductively isolated from other giraffe populations, such as Gene's. Meaning, no *gene flow* and they're not mating with giraffes from these other populations. When evolution works like this over long periods of time (a matter of hundreds of thousands to millions of years), coupled with reproductive isolation, you get new species. And if you can understand just this much by the time you get to college, you'll be... (awesome).

Chapter 4: Embryology

Embryology is the science which studies the development of embryos, from the fertilization of the ovum to the fetus stage. What does embryology have to do with Evolution? We know that DNA mutations in the germ-line cells (that is, the egg and sperm) cause changes in the development of the offspring. And this changes the morphology, or form and structure, of the adult organism. And over hundreds of millions of years the changes in morphology can gradually become very great. But how does this idea show relationships between the species?

Well, did you know our embryology still has a lot in common with our recent relatives? Like all vertebrates, for instance, go through very similar stages of development. We see the following pattern in all fish, amphibians, reptiles and mammals (including humans). First there comes a fertilized egg which starts off as a *single cell*. That cell divides to form two cells in the *cleavage stage*, and then many cells in a stage called a *morula*. This ball of cells forms a cavity, becoming hollow, and goes through a stage called a *blastula*. The blastula develops a little hole, which in all vertebrates becomes the anus, and forms 3 layers of tissue (called endoderm, mesoderm and ectoderm), thereby becoming a *gastrula*. And then this develops into a little guy with a head, eyes, pharyngeal arches (we'll talk about those later), 4 limbs and a notochord.

So, how is it that our development has so much in common with all these other species? The answer is that the specific genes, in our DNA, which control development, are essentially identical to the genes in these other species. We still have a lot of the same genes with the same developmental functions. These genes include egg polarity genes, segmentation genes, and homeotic genes (or Hox genes). Basically they encode transcription factors which transcribe the next set of genes in the genetic cascade. This genetic cascade is just like the domino effect.

First, egg polarity genes divide the egg along the anterior/posterior axis. This tells the egg where it will form a head and where it will form a tail. Along this axis, segmentation genes divide the developing embryo into specific areas, or segments. And then homeotic genes, called Hox genes for short, give those areas a specific identity.

So, these developmental genes, in general, are very "conserved" in nature, meaning they don't mutate very much at all. Because when there is a mutation in one of these genes, it affects this critical early development, which affects everything after that in the genetic cascade, and almost always results in an unsuccessful organism.

But the question remains, what part of DNA does create successful mutations? If not the very conserved egg polarity, segmentation, or hox genes, then what? Well, this is what is currently being researched on the frontiers of evolutionary developmental science, called "evo-devo." While conducting research at UTSW Medical Center in Dallas, evolutionary biologist Dr. Trey Fondon, discovered one possibility for how, or where, DNA mutates. He studied many breeds of dog skulls and the variation in their morphology. He scanned the skulls with a 3d laser and found mathematical relationships in their shapes. The mutations he found in their DNA were tandem repeats of triplet DNA code upstream from the Hox genes controlling the skull morphology. This would allow for more or less transcription of the developmental protein, which would affect skull morphology. Evolution almost never takes the simplest path, but that's what makes it so fascinating. And there's so much more out there left to discover about how genes mutate and affect Evolution.

Chapter 5: Phylogeny

Phylogeny is the evolutionary history of a species or group of related species. Meet your extended family tree for the last 400 million years. At these nodes are all the living species that you can go observe today. And at these nodes are representations of our common ancestors with these species. Every year, as we uncover more fossils and gain better technologies science is improving our understanding of what these ancestor species looked like. So these are visual estimates which are becoming more definite over time. Also keep in mind that this is an incredibly simplified version of a phylogenetic tree. If we were to zoom in on just one of these branches we would see many smaller branches of species.

Phylogenetic trees are often just represented like this, to simplify matters. So, where would you find our most recent common ancestor with Amphibians? The node representing Tetrapods is correct. Your genetic link to a frog or salamander was a four-limbed Tetrapod with air breathing lungs. Now can you find the most recent common ancestor of all Chondrichthyes and all Reptiles? A fish with jaws and paired fins was the common ancestor between these two groups. It was a Gnathostome, and this fish was also our ancestor. And because this represents a part of our lineage, it means that humans are also Mammals, Amniotes, Tetrapods, Gnathostomes, Craniates, and Deuterostomes. But we are also so much more. Our DNA is a shared trait that relates us to all life, like trees and even bacteria.

Which leads to the question, what is this so called "phylogenetic tree" based on? In other words, how do we know that the puzzle pieces fit together just like this? Well, a phylogenetic tree like this one is based on something called homologies. A homology is a shared trait between species that is due to common ancestry. Sometimes biologists refer to homologies as "synapomorphies." When a homology is structural we call it a homologous structure.

We can label our tree with some homologous structures like this. These are certainly not all the homologous structures, but just a few to give you an idea of how this works. Now, when we label this with homologous structures, it means that every group after has that structure, or something homologous to that structure. So, looking at the homologous structures on this phylogenetic tree, which group or groups have terrestrial legs? Yes, all tetrapods originally had legs that evolved to walk on land. That includes mammals, reptiles, and amphibians.

So we can say that your arms and legs are "homologous" to the arms and legs of any amphibian, reptile, or mammal. These are homologous structures; our ancestral tetrapod evolved legs that walked on land and amphibians, reptiles and mammals continued to evolve those legs. Do you see how in all these limbs there is a very similar arrangement of bones? But then what about this fish fin? Pretty different arrangement right? We do know, however, that our tetrapod limbs evolved from fish fins. But how do we know this? How do we know this when both the structure and function of fish fins are different than the structure and function of our arms and legs?

This is where current DNA research enters the picture. Remember those hox genes from the previous chapter, the ones that control those critical stages of embryological development? Well it just so happens that these hox genes regulate another gene called Sonic Hedgehog (named after the video game), which controls development of both fish fins and our arms and legs. So we know that even shark fins are genetically homologous to our arms and legs, which makes them homologous structures. So all "Gnathostomes," which are jawed vertebrates and include everything from sharks to mammals, have homologous limbs.

OK, so what about insect legs or wings? Are they homologous to all of these other homologous structures? Actually, no. We can trace our phylogenetic lineage back to when our aquatic ancestors had no fins... no limbs at all. But our common ancestor with arthropods, including all insects, lived millions of years before this. So, the insects developed their limbs independently from ours in a process known as convergent evolution: that's when a similar, but not homologous, trait evolves in two or more distinct lineages. And we call that trait an analogous structure. These are structures which have similar functions but evolved separately. Therefore, insect limbs and vertebrate limbs are called analogous structures.

Now, I said all reptiles have limbs which are homologous to our limbs, right? And that includes birds because they are actually reptiles that evolved from dinosaurs. That's right. Phylogenetically speaking, the dinosaurs are still roaming... and er, flying over... the planet. And their wings are analogous to insect wings but homologous to our arms. But how about snakes, they're reptiles right? Where are the homologous limbs? They don't appear to have ANY limbs... or do they? In truth, some snakes, like boas and pythons, do still develop little hind limbs when they're embryos, and the limbs remain as vestigial structures in the adult.

Now, a vestigial structure is a homologous structure which has lost all or most of its original function through Evolution. So do humans have any vestigial structures? Yeah, lots of them. First of all you're probably sitting on one right now. That little nubbin of a bone called a "tailbone" you got back there is homologous to the tails of all our vertebrate cousins, even the ones swimming in the ocean. But it's not much use to us any more, kind of like those limbs on snakes, so we call it a vestigial structure. You even have vestigial blood vessels. Here's one in your heart, called the ductus arteriosus. It was useful for delivering blood in our fish ancestors, but for human adults... not so much. It closes up during our development and becomes, well, a vestigial structure.

There's one more very fascinating human homology which you should know about: the pharyngeal arches. The pharyngeal arches look kind of like little gills, right? Here's a fish embryo during the same stage of development. In adult fish the pharyngeal arches develop into jaws and gills. But since our development has evolved in another direction, gills not being so adaptive to breathing air on land, our pharyngeal arches develop into jaws and various

structures in your neck. So, these bones and cartilages in your neck and the bones and cartilages in fish gills are homologous structures. Our lower jaw, which forms from the 1st pharyngeal arch, is homologous also.

Chapter 1 Quiz

1. (TRUE OR FALSE) We've known for a long time exactly how many species there are on Earth.

2. All of the following are based on empirical observations which support evolution, except:
   A. The Fossil Record
   B. DNA and protein analysis
   C. Comparative Embryology
   D. All the shared traits between species.
   E. One's personal religious faith.

3. Evolution is
   A. the same thing as Natural Selection.
   B. a theoretical fringe science of Biology.
   C. kind of interesting, but not that useful.
   D. the change in the genetic material of a population of organisms from one generation to the next.
   E. adapting to your environment to become the superior organism.

4. (TRUE or FALSE) Evolution is "just a theory," and there are other theories out there which can explain the same biological phenomena.

Chapter 2 Quiz

1. Fossils are
   - A. randomly scattered in the Earth's surface.
   - B. in layers, with the newer fossils beneath the older fossils.
   - C. in layers, just like the rocks in the Earth's surface, with the newer fossils on top of the older fossils.
   - D. in layers of no chronological significance.

2. Which of these statements is true about the Earth's surface?
   - A. The older layers of sedimentary rock are generally under the newer layers.
   - B. The newer layers of sedimentary rock are generally under the older layers.
   - C. It's been disrupted by tectonic shifts so much that we cannot discern its history.
   - D. It's been disrupted by tectonic shifts, but geologists can still discern the pattern of rocks and their history.
   - E. Both A and D are true.
   - F. Both A and C are true.
   - G. Both B and C are true.

3. Radiometric dating
   - A. uses the compounds of radioactive atoms to prove the existence of fossils.
   - B. has shown that the Earth is about 4.5 billion years old
   - C. uses the rate of decay in certain radioactive atoms to determine the age of a rock sample.
   - D. Both A and B are true.
   - E. Both B and C are true.
   - F. Both A and C are true.

4. (TRUE or FALSE) In the fossil record, mammals can be found in any geological layer.

5. In the fossil record
   - A. organisms with heads are not found below a certain geological layer.
   - B. organisms with jaws are not found below a certain geological layer.
   - C. organisms with hair are not found below a certain geological layer.
   - D. All of the above are true.
   - E. None of the above are true.

6. (TRUE or FALSE) Some organisms without heads evolved after the first organisms with heads.

7. (TRUE or FALSE) Humans are the superior species on the planet because they are so intelligent. In a sense, they are the highest rung on the evolutionary ladder.

8. In the fossil record
    A. creatures with hair evolved before the first creatures with jaws.
    B. creatures with jaws evolved before the first creatures that walked on land.
    C. creatures that walked on land evolved before the first creatures evolved with heads.
    D. creatures with jaws evolved after the first creatures with heads.
    E. B, C and D are correct.
    F. B and D are correct.
    G. None of the above are correct.

Chapter 3 Quiz (Part 1)

1. Evolution works on
   A. individuals
   B. communities
   C. ecosystems
   D. populations

2. A population is a localized group of individuals that
   A. belong to the same species.
   B. belong to different species.
   C. can interbreed and produce fertile offspring.
   D. do not migrate and are not part of any other group.
   E. Both B and C are correct.
   F. Both A and C are correct.
   G. None of the above are correct.

3. Natural selection is the differential success in the _______ of different phenotypes resulting from the interaction of the organisms with their ________.
   A. competition, species
   B. attraction, sexual selection
   C. avoidance of predators, population
   D. reproduction, environment

4. Two rams butting heads for the female sheep (ewes) is an example of
   A. intersexual selection.
   B. intrasexual selection.
   C. primitive male bonding.
   D. true love.

5. Sexual “choosiness” for members of the opposite sex is
   A. intersexual selection.
   B. intrasexual selection.
   C. good fashion sense.
   D. completely random.

6. Natural selection might involve all the following, except:
   A. competition for food

B. predation
C. sexual selection
D. genetic drift

7. A few fertile members of one population move to another population. This is an example of
   A. heterozygous advantage
   B. genetic drift
   C. gene flow
   D. the founder effect

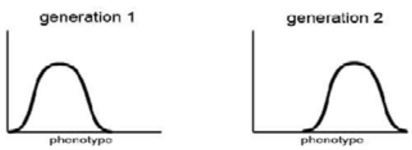
8. Genetic drift causes evolution strictly by
   A. meteor showers
   B. random chance
   C. surprise
   D. adaptation

9. Which of these causes a population to adapt?
   A. genetic drift
   B. natural selection
   C. gene flow
   D. all of the above

10. An example of artificial selection is
   A. humans breeding dogs from wolves.
   B. bacteria having antibiotic resistance.
   C. humans growing Gala apples to eat.
   D. both A and C

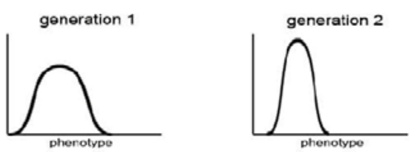
Chapter 3 Quiz (Part 2)

11. The mode of natural selection represented in the population distribution curves below is



A) directional selection
B) stabilizing selection
C) disruptive selection

12. The mode of natural selection represented in the population distribution curves below is



A) directional selection
B) stabilizing selection
C) disruptive selection

13. The mode of natural selection represented in the population distribution curves below is

A) directional selection
B) stabilizing selection
C) disruptive selection

14. The mechanisms of natural selection, gene flow and genetic drift are dependent on a population's ________, to cause evolution.
    a. genetic substitution
    b. genetic variation
    c. dominant phenotype
    d. adaptation

15. Genetic variation in a population is generated by
    a. mutation
    b. sexual recombination
    c. adaptation
    d. natural selection
    e. Both A and B are true.
    f. None of the above are true.

16. For a new species to evolve, a population needs
    a. genetic drift
    b. gene flow
    c. adaptation
    d. reproductive isolation

Chapter 4 Quiz

1. Mutations in the ______ cells change ________, which changes _______ in the adult organism .
    A. somatic, morphology, development
    B. germ, embryological development, morphology
    C. stem, ontogeny, phylogeny
    D. single, recombination, selection

2. (TRUE or FALSE) All vertebrates (mammals, reptiles, amphibians and fish) go through very similar stages of embryological development.

3. Species have similarities in development with other species because of the conservation of similar developmental
    A. embryos.
    B. cells.
    C. genes.
    D. patterns.

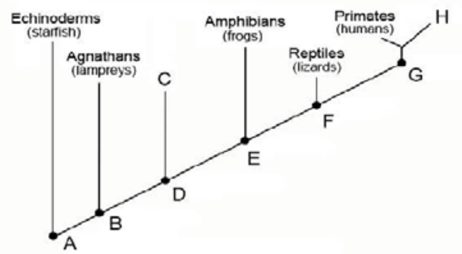
4. Developmental genes include all the following, except:
    A. homeotic genes
    B. egg polarity genes
    C. segmentation genes
    D. m-transcoder genes

5. Hox genes are very conserved among the species because
    A. they are responsible for critical stages in embryological development.
    B. they mutate more than other genes.
    C. they are the "genetic blueprint" for all the higher species.
    D. they determine where the single cell embryo will form a head and where it will for a tail.

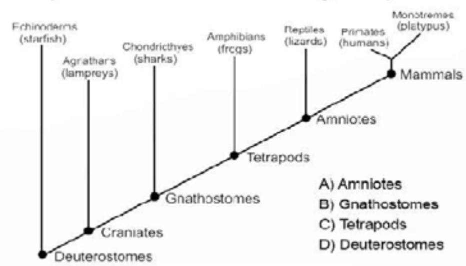
6. Current research has shown that the evolution in dog skull morphology has occurred mostly because of
    A. translocations in maternal effect genes.
    B. duplications in segmentation genes.
    C. tandem repeat mutations of triplet DNA code in cis-regulatory regions.
    D. embryological conservation.

Chapter 5 Quiz

1. Where would you find the most recent common ancestor of Agnathans and Primates?

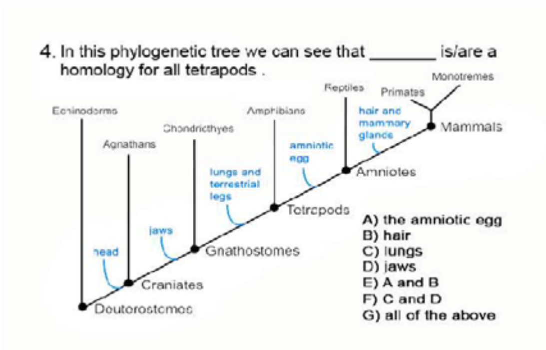


2. Amphibians are all of the following, except:



A) Amniotes
B) Gnathostomes
C) Tetrapods
D) Deuterostomes

3. A homology is a ______ between species that is due to _______.
   A. branch, random chance
   B. relationship, natural selection
   C. shared trait, common ancestry
   D. convergence, environmental pressures



5. Your arms are homologous to the forelimbs of all ________.
    A. Reptiles
    B. Primates
    C. Mammals
    D. Amphibians
    E. All of the above
    F. None of the above

6. (TRUE or FALSE) Shark fins are homologous to our limbs.

7. Bird wings are analogous to _______.
    A. human arms
    B. bat wings
    C. vestigial snake limbs
    D. insect wings

8. The evolution of bat wings and insect wings is an example of ________.
    A. homologous evolution
    B. convergent evolution
    C. speciation
    D. divergent radiation

9. One example of a vestigial structure in your body is your _______.
    A. lungs
    B. limbs
    C. jaws
    D. tailbone
    E. ribs
    F. brain

10. (TRUE or FALSE) Your jaws, earbones, and various bones and cartilages in your neck are homolgous to the fish gill arches.

Evolution Concepts

Evolution:

* Population:

* Natural Selection:

* Sexual Selection:

* Gene Flow:

* Genetic Drift:

* Artificial Selection:

Embryology:

Phylogeny:

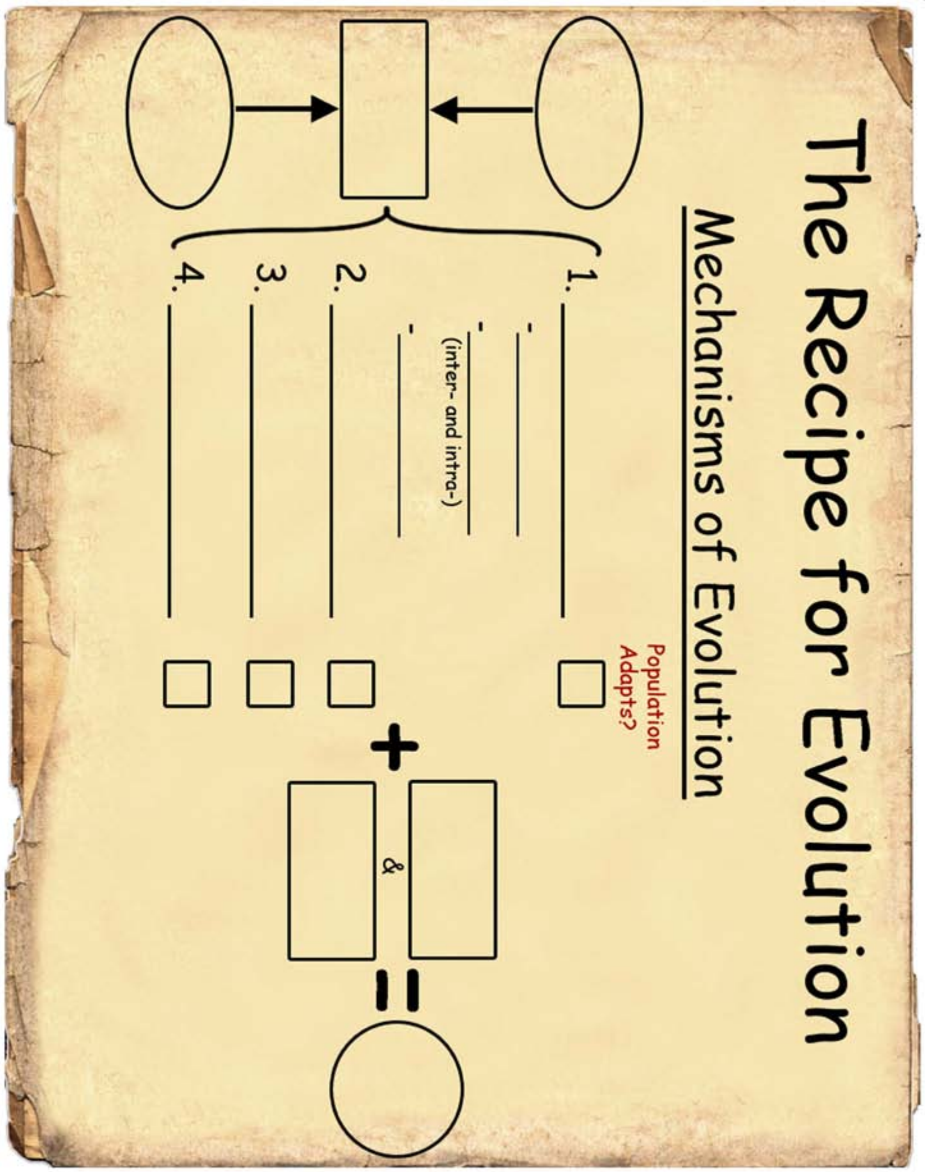
* Homology:

* Convergent Evolution:

* Analogous Structure:

* Vestigial Structure:

* Define AND give an example


The Recipe for Evolution
Mechanisms of Evolution
Population Adapts?
1.
(inter- and intra-)
2.
3.
4.
+
&
=

Materials Included

1) a population with genetic variation (3 phenotypes)

2) a limited resource (food)

large food x25

small food x25

3) 2 different environments

shallow environment

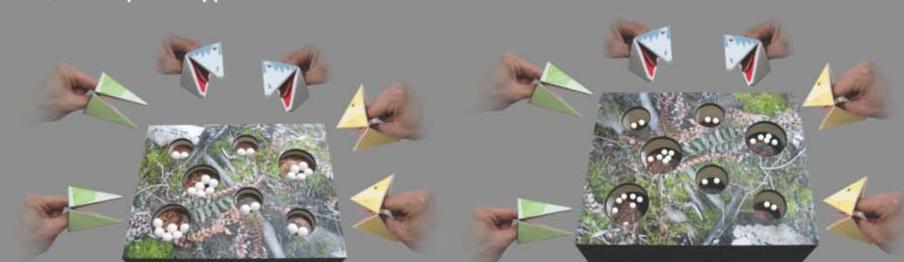
deep environment

Evenly Distribute 25 Food In Each Environment

(5-6 food in larger holes and 2-3 food in smaller holes)

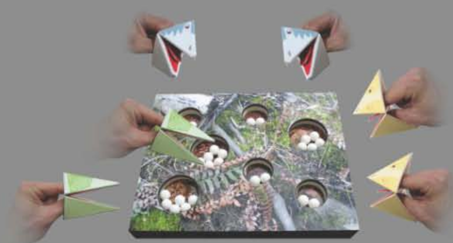
Spawn First Generation

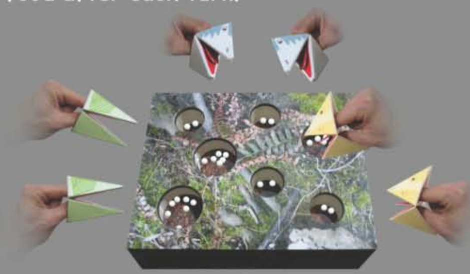
2 of each phenotype at each environment



First Generation Compete!

Take turns competing for food one-at-a-time. Each individual gets two, 10-second turns to gather as much food as possible. Keep track of the amount of food each player gets. Replace the food after each turn.





No Cheating, Please!

You must get the food in your mouth.

"Scooping" does not count. Replace any food that flies out by accident.

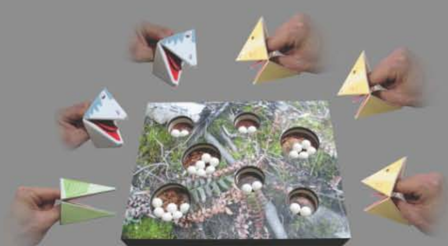
Reproduce!

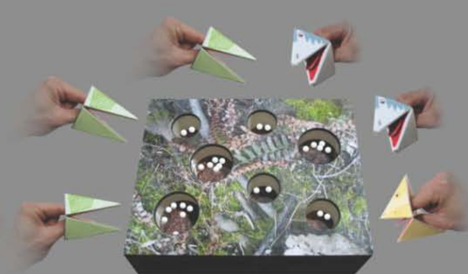
The total amount of food you aquired in both turns determines the number of offspring you can support.

Tally the results for each individual.

0 food	= 0 offspring
1-6 food	= 1 offspring
7-13 food	= 2 offspring
14-20 food	= 3 offspring
21-25 food	= 4 offspring

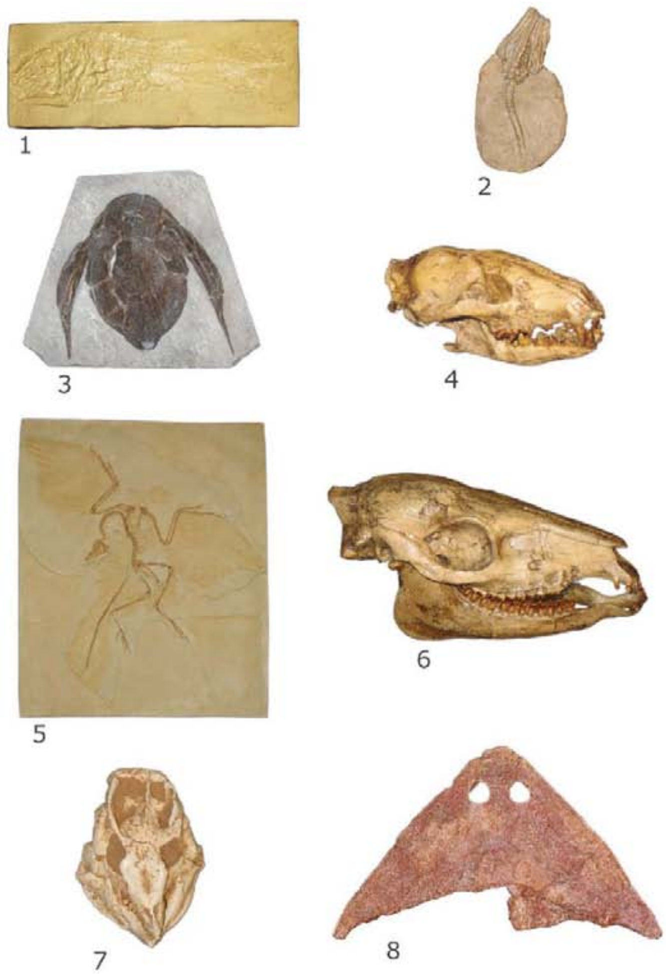
Spawn Next Generation

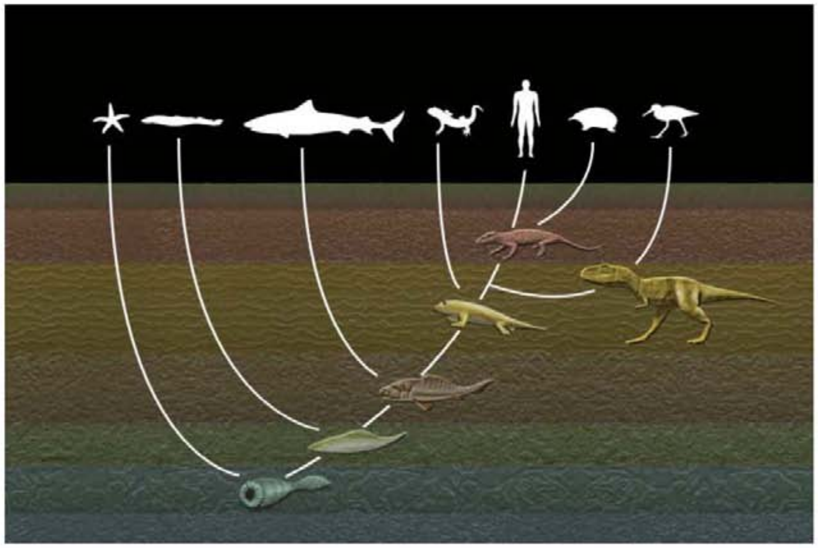




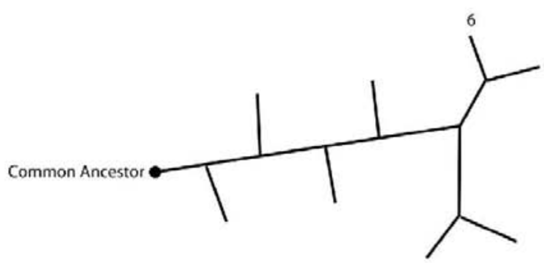
Repeat!

Fossil Lab





Hypothetical Tree (take a guess and fill in the blanks with the number labels on the species)



Now observe the fossils and images, and match the description to the correct number of the fossil.

Species descriptions:

Coccoderma barvaricum

This Sarcopterygian ("fleshy-finned") Coelacanth fish, with both pectoral and pelvic fins, was found in rocks dated 155 million years old. Older Sarcopterygians had similar fleshy fins which evolved into the terrestrial limbs of Tetrapods.

Actinocrinites gibsons

This Deuterostome with radial symmetry was discovered in rocks dated at 340 million years old.

Bothriolepis canadensis

This ancient fish, known as a Placoderm ("armored fish") had an extensive dermal skeleton, an adaptation that functioned as a protective armor, and well-developed spine-like pectoral fins. Placoderms are some of the earliest known Gnathostomes (jawed vertebrates).

Hesperocyon gregarious

This early Canidae species, found in rocks dated over 30 million years old, was an early ancestor to dogs and it climbed trees. Like modern canid species, it had prominent canine teeth.

Archaeopteryx lithographica

This reptile is regarded as an intermediate species between dinosaurs and modern birds. It was found in rocks dated at 150 million years old.

Mesohippus bairdi

This tiny horse species stood only 60cm, and was found in rocks dated about 30 million years ago. Like the modern horse, it had an interdental region, or space between the front and back teeth.

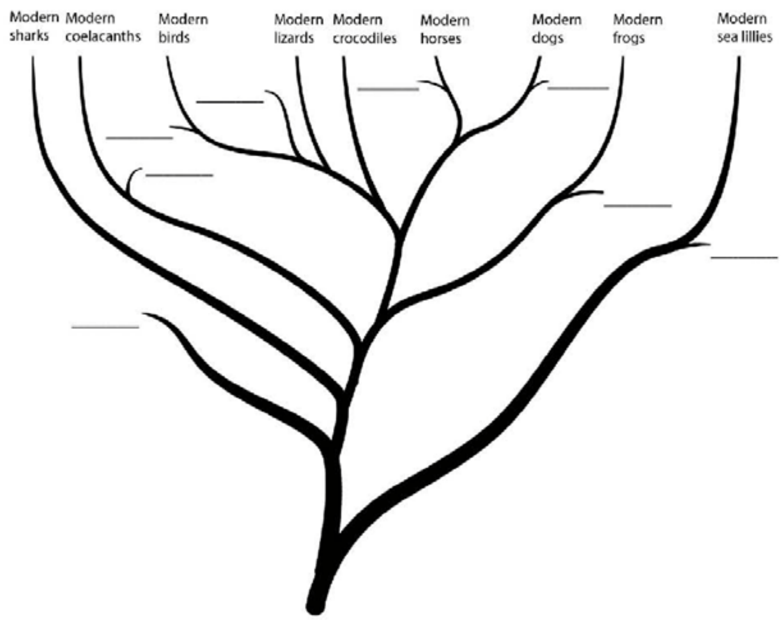
Liaoceratops yanzigouensis

This newly discovered dinosaur species was found in 130 million year old rocks. While being relatively close in relation to the familiar Triceratops, Liaoceratops was in fact a very tiny dinosaur, stood about one foot off the ground, and weighed about 7lbs.

Diplocaulus magnicornis

This amphibian species was found in rocks over 250 million years old. Like other early Tetrapods, it had a flattened skull with eyes on top of its head.

Now fill in the in the blanks with the correct species on the phylogenetic tree.



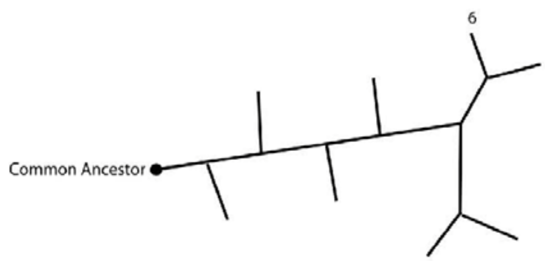
1) After you place the species on the tree, label it with the following homologies: terrestrial limbs (for walking on land), wings, specialized teeth (hint: look at the skulls!), radial symmetry, hair, jaws. fleshy fins, paired fins

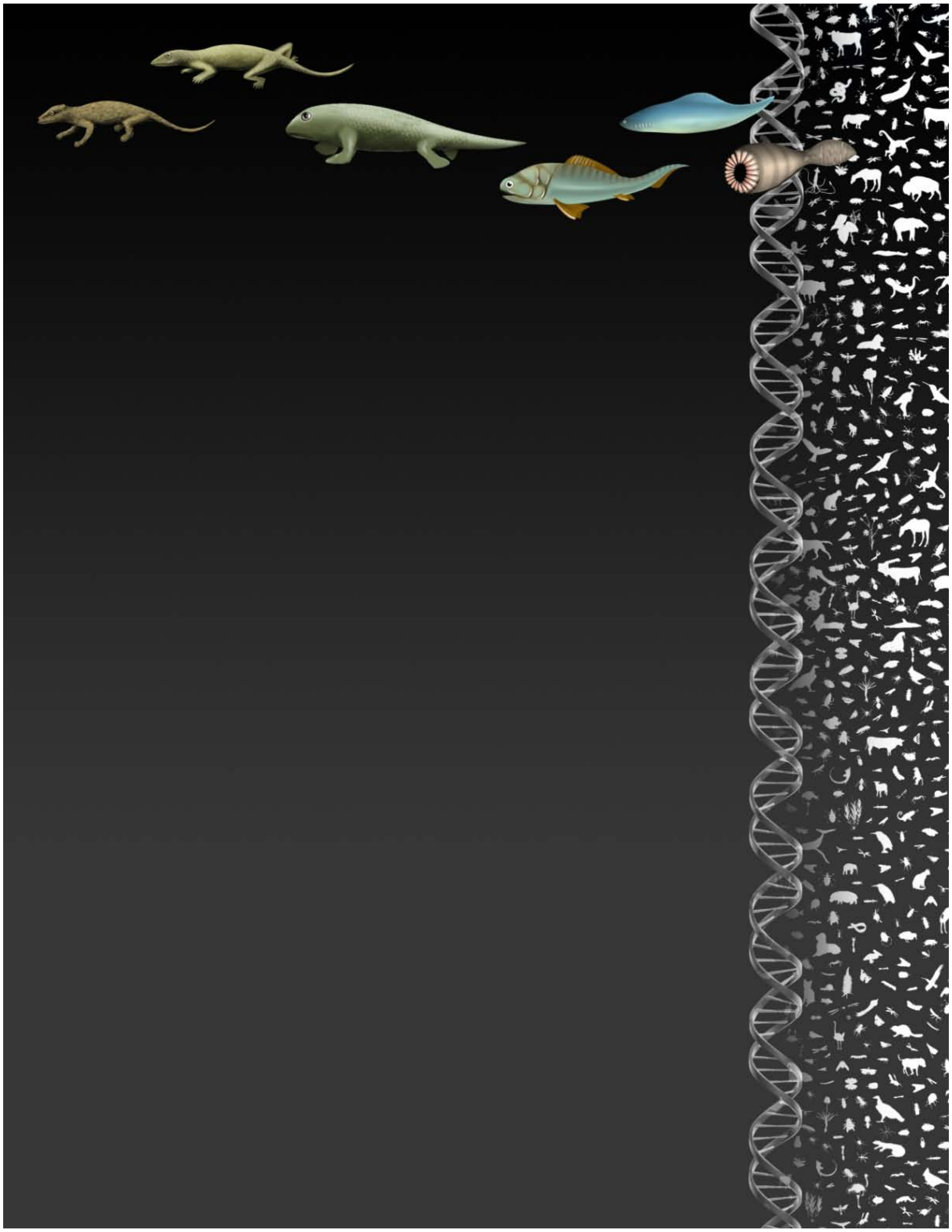
2) Label the most recent common ancestor of frogs and dogs with the name Tetrapods.

3) Label the most recent common ancestor of crocodiles and all jawed fishes with the name Gnathostomes.

4) Label the most recent common ancestor of all mammals and all reptiles with the name Amniotes. Also add the homology of the amniotic egg in the correct spot.

Was your hypothesis correct? Make any necessary corrections.





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