Manitoba
Education, Citizenship and Youth

Grade 12 BIOLOGY
A Foundation for Implementation
Part 2 - Biodiversity
Unit 3 – Evolutionary Theory and Biodiversity

DRAFT / Unedited Version

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Evolutionary Theory and Biodiversity

S4B-3-01 Define the term evolution, explaining how evolution has led to biodiversity by altering populations and not individuals.
Include: gene pool, genome.

Entry-level Knowledge

Students will have familiarity with the term evolution, but have not previously studied the topic.

Teacher Background

Evolution is the theme that unifies all of the different fields of biology. Emphasize the links among evolution, biodiversity, DNA and genetics. The modern synthetic theory of evolution combines Darwin's basic theory of evolution by natural selection with the findings of population biology and genetics. According to this theory, evolution occurs not to individuals, but to populations. Evolution is a change in the allele frequency in a population's gene pool. The fact that evolution occurs in populations (not individuals) must be emphasized.

Teacher Notes

Non-scientists may confuse two aspects of the term evolution. Some may believe that evolution is only a theory, and therefore is not as believable as a law. Take the opportunity to discuss that theories are explanations of observed phenomena and supported by a large body of evidence and experimentation. Theories are never "proven" into laws; they continue to be refined as more evidence supporting them is accumulated, or rejected when a better explanation of phenomena (another theory) is proposed. Laws are generalizations or patterns in nature (such as Boyle's Law, Newton's Laws of Gravity, the Laws of Thermodynamics), often expressed as mathematical relationships.

Some of the difficulties associated with evolution arise when the distinction between the reality that evolution has occurred (the fact) and the explanation for how evolution occurs (the theory). Evolution is indeed a fact. There is a massive body of evidence in the fossil record, in embryological, morphological and biochemical (DNA) studies etc. that demonstrates modern organisms evolved from older ancestral organisms, and that modern species are continuing to change over time. What is less certain is the exact mechanism of evolution. Several theories have been suggested to explain this. Charles Darwin proposed a theory – natural selection – to explain the mechanism of evolution. Biologists continue to debate the mechanisms of evolution today.

One of the key elements to the nature of science that students must understand is that there are limits to the questions that science can investigate. Science and its methods cannot address moral, ethical, aesthetic, social and metaphysical questions as it relies on evidence gained from nature, either directly or through inference. While scientists may have personal opinions on issues related to such questions, science inquiry is unable to provide answers to those questions.

Suggestions for Instruction

Activate

Demonstration

Use pictures or photographs to illustrate the evolution of a style or product (e.g. hairstyles, clothing, automobiles, telephones…). Pose the following questions:

- Can you explain how the style or product is the same? (It still has the same function)
- Can you explain how it changed over time? (Answers will vary depending on the example used.)
- What might have caused the observed changes? (Answers will vary depending on the example used. Possible suggestions could be improved technology, fashion design trends…)
- Organisms also change over time. How is the evolution of organisms different from the evolution of styles or products? (The evolution of organisms is usually much slower.)

Acquire/Apply

Group Work

Group students into teams and have the teams consult a variety of sources to gather definitions of the term evolution. These sources should include print (textbook, dictionary…), electronic (Internet) and personal (teacher, parent…).

Share a biological definition of evolution with the class. Ask the teams to examine the definitions they have gathered, and compare them to the biological definition of evolution, discussing commonalities and differences. Remind students of the distinction between the reality that evolution has occurred (the fact) and the explanation for how evolution occurs (the theory of natural selection).

Direct Instruction

Provide students with a definition of the term evolution. Make the distinction between the fact that evolution has occurred (fossil evidence, DNA analysis…) and explanation for the mechanism of how evolution occurs (the theory of natural selection). Discuss that evolution occurs not to individuals, but to populations. Evolution is a change in the allele frequency in a population's gene pool.

Suggestions for Assessment

Exit Slip

Pose the following to students:
How has your understanding of the term evolution changed?
Responses should indicate a clearer understanding of the biological definition of evolution.

Resources

The University of California, Berkely, Museum of Paleontology website contains an Evolution wing (www.ucmp.berkeley.edu/history/evolution.html) that traces evolutionary thought as it developed over time. There is a link to the Understanding Evolution website (http://evolution.berkeley.edu) which is an excellent resource for teachers.

The Evolution and the Nature of Science Institutes website (www.indiana.edu/~ensiweb) has a collection of lessons, activities and resources for teaching about the nature of science and evolution.

The Talk.Origins Archive is a newsgroup devoted to the discussion and debate of biological and physical origins. Visit the website at www.talkorigins.org.

Michaels, Erica and Randy L. Bell (2003). The Nature of Science & Perceptual Frameworks. *The Science Teacher*. November, 36-39

McComas, William F. (2004). Keys to Teaching the Nature of Science. *The Science Teacher.* November, 24-27.

Farber, Paul (2003). Teaching Evolution and the Nature of Science. *The American Biology Teacher 65,* (5), 347-354.

S4B-3-02 Describe and explain the process of discovery that lead Darwin to formulate his theory of evolution by natural selection.
Include: the voyage of the Beagle, his observations of South American fossils, the impact of the Galapagos Islands on his thinking, the work of other scientists

Entry-level Knowledge

Students have not previously studied this topic, but may have some familiarity with Charles Darwin, evolution theory and “survival of the fittest”.

Teacher Background

The dynamic nature of the "evolution" of evolution theory is an excellent vehicle with which to explore of the nature of science with your students.

- James Hutton (1726-1797) and Charles Lyell (1797-1875) studied the forces of wind, water, earthquakes and volcanoes. They concluded the earth is very old and has changed slowly over time due to natural processes.
- Erasmus Darwin (1731-1802) suggested that competition between individuals could lead to changes in species. (He also was Charles Darwin's grandfather.)
- Jean Baptiste Lamarck (1744-1829) proposed a mechanism by which organisms change over time. He hypothesized that living things evolve through the inheritance of acquired characteristics.
- Thomas Malthus (1766-1834) observed that human populations cannot keep growing indefinitely. If the birth rate continued to exceed the death rate, eventually humans would run out of living space and food. Famine, disease and war prevented endless population growth.
- Charles Darwin (1809-1882) formulated a theory of evolution by natural selection based on observations made during his voyage on the *Beagle,* and of selective breeding of farm animals, plants and pets. Darwin drafted manuscripts outlining his theory in the 1840's but hesitated to release them to the public. His most famous work *On the Origin of Species by Means of Natural Selection* was published in 1859.
- Alfred Russell Wallace (1823-1913) proposed a theory of evolution by natural selection similar to that of Darwin. He wrote a paper and sent it to Darwin to review. This spurred Darwin on to finally agree to the release of his theory. In 1858 Charles Lyell presented Darwin's 1844 essay and Wallace's paper to the public.

Teacher Notes

This outcome provides an opportunity to explore the nature of science with students. For example, while Lamarck's ideas may seem silly to us today, at the time, he was a well-respected scientist who was one of the first to propose a mechanism explaining how organisms change over time. The fact that his theory was discarded when another theory with a better explanation was proposed is an excellent illustration of how science works.

The story of Charles Darwin is a fascinating one. See Appendix 1: The Story of Charles Darwin for a brief summary of his work.

Suggestions for Instruction

Activate

Setting the Scene

Imagine that you are 21 years old and have just graduated from university. You aren't quite sure if you want to settle down and start working in your field of study. You have always enjoyed going on hikes and observing nature, when one day you see job advertisement in the paper. The government is looking for people to work on a five year surveying expedition around the coast of South America. Would you apply for the job?

Acquire/Apply

Direct Instruction

Describe evidence Darwin collected on his journey on the *Beagle* including:

- Fossil glyptodonts similar to armadillos of today
- Fossil *Megatherium* similar to sloths of today
- Galapagos Island finches looked similar to those of South America, but were in fact distinct species
- Finch species varied from island to island in the Galapagos
- Species in the Galapagos Islands similar to those found on the west coast of South America

Describe the work of other scientists that influenced Darwin's thinking including:

- James Hutton (1726-1797) and Charles Lyell (1797-1875). They concluded the earth is very old and has changed slowly over time due to natural processes.
- Thomas Malthus (1766-1834) observed that human populations cannot keep growing indefinitely. If the birth rate continued to exceed the death rate, eventually humans would run out of living space and food. Famine, disease and war prevented endless population growth.

RAFT Creative Writing Assignment

RAFTs are creative writing assignments in which students are encouraged to adopt new perspectives on a science concept or issue. In the acronym RAFT, R stands for role, A for audience, F for format, and T for topic. Refer to Appendix 2 for assignment details.

Timeline/Flowchart

Using the student research project and presentation assignment described below, create a class bulletin board containing a timeline/flowchart of the development of evolution theory.

Web Activity

Darwin's Diary is a web activity that contains selections from Darwin's private journals and published works. Three themes are explored – Voyage of the

Beagle, Origin of Species, and Darwin's God. The activity is part of the PBS Evolution website and is located at www.pbs.org/wgbh/evolution/darwin/diary.

Suggestions for Assessment

Research Project and Presentation

To individual or groups of students, assign a scientist that contributed to the development of a unifying theory explaining how species can change over time Students research the following:

- Date of work or publication
- Key finding(s)
- Biographical information (e.g. where the research took place, background of the researcher…)

Students orally present their research to the class and create a one page summary to be added to the class bulletin board containing the timeline/flowchart.

Resources

The eight hour PBS television series Evolution (www.pbs.org/wgbh/evolution) first aired in September of 2001. The episodes cover a variety of topics, from the genius and torment of Charles Darwin to the vast changes that spawned the tree of life, from the role of mass extinctions in the survival of species to the power of sex to drive evolutionary change. The series also explores the emergence of consciousness, the success of humans, and the perceived conflict between science and religion in understanding human life. The website contains resources for learning about and teaching evolution, an extensive library of print and multimedia resources, web activities, and animations.

The Online Literature Library (www.literature.org/authors/darwin-charles) website contains full and unabridged texts by Charles Darwin. Several of his publications are available including *The Voyage of the Beagle, The Origin of Species* and *The Descent of Man.*

The Evolution and the Nature of Science Institutes website (www.indiana.edu/~ensiweb) has a collection of lessons, activities and resources for teaching about the nature of science and evolution.

S4B-3-03 Outline the main points of Darwin's theory of evolution by natural selection.
Include: overproduction, competition, variation, adaptation, natural selection, speciation.

Entry-level Knowledge
None

Teacher Background
The main points of Darwin's theory:

- Overproduction: more offspring are produced by an organism than can possibly survive
- Competition: high birth rates cause a shortage of life's necessities leading to competition between organisms
- Variation: each individual differs from all other members of its species; some differ more than others
- Adaptation: allows organisms to become better suited to their environment
- Natural selection: the most fit (best adapted) organisms survive and reproduce
- Speciation: formation of new species from ancestral species by means of natural selection

Teacher Notes
Emphasize that variation in a species is the result of mutations in DNA. These mutations are the source of new alleles, the variations upon which natural selection can act. It is important to remind students that mutations are not goal-directed. They arise randomly in a population, and may produce a change in the structure or function of the organism. Whether or not the mutation is beneficial or harmful depends on the environment. Evolution then selects for those organisms that are best adapted to their environment at the time.

<u>Suggestions for Instruction</u>
Activate
Opening Question
Some forms of bacteria can divide by fission as frequently as every 20 minutes in optimal conditions. Assuming we start with one bacterium, how may bacteria could be produced by the end of one minute? (8). After two minutes? (64). After five minutes? (37268). After 30 minutes? (1.07×10^9). So why aren't we drowning in bacteria?

Possible responses could include:

- The bacteria could run out of food
- The bacteria could run out of oxygen
- The bacteria could run out of living space
- Some bacteria could die of old age
- Some bacteria could be eaten by predators (e.g. white blood cells, mosquito larvae)

Acquire/Apply
Simulation
Students model natural selection by using different utensils to "capture food". See Appendix 3: Natural Selection Simulation for details of the activity.

Suggestions for Assessment
Simulation
Assess student responses for logic and accuracy. The assessment can be informal (questioning, class discussion of results) or formal (an exit slip, written responses to the questions posed).

Resources
Visit the PBS Evolution series website (www.pbs.org/wgbh/evolution) for resources for learning about and teaching evolution, an extensive library of print and multimedia resources, web activities, and animations.

S4B-3-04 Demonstrate, through examples, what the term "fittest" means in the phrase "survival of the fittest".
Examples: Walking Stick insect blending with its environment, sunflowers bending towards sunlight, antibiotic resistant bacteria…

Entry Level knowledge
none

Teacher Background
An adaptation is a variation that allows an organism to be better suited to its environment. Organisms that are better adapted to their environment are more "fit", thereby increasing their chance of survival and successful reproduction. Thus, adaptations are the result of natural selection.

Adaptations can be classified as behavioural, physiological or structural. Behavioural adaptations are associated with how organisms respond to their environment. Seasonal migration by monarch butterflies, birds and caribou, hibernation by bears and garter snakes, the bending of sunflowers toward the sun, and the shedding of leaves in the fall by deciduous trees are all examples of ways in which organisms have adapted their behaviour.

Variations in organism's metabolic processes across a species are known as physiological adaptations. Antibiotic-resistant bacteria and pesticide-resistant insects developed because some organisms developed adaptations that allowed them to survive in the presence of antibiotics and pesticides.

Structural adaptations affect the shape or arrangement of physical features of an organism. For example, the blowholes of whales and dolphins are relocated nostrils, while the needles of a cactus are modified leaves that both protect the plant and reduce water loss.

Mimicry is a type of structural adaptation that allows one species to resemble another. The large (up to 75 mm) caterpillar larva of the elephant hawk moth (*Deilephila elpenor*) defends itself by mimicking a snake. The swollen segments near the head contain two large "eye spots" that fool insectivorous birds (and people) into thinking it is dangerous.

Camouflage is second type of structural adaptation to the appearance of an organism. Adaptations such as these assist an organism's chance of survival by allowing it to blend in with its environment. The walking stick is an insect that resembles the shrub branches that it inhabits. The stripes on a tiger help it to blend in to the jungle.

Teacher Notes

Make a clear distinction between adaptation and acclimatization. Acclimatization is when an organism becomes accustomed to changing environmental conditions. It is not the product of natural selection. There is no change in the gene pool of the species.

For example, when the warm weather arrives after the cold of winter, we are quick to shed our winter coats and put on shorts and sandals, even though the temperature may be only $+10^{o}$. However, should a cold front sweep down from the north in the middle of summer, we dress more warmly and complain about how cold it is. We had become acclimatized to the warmer temperatures of summer.

Suggestions for Instruction

Activate

Visuals

Provide students with visuals (overheads, power point, diagrams, pictures…) of organisms with structural, behavioural or physiological adaptations. Examples could include needles on a cactus, canine teeth on a carnivore such as a wolf, seasonal feather colour change in ptarmigans etc.

Ask students to describe how each organism is well suited to its environment. What special feature does each have that increases its chance of survival or reproduction?

Acquire/Apply

Direct Instruction

With the use of examples, distinguish between behavioural, structural and physiological adaptations. Include mimicry and camouflage (also known as cryptic colouration) in the discussion of structural adaptations.

Student Research

Students individually research and report on an adaptation present in a species of their choice. The report can take the form of a poster (see Suggestions for Assessment).

Suggestions for Assessment

Poster

Each student prepares and presents a poster describing an adaptation found in a species of his/her choice. The poster should include:

- The name of the species
- A description of the adaptation
- The type of adaptation present (behavioural, physiological, structural)
- An explanation of how the adaptation allows an organism to be better suited to its environment.
- A picture, drawing or diagram of the organism

Evaluation can take the form of peer assessment. A gallery walk can be used in which students circulate and assess the posters using rating scales. The rating scale should be developed as a whole class, and could include criteria such as:

- Visually presents the information in an organized manner
- Required components present (name of species, picture/drawing/diagram present, type of adaptation)
- Description of the adaptation is clear and concise
- Explanation of how the adaptation allows an organism to be better suited to its environment is clear and concise

S4B-3-05 Explain how natural selection leads to changes in populations. Examples: industrial melanism, antibiotic resistant bacteria, pesticide resistant insects…

Entry-level Knowledge

none

Teacher Background

There are two well-known examples in which natural selection has been observed in action. The first was H.B. Kettlewell's study of camouflage adaptation in a population of light coloured and dark coloured pepper moths in England. The second example is that of the development of antibiotic-resistant bacteria such as *Staphylococcus aureus*.

Teacher Notes

Microevolution is the term used to describe changes that occur within a population of a single species. It includes the process of natural selection, changes in allele frequencies, and changes in populations that result over time. Industrial melanism and development of antibiotic resistant bacteria are examples of microevolution.

Macroevolution refers to large scale and long-term evolutionary patterns among many species. The evolution of new species from a common ancestor, as seen in Hawaiian honeycreepers and Darwin's finches, or the origin, adaptive radiation and extinction of the dinosaurs are all examples. Evolutionary biologists today are debating the extent to which microevolutionary mechanisms can explain macroevolutionary patterns (Martin, 2004).

Caution students against assuming that natural selection and evolution lead to perfection in organisms. Natural selection operates on the variation already present in a species; it cannot create new structures or processes. Regardless of how much time humans spend in the sunlight, we will never be able to manufacture our own food through photosynthesis.

Adaptation is the result of natural selection. Species that are well adapted to their environments tend to be successful. They survive and reproduce, but again they are not perfect. Should the environment change, many will die, as they are no longer suited to the new environment.

Suggestions for Instruction

Activate

Opening Question

Have you ever taken antibiotics for an illness such as strep throat or tonsillitis? When you had the prescription filled, did the doctor and pharmacist remind you to finish all of the antibiotic prescribed, and not discontinue taking the antibiotic, even if you started feeling better? Why do you think this is so?

Acquire/Apply

Demonstration

In this activity, students become unwitting subjects in a demonstration about natural selection. Students select candies from a bowl and have the opportunity to think about what brought about the "survival" of some candies. See Appendix 4: Natural Selection in a Candy Dish.

Direct Instruction
Use the opening question outlined above to discuss the development of antibiotic resistant bacteria, an example of natural selection in action. Discuss with students that variation in antibiotic resistance occurs naturally within a bacterial population. Some bacteria have a low resistance and are killed rapidly when the antibiotic is present. However, some do survive and reproduce, as they are better adapted to their environment (i.e. more fit). With less competition from other bacteria, the resistant bacteria quickly spread. The antibiotic that had once controlled the bacteria is no longer effective.

Suggestions for Assessment
Investigation
The Natural Selection in Legocarnivora activity simulates natural selection in fictitious animals. See Appendix 5a for the investigation and Appendix 5b for the answer key. Assess student responses for logic and accuracy.

Resources
Visit the PBS Evolution series website (www.pbs.org/wgbh/evolution) for resources for learning about and teaching evolution, an extensive library of print and multimedia resources, web activities, and animations.

S4B-3-06 Describe how disruptive, stabilizing and directional natural selection act on variation.

Entry-level Knowledge
None

Teacher Notes
Stabilizing, directional and disruptive selection are ways in which natural selection can affect genetic variation. The discussion of the three types of selection can be enhanced with the use of graphs and examples.

Teacher Background
Stabilizing selection – favours individuals with an "average" value for a trait, and selects against those with extreme values. Human birth weight is an example. Until recent medical advance, infants that were too small tended not to survive and infants that were too large died during birth.
Directional selection – favours individuals possessing values for a trait at one extreme of the distribution, and selects against the average and other extreme. The development of antibiotic resistant bacteria is an example of directional selection. Only those bacteria that can tolerate the presence of an antibiotic survive.

Disruptive selection – favours individuals at both ends of the distribution and selects against the average. It is also known as diversifying selection. Marine organisms known as limpets have shell colours that range from white to dark brown. The dark coloured limpets attached to dark coloured rocks in the ocean and light coloured limpets attached to light coloured rocks tend to be less visible to predators and have a higher survival rate. The intermediate coloured limpets (tan coloured) are highly visible to predators and are consumed. The intermediate colour is therefore being selected against.

Suggestions for Instruction

Activate

Demonstration

Working in pairs, students measure their heights and round off to the nearest 0.05 metres (e.g. 1.60 m, 1.85 m). As a large group, determine the maximum and minimum heights in the class. Draw a continuum across the whiteboard with the minimum and maximum heights at opposite ends. In between these heights, note the intermediate heights on the white board. Ask students to stand in front of the board at their height. Should there be more than one student per height, ask the students to form a row in front of the height. When the students are organized, a bell shaped curve should result. This reflects the height variation in the classroom.

Acquire/Apply

Investigation

The Investigating Variation activity examines observable differences in a trait. Students measure the length of dried kidney beans and graph the class results. See Appendix 6 for the investigation. Assess student responses for logic and accuracy.

Direct Instruction

With the use of graphs and examples, illustrate the effects of stabilizing, directional and disruptive selection on a population. Note that stabilizing selection tends to keep allele frequencies relatively constant, thereby limiting evolution. In this way, species such as the cockroach and shark have remained stable for million of years.

Directional selection often operates when an environmental change favours an extreme phenotype. The progressive change in coloration of peppered moths in Great Britain (industrial melanism) occurred as a result of air pollution. Over time, the allele frequency for the darker form of the peppered moth increased in the population.

Disruptive selection leads to the formation of distinct subpopulations of organisms. In time, the allele frequencies in the subpopulations may change to the extent that the two groups may no longer be able to interbreed.

Suggestions for Assessment

Case Study

See Appendix 7a for the case study – Where Did All the Four-Leaf Clovers Go? (BLM). Appendix 7b contains the answer key for the case study.
Assess student responses for logic and accuracy.

S4B-2-07 Distinguish between natural selection and artificial selection.

Entry Level Knowledge

none

Teacher Background

Both natural selection and artificial selection are mechanisms of change in the gene pool of a population. The key difference is that in artificial selection, humans ensure individuals with the more desirable traits are allowed to reproduce. In natural selection, those individuals who are best suited to their environment survive and reproduce.

Artificial selection is a form of non-random mating, one of the causes of change to a gene pool. For centuries, breeders have used the natural variation within a population to selectively breed those plants or animals that best represent the properties they wish in future generations, such as more productive milk cows, earlier ripening fruits, greater grain yields, faster racehorses. Charles Darwin was able to use artificial selection as a model for change in the natural world (i.e. natural selection).

Teacher Notes

Students will have familiarity with artificial selection with respect to various breeds of dogs and cats. Some may be familiar with varieties of fruits and vegetables, or domestic farm animals (horses, cattle, chickens…).

The many varieties of *Brassica oleracea* (broccoli, broccoflower, cauliflower, cabbage, Brussell sprouts, kale, kohlrabi) are all derived from wild mustard through artificial selection. See the demonstration in outcome S4B-4-02 for more information.

Suggestions for Instruction

Activate

Demonstration

Provide students with samples of different types of winter squash such as acorn, butternut, hubbard, pumpkin, and spaghetti. All are members of the same species, *Curcurbita maxima.* Ask students to write an explanation of how they think humans have been able to produce such a variety of squash.

Acquire/Apply

Guest Speaker

Invite a local plant or animal breeder to the class. Students should prepare questions for the speaker in advance. Questions could include: What type of plant/animal do you breed? What are the traits for which your plant/animal is bred? What selective breeding practices do you use for your animals? How do you propagate your plants?

Field Trip

Visit a plant research station, local horticulturalist or animal breeder for a demonstration of traits selected for in a plant or animal and the selective breeding practices used.

Suggestions for Assessment

Research Report

Students individually select and research a particular breed/varietal/cultivar of organism. Possible organisms can include Siamese cat, Hereford cattle, hybrid tea rose, cocker spaniel, hard red spring wheat…

The report should include the name of breed/varietal/cultivar, the characteristics or traits selected for, and a picture of a representative organism. An assessment rubric can be developed with student input.

Resources

The PBS Nova episode Dogs and More Dogs (aired Nov. 30, 2004, 1 hour) examines theories of the evolution of dogs, as well as the reasons for their great diversity. Visit the website at http://www.pbs.org/wgbh/nova/dogs for information on the program, additional links, teacher resources and student activities.

The Cereal Research Centre is one of 19 research facilities for Agriculture and Agri-Food Canada. Two of its facilities are located in Winnipeg and Morden. Visit the website (http://res2.agr.ca/Winnipeg) for more information.

S4B-3-08 Outline how scientists calculate if a gene pool has changed, according to the criteria for genetic equilibrium.
Include: large population, random mating, no gene flow, no mutation, no natural selection.

Teacher Background
The Hardy-Weinberg Principle is a mathematical model that deals with the frequencies of alleles in a gene pool. If the allelic frequency does not change in a population over successive generations, then evolution does not occur and the population is at equilibrium. Several conditions must met in order to maintain this equilibrium. They are:
1. No mutation occurs so that the alleles do not change.
2. Immigration and emigration do not occur as they would alter the gene pool.
3. The population must be large so that changes do not happen by chance alone.
4. All reproduction must be totally random so that one form of the allele is not selected for over another.
5. All forms of the allele must reproduce equally well so that there is no natural selection.

As it is virtually impossible to meet these conditions, allelic frequencies do change in populations and therefore evolution does occur. The Hardy-Weinberg Principle is also useful in explaining why genotypes within a population tend to remain the same, as well as for determining the frequency of a recessive allele.

Teacher Notes
Introduce students to the conditions required to maintain genetic equilibrium prior to discussing the Hardy-Weinberg equation. Emphasize the fact that as it is virtually impossible to meet these conditions, allelic frequencies do change in populations and therefore evolution does occur.

The main application of the Hardy-Weinberg Principle in population genetics is in calculating allele and genotype frequencies in a population. It is the means by which changes in gene frequency and their rate of change are determined. Students should have the opportunity to perform population genetics calculations.

<u>Suggestions for Instruction</u>
Activate
Demonstration
Students often wonder why recessive alleles don’t disappear from a population. This demonstration can be used to illustrate the frequency of a recessive allele.

Free earlobes are caused by a dominant gene (E), while attached earlobes are due to the homozygous recessive (ee). Survey the class to determine the number of students with free earlobes and the number with attached earlobes.

- Sample data: 15 students with free and 5 with attached earlobes

Determine the frequency of the recessive allele using the frequency of individuals homozygous for the recessive allele (q^2).

- Sample data: 5/20 students (25 % or 0.25) are ee (i.e. q^2). The frequency of the recessive allele is the square root of .25, or 0.50 (i.e. q). Remind students that all calculations are carried out using proportions, not percentages.

Determine the frequency of the dominant allele using $p + q = 1$.

- Sample data: The frequency of the dominant allele is therefore 1 – 0.50 or 0.50. (i.e.$1 - q = p$)

Determine the frequency of individuals homozygous for the dominant allele (p^2).

- Sample data: $(0.50)^2 = 0.25$

Determine the frequency of heterozygous individuals (2pq).

- Sample data: $2(0.50)(0.50) = 0.50$

Check calculations using the Hardy-Weinberg equation ($p^2 + 2pq + q^2 = 1$).

- Sample data: $0.50^2 + 2(0.50)(0.50) + q^2 = 1$

Discuss how this example illustrates how frequently a recessive gene may occur in a population, even though the number of homozygous recessive individuals is quite low.

Acquire/Apply

Direct Instruction

Introduce students to calculations of allele and genotype frequencies using the Hardy-Weinberg equation.

In a population, the frequency alleles in a stable population will equal to 1.
This can be expressed as $p + q = 1$, where:
p = frequency of the dominant allele
q = frequency of the recessive allele

The distribution of the sickle-cell anemia allele can be used as an example for calculations. In some areas of Africa, the recessive sickle-cell allele has a frequency of 0.3. The frequency of the normal hemoglobin allele is calculated as $1 – 0.3 = 0.7$

Use the above data to illustrate the Hardy-Weinberg Equation ($p^2 + 2pq + q^2 = 1$) where:
p^2 = frequency of individuals homozygous for the dominant allele
q^2 = frequency of individuals homozygous for the recessive allele

2(0.70)(0.3) = 0.42 = Ss (42% of the population)
$0.3^2 = 0.09$ = ss (9% of the population, affected by sickle cell anemia)
0.49 + 0.42 + 0.09 = 1

Based on theses calculations, one can determine that although a relatively small percentage of individuals (9%) in the population are affected by sickle-cell anemia, the recessive allele is widely distributed in the population. In fact, 51% of the population carry at least one copy of the sickle cell allele. This can be used to illustrate why recessive alleles are not removed from a population, even though the number of individuals with the homozygous recessive condition may be quite low.

Suggestions for Assessment

Investigation

There are a variety of laboratory activities that incorporate the Hardy-Weinberg Equation in population genetics simulations. See textbooks, lab manuals or the Internet for resources. Assess student lab reports for accuracy in problem-solving and answers to questions.

Exit Slip

Pose the following to students:
Some people think that the dominant allele of a gene should constantly increase in frequency in a population, and quickly force out the recessive allele. Use the Hardy-Weinberg Principle and/or Equation to explain why this idea is incorrect. What false assumption could cause people to have this incorrect idea?

Assess student responses for logic and accuracy. Answers can include:

- People may assume that because few individuals show the recessive phenotype, the recessive allele is rare.
- The Hardy-Weinberg equation can show how widespread a recessive allele is in a population, even though few individuals show the recessive phenotype
- Large populations are relatively genetically stable and large shifts in allele frequencies do not occur from one generation to the next.

S4B-3-09 Discuss how genetic variation in a gene pool can be altered. Examples: natural selection, gene flow, genetic drift, non-random mating, mutation…

Teacher Background

- Natural selection affects variation in a population as the better adapted (more fit) individuals survive and reproduce, passing on their genes to successive generations.
- Immigration and emigration of individuals from a population will affect allele frequencies and therefore gene flow.
- The change in the gene pool of a small population due to random chance is genetic drift. The bottleneck effect is a form of genetic drift that results from the near extinction of a population. The founder effect is a form of genetic drift that results from a small number of individuals colonizing a new area. In both cases, allele frequencies can change dramatically.
- In animals, non-random mating is more often the case as the choice of mates is often an important part of behaviour (e.g. courtship rituals). Many plants self-pollinate, which is a form of inbreeding or non-random mating.
- Mutations, although rare, do constantly occur. They provide the source of new alleles, or variation upon which natural selection can take place.

Teacher Notes

In outcome S4B-3-08, students are introduced to the conditions required to maintain genetic equilibrium. Students should understand that, as it is virtually impossible to meet these conditions, allelic frequencies do in populations. Use this as a springboard for a discussion into how genetic variation in a gene pool can be altered.

<u>Suggestions for Instruction</u>

Activate

Brainstorm

Ask students to recall the five conditions required to maintain genetic equilibrium (see outcome S4B-3-08 for details). Knowing that it is virtually impossible to meet these conditions, ask students to propose situations/events that may alter a gene pool. For example, the condition of no gene flow could be affected by immigration and emigration.

Acquire/Apply

Direct Instruction

There are many known instances of the founder effect in human populations. Examples include tyrosinemia in the Quebecois of Saguenay-Lac St. Jean region (see outcome S4B-1-08, Case Study: The Death of Baby Pierre), limb-girdle muscular dystrophy in Manitoba Hutterites, retinitis pigmentosa on the island of Tristan da Cuhna, and Ellis-van Creveld syndrome in the Pennsylvania Amish community. Use diagrams and the Hardy-Weinberg equation to demonstrate how the allele frequencies in a founding population can evolve differently from the parent population.

Web Activity

Sex and the Single Guppy is a web activity that examines the interplay between natural and sexual selection in a population of wild guppies. Students can see how a new species can evolve by observing natural selection and adaptive radiation in action. The activity is part of the PBS Evolution website and is located at www.pbs.org/wgbh/evolution/sex/guppy

Suggestions for Assessment

Case Study

See Appendix 8a for a case study about the endangered Whooping Crane, entitled Population Bottlenecks and Endangered Species (BLM). Appendix 8b contains the answer key for the case study. Assess student responses for logic and accuracy.

Resources

For more information about whooping cranes, visit the Environment Canada website (www.mb.ec.gc.ca/nature/endspecies/whooping).

The University of Toronto website (www.cquest.utoronto.ca/zoo/bio150y/cranes) has an online exercise on whooping crane conservation.

S4B-3-10 Describe how populations can become reproductively isolated Examples: geographic isolation, niche differentiation, altered behaviour, altered physiology…

Entry-level Knowledge

none

Teacher Background

When a part of a population becomes geographically isolated from the parent population, allopatric speciation can occur. Geographic isolation can occur due to the formation of physical barriers such as mountains, canyons, rising sea levels, glaciers etc. The physical barrier prevents gene flow between the two populations. If the different populations are subjected to different natural selection pressures, allele frequencies for genes will change. The two populations may accumulate substantial genetic differences so that they become reproductively isolated and are unable to interbreed. Two distinct species therefore result.

When the gene flow between members of a population is restricted due to ecological isolation (niche differentiation), sympatric speciation can occur. Some members of a population may be better adapted to a slightly different habitat in an ecosystem, and begin to specialize in that habitat. Different selective pressures in the two habitats lead to genetic changes in the organisms. The two populations become reproductively isolated, and two distinct species result, even though there are no physical barriers separating the population.

Alterations in behaviour can lead to reproductive isolation. Should a group of nocturnal mammals become active during the day, they may no longer interbreed with their counterparts who are active at night. Chromosome mutation can also result in reproductive isolation. A malfunction in meiosis can lead to polyploidy (multiple copies of chromosomes) in a plant. Because plants can reproduce asexually and self-pollinate, the new polyploid can reproduce, even though it is reproductively isolated from its parent(s).

Teacher Notes
You may wish to discuss with students the definition of species. (See outcomes S4B-4-01and S4B-4-02 for more information). The evolutionary biologist Ernst Mayr defined a species as a reproductive community of populations (reproductively isolated from others) that occupies a specific niche in nature.

Suggestions for Instruction

Activate

Darwin's Finches
Obtain pictures or diagrams of some of the fourteen Galapagos Island finches that show their beaks and information as to the diet of each of the species illustrated. Ask students to hypothesize how these differences evolved from one ancestral species.

Acquire/Apply

Jigsaw
Break the class into four groups. Assign each student groups a particular stage in the process of allopatric speciation (stage 1: two populations with normal gene flow, stage 2: gene flow is prevented by a geographical barrier, stage 3: genetic differences accumulate, stage 4: two populations are reproductively isolated). Each group then investigates the characteristics and events of their assigned stage and prepares a summary.

Jigsaw the groups, and arrange the students so that each new group contains one expert from each of the previous groups. Each expert then shares his/her summary with the new group members. In this way all members of the class receive the summaries of all the groups. If paper copies of the summaries are provided, the experts should be prepared to discuss the important points of their summary.

Direct Instruction
Use real or hypothetical examples to complement a discussion of the process of speciation. Remind students that new species result when members of a population become reproductively isolated from one another, and no longer interbreed to produce fertile offspring in their natural environment.

Web Activity
An Origin of Species is a web activity that allows students to see how a new species can evolve by observing natural selection and adaptive radiation in action. The activity is part of the PBS Evolution website and is located at www.pbs.org/wgbh/evolution/darwin/origin.

Suggestions for Assessment

Concept Map
Provide students with the following list of key terms related to speciation: population, gene pool, speciation, reproductive isolation, adapt, interbreed, species, selection.

Students are to use the key terms and any others they might wish to add, to create a concept map that illustrates the process of speciation. Students may base their concept maps on type of speciation (e.g. allopatric, sympatric), or on a real or hypothetical example (Darwin's finches, geographic isolation due to the formation an inland sea…).

Inspiration software can be used to create the concept map. Assess the concept maps for logic in the layout and linkages, as well as accurate use of terminology.

S4B-3-11 With the use of examples, differentiate between convergent evolution and divergent evolution (adaptive radiation).

Entry Level Knowledge
None

Teacher Background
Divergent evolution (also known as adaptive radiation) is the process in which an ancestral species gives rise to a number of new species that are adapted to different environmental conditions. This often occurs when a species colonizes a new environment in which there are unoccupied ecological niches. For examples, the adaptive radiation of Hawaiian honeycreepers and Darwin's finches occurred on islands. In other cases, adaptive radiation occurred after the extinction of many other species. The rapid increase in the number of species of mammals took place after the mass extinction of the dinosaurs.

Convergent evolution is the process in which different organisms that live in similar habitats become more alike in appearance and behaviour. As they encounter similar environmental pressures, the organisms develop analogous structures. For example, dolphins and sharks live in the water and both use their tails for propulsion. However, their tails are analogous structures with different origins. Sharks move their tails side to side, while dolphins move their tails up and down. Similarly, bat, butterfly and bird wings are analogous structures.

Teacher Notes
Differentiate between homologous and analogous structures. Use pictures or diagrams to aid in your presentation. Evidence for evolution is provided for by homologous structures, as they indicate descent from a common ancestor. Analogous structures also give evidence for evolution as they show how dissimilar organisms can independently adapt to similar environments.

Suggestions for Instruction
Activate
Opening Question
Recall the term homologous, as in homologous chromosomes. What does homologous mean in this case? (similar or related chromosomes).
Based on your knowledge of homologous chromosomes, can you predict to what the term homologous structures refers? (similar or related structures in organisms, for example human arm, bird wing, dog foreleg).
What does the term analogous mean? (partial similarity, corresponding in some manner). Can you predict to what the term analogous structures refers? (structures correspond in function, but not related in origin, for example, butterfly wing and bird wing).

Acquire/Apply
Demonstration
Obtain samples of bird wings (e.g. turkey, chicken, duck…) and samples of insect wings (e.g. butterfly, moth…). Use the bird wings to illustrate homologous structures. Describe the structure and function of a bird's wing and have students identify the homologous structures in the various bird wings.

Present the insect wings. Describe the structure and function of an insect's wing and have students identify the homologous structures in the various insect wings. Note that homologous structures are evidence that organisms evolved from a common ancestor. The differences among homologous structures are the result of adaptations to different environments.

Ask the students to compare the bird wings with those of the insect wings. Students should note that they have similar functions, but their structures are quite different. Bird and insect wings are analogous structures. They do not have a common evolutionary ancestor, but have similar functions. Analogous structures are the result of adaptations to a similar environment.

Direct Instruction
Compare divergent and convergent evolution by focusing on the key differences between the two processes. Use examples in the discussion.

Suggestions for Assessment
Research Report
Students investigate examples of homologous and analogous structures and prepare a written report. The report should contain:

- Examples of two organisms that share a homologous structure
- A description of the homologous structure
- An explanation of how the difference in structure is an adaptation to a different environment
- An example of an organism that has a structure analogous to one of the homologous structures
- A description of the analogous structure
- An explanation of how the similarity in function is an adaptation to a similar environment

Assess reports for accuracy and completeness.

Resources
For an overview of, and examples of homologies including pictures and diagrams, visit the web page 3. Evolution Makes Sense of Homologies by Dr. Sally Otto of the University of British Columbia at www.zoology.ubc.ca/~bio336/Bio336/Lectures/Lecture5/Overheads.html.

The University of California, Berkeley, Museum of Paleontology website contains a Vertebrate Flight Exhibit (www.ucmp.berkeley.edu/vertebrates/flight/enter.html) that explores the convergent evolution of flight in three taxa of vertebrates – pterosaurs, birds and bats.

S4B-3-12 Distinguish between the two models for the pace of evolutionary change: punctuated equilibrium and gradualism.

Entry Level Knowledge
None

Teacher Background
Gradualism describes the pattern of slow and gradual evolutionary change over long periods of time. Populations slowly diverge from one another due to

differing selective pressures. The changes result in transitional forms that are seen in the fossil record. Examples in the fossil record include the evolution of the trilobites.

Punctuated equilibrium describes the pattern of long stable periods in which species stayed much the same. These periods were interrupted (punctuated) by short periods in which the quick pace of evolution rapidly resulted in the formation of new species. The stimulus for evolution is a sudden significant change in the environment. The fossil record shows that rapid bursts of evolution have often followed mass extinctions (e.g. the Cretaceous extinction of the dinosaurs was followed by the rapid increase of mammalian species).

Teacher Notes
Discuss with students that evolutionary theory continues to be refined and expanded as our knowledge of biology grows. The debate over gradualism versus punctuated equilibrium is just one example of the “evolution” of evolutionary theory.

The new or modern synthesis of evolutionary theory (sometimes called neo-Darwinism) contains findings from genetics, population biology, paleontology, and most recently from evolutionary developmental (evo-devo) biology. Some key contributors include:

- Theodosius Dobzhansky (1900-1975) was one of the biologists initiating modern evolution theory that unites the fields of genetics and evolution. He is notable for defining evolution as a change in the frequency of an allele in a gene pool and is famous for his quotation “Nothing in biology makes sense except in light of evolution” (1973).
- Ernst Mayr (1904-2005) was one of the biologists initiating modern evolution theory that unites the fields of genetics and evolution. His work included the development of the concept of biological species and proposed the mechanism of peripatric speciation
- Niles Eldredge (1943-present) and Stephen Jay Gould (1941-2002) proposed the theory of punctuated equilibrium which hypothesizes that changes in species can occur relatively quickly, with long periods of little change (equilibrium) in between.

Suggestions for Instruction

Brainstorm

Introduce the topic by posing the following to students.
Have you ever wondered how fast evolution occurs? Does it occur at the same rate all the time?

Next, point out that the fossil record shows that some groups of organisms seem to have been unchanged for millions of years. Ask student to brainstorm and come up with suggestions as to why the rate of evolution in organisms such as the cockroach, shark and horsetail (*Equisitum sp.,* a type of plant) is so slow. Possible answers include:

- stabilizing selection tends to keep allele frequencies relatively constant, thereby limiting evolution
- environmental conditions remained fairly constant
- few chromosomal mutations have occurred

Then, indicate that the fossil record shows that some groups of organisms seem to have undergone rapid speciation events. Ask student to brainstorm and come up with suggestions as to why some species evolved so rapidly. Examples include the adaptive radiation in the Galapagos finches, the Cambrian explosion of animal phyla, the rise of the mammals in the Tertiary Period. Possible answers include:

- genetic drift in a small isolated population
- mass extinction of many life forms (e.g. dinosaurs),
- rapidly changing environmental conditions (e.g. meteor strike, glaciation period)
- exploitations of new niches (due to extinction or colonization)

Acquire/Apply

Direct Instruction

With the use of illustrations, differentiate between the two models for the pace of evolutionary change. Note that these are extreme models. The majority of evolutionary biologists believe that some aspects of both models occur during the evolutionary history of a species. At some points there is gradual change, due to stabilizing selection and unchanging environmental conditions. At other points, genetic drift, directional selection, sudden environmental changes or coevolution can lead to rapid changes.

Suggestions for Assessment

Exit Slip

Pose the following to students:

How do proponents of punctuated equilibrium explain the scarcity of transitional forms (missing links) in the fossil record? How does their explanation differ from that offered by proponents of gradualism?

Assess student responses for logic and accuracy. Answers can include:

- Proponents of punctuated equilibrium argue that transitional forms between species are missing because evolution occurs so rapidly in a very short period of time.
- Gradualists believe that transitional forms of organisms or missing links between species are missing from the fossil record because they are rare.

Resources

Wonderful Life: The Burgess Shale and the Nature of History by Stephen Jay Gould (1990) contains a description of the fossils of the Burgess Shale in British Columbia. Gould then presents an analysis of the fossils to support his theory of punctuated equilibrium.

Appendix

Appendix 1: The Story of Charles Darwin

The story of Charles Darwin is a fascinating one. While he is associated with the study of biology, he had actually graduated from Cambridge University with a degree in theology. He began is university training in medicine, but changed his studies when he found he couldn't stand the sight of blood.

Darwin's real interest lay in the area of natural history. He enjoyed hiking in the wilderness, observing nature, collecting plant and insect specimens and classifying them. John Henslow, a botanist who accompanied Darwin on these hikes, recommended him to Robert Fitzroy, the captain of the HMS *Beagle* as a companion on the voyage. In 1831, the *Beagle* set sail with Charles Darwin onboard.

Over the next five years, Darwin observed and collected geological and biological specimens along the route. The letters and specimens he sent home during the voyage made him a well-known and respected naturalist. Upon his return to England, Darwin spent a number of years compiling his data and having his specimens classified. He became convinced that species could change over time. After reading work by Malthus in 1838 on the consequences of overpopulation, he had a flash of insight. He was able to propose a mechanism of evolution – natural selection.

Darwin drafted two manuscripts (1842 and 1844) in which he outlined his theory, but withheld them from publication, only showing the manuscripts to trusted friends. Why was Darwin reluctant to publish? Darwin knew his ideas would be controversial, and could be perceived as being contrary to the religious teachings of the time. But this was not the main reason for his reluctance to publish. Darwin recognized that there were two main aspects of his theory that were problematic at the time. He was unable to explain the origin of the variation within populations that natural selection acted upon, as well as the mechanism of the transmission of variation from one generation to the next**.**

In the mid1850's Alfred Russell Wallace conceived the same ideas as Darwin, based on his observations in Indonesia. He wrote a paper and sent it to Darwin to review. This spurred Darwin on to finally agree to the release of his theory. In 1858 Charles Lyell presented Darwin's 1844 essay and Wallace's paper to the public. Darwin's *On the Origin of Species by Means of Natural Selection* was published in 1859. The book is a well-constructed argument for natural selection, backed by considerable evidence.

Appendix 2: RAFT Creative Writing Assignment (BLM)

Introduction

You are to assume the role of Charles Darwin during his five-year voyage on the *Beagle*. While on your travels you visit many places and see many fascinating things. Whenever you stop at a port, you send letters and notes home to family and friends. You are to select a region you have just visited, and send a 100 word postcard home to a friend describing your observations and thoughts about what you have seen in that area.

Here are some tips to get you started:

- Remember that Darwin formulated his theory of evolution by natural selection after his voyage was finished
- Make your postcard clear and concise
- Provide the name of the region or area you have written about (e.g. Tasmania, Galapagos Islands, Patagonia…)
- Include at least one observation and one question or thought that arose in your mind from your observation

All of the postcards will then be fixed to the map of the world, tracing the voyage of the *Beagle.*

Assessment

_____/5 Format (postcard, required length)
_____/10 Science Content (observations, question/thought, region)
_____/5 Language Mechanics (spelling, grammar, appropriate terminology)

Total _____/20

Comments:

Appendix 3: Natural Selection Simulation

Overview: Students model natural selection by using different utensils to “capture food”.

Materials:

- large bag of dried beans (e.g. kidney, lima, or northern)
- dissecting trays
- clothespins
- dissecting needles
- plastic spoons
- tweezers
- small beakers or petri dishes

Introduction: (read to students)
On a distant planet in a galaxy far, far away live creatures known as foofoos. While they all eat beans, there are variations in their mouthparts. Some foofoos have a clothespin mouth (demonstrate how to use the clothespin to pick up beans), some have a needle mouth (demonstrate) and some have a tweezer mouth (demonstrate). One year, a new foofoo with a spoon mouth was discovered (demonstrate). These foofoos are quite rare. In this activity, each of you will play the part of a foofoo on the planet and feed on beans.

Procedure:

- Provide each group of 3 or 4 students with a dissection tray containing about 100 dried beans, and give each student a utensil and a small beaker or petri dish. Hand out only two or three spoons to the class in the initial trial, and distribute clothespins, dissecting needles and tweezers to the rest of the students. Caution students about cheating, as they must use the utensils in the way that had been demonstrated.
- Tell the students that there will be 4 trials, and that each trial will require their foofoo to eat at least 20 beans to survive. Students are to use their utensils to pick up beans from the tray and deposit them into their beaker/dish. If a foofoo does not eat the required 20 beans, it will die.
- For the first trial, give students 1 minute to pick up the beans. If any foofoos die, the students can play the offspring of surviving foofoos. Give these students either spoons or tweezers for the next round.
- Run three more trials, one of 45 seconds, one of 30 seconds, and one of 15 seconds. At the end of the four trials the only surviving foofoos will probably be the spoon mouthed ones.

Assessment:
Pose the following questions to students:

- Which type of foofoo was the best adapted to its environment? (spoon mouthed)
- How does the type of mouth part affect the survival rate of foofoo? (those foofoos with spoon mouth are able to feed faster and outcompete the others, so they survive and reproduce)
- What happens to the foofoos that cannot compete as well with other animals? (they die and do not reproduce, they are not as well adapted)
- How does foofoo scenario model natural selection? (the spoon mouthed foofoos are better adapted and outcompete the others. Natural selection favours the spoon mouthed foofoos and the other variations in mouthparts would decline in numbers. Eventually all of the other variations of foofoos could disappear and a new species could emerge – spoon mouthed foofoos. This would represent speciation.)

Assess student responses for logic and accuracy. The assessment can be informal (questioning, class discussion of results) or formal (an exit slip, written responses to the questions posed).

Appendix 4: Natural Selection in a Candy Dish

Overview:
In this activity, students become unwitting subjects in a demonstration about natural selection. Students select candies from a bowl and have the opportunity to think about what brought about the “survival” of some candies. It is, of course, artificial both in the sense that the selecting is done by people and that the “organisms” being selected are nonliving entities with no genetics and no ability to reproduce.

Materials:

- Large candy dish or bowl
- Variety of candies of different shapes, sizes, brand names, flavours/ colours. There should be at least 2 candies (popular ones such as Hershey kisses, Starburst…) for each student and plenty of unpopular ones (e.g. licorice Allsorts). Avoid candies containing nuts.

Teacher Preparation:

- Prepare a list of candies and their initial abundance in the dish.

Procedure:

1. Make the candy dish accessible in advance so students can pick candies over a period of time, or the dish can be passed around the room a few times. You can avoid commenting about it at all, or you can make very innocent remarks about providing a treat for the students.
2. After more than half of the candy has been removed, gather the class together. Start the discussion by pointing out that there is often great variation among individuals of animal species. For example, students can look around the room and list the characteristics that vary among humans. Then, ask the students why variation is significant. (One reason variation is important is that variation allows for differential survival of individuals.)
3. Show them the candy bowl and the remaining candies. Count what candies remain and list them on the board. Ask them if they remember which candies were originally available. Make a list on the board of the original set of candy.
4. Now ask them to list the traits of the candy they *selected* from the candy dish. (examples include: chocolate flavour, large size, favourite brand, etc). These are the traits that led to the removal of certain candies.
5. Make a list now of the traits of the candies that were *not selected* (examples: bad flavour, small size). These are the traits that allowed the candies to survive being passed around the room.
6. So, the fact that there were different candies with different traits resulted in some candies being eaten and others surviving. This is what natural selection does with individuals in a population. Each individual has unique traits; some traits will help an individual survive and some traits do not.

Extension:

The teacher could continuously add candy into the candy bowl according to the proportions left in the candy bowl. For example, if after the first round all the Hershey kisses disappeared but there were a lot of green Starbursts, add more green Starbursts but do not add any more kisses. This will accentuate the loss of favourite candies and the proliferation of the remaining ones. In addition, this extension will simulate the production of new generations, similar to the evolution of populations over time. Another possibility is that you will see students taking their second choice of candies, simulating the natural situation where predators will start consuming another prey item when their favourite prey item is eliminated.

(adapted from Candy Dish Selection by Carol Tang, University of California Museum of Paleontology website
www.ucmp.berkeley.edu/education/lessons/candy_dish.html)

Appendix 5a: Natural Selection in Legocarnivora (BLM)

Introduction

Within any given population there is variation. Each individual differs from all other members of its species; some differ more than others. Some individuals have adaptations that allow them to better suited to their environment. In nature, the most fit (best adapted) individuals survive and reproduce. This is process is known as natural selection.

Purpose:

In this activity you will use coins and dice to simulate natural selection of the best adapted arrangement of wheels on a Legocarnivora for travelling the furthest distance.

Materials (per student group):

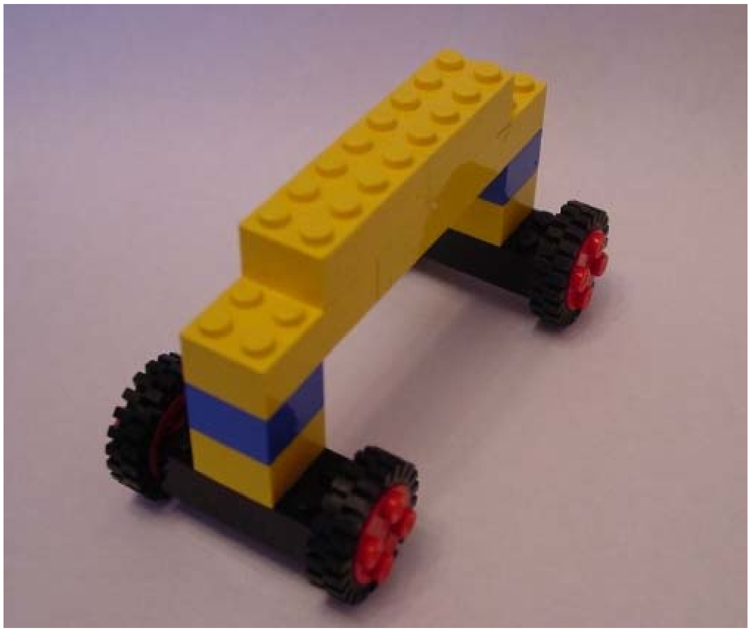
- Two sets of Lego wheels
- One 2 x 12 block of Lego
- Twelve 2 x 2 blocks of Lego
- Ramp (1 m long)
- One six-sided die
- One penny
- Two metre sticks

Procedure:

Part A: Parental Generation

1. Build your parental Legocarnivora. On top of each set of wheels, place two 2 x 2 Lego blocks. Connect the two sets of wheels and blocks with the 2 X 12 block of Lego (See Figure 1).

Figure 1: Legocarnivora



2. Set up your test ramp with a 25-35° incline. Make sure there is enough room at the bottom of your ramp so that your Legocarnivora can roll up to 2 metres.

3. Run your parental Legocarnivora down the ramp. Measure the distance it rolls from the bottom of the ramp and record this in the data table.

4. Repeat step 3 for your second trial. Average your results.

Part B: F_1 Generation

1. Your Leogocarnivora has three offspring. One is identical to its parent (Offspring 1) and the other two are mutations of the parent (Offspring 2 and Offspring 3).

2. Run Offspring 1 down the ramp (i.e you run the parent again). Measure the distance it rolls from the bottom of the ramp and record this in the data table. Repeat for a second trial. Average your results.

3. You will now modify Offspring 1 to create Offspring 2. Flip a coin. If it lands heads, you will modify the front of the Legocarnivora. If it lands tails, you will modify the back of the Legocarnivora.

4. Roll a six-sided die, and use the chart below to determine how to modify Offspring 1 to create Offspring 2.
   1 – add one 2 x 2 block above the wheels
   2 – add two 2 x 2 blocks above the wheels
   3 – add three 2 x 2 blocks above the wheels
   4 – remove one 2 x 2 block from above the wheels
   5 – remove two 2 x 2 blocks from above the wheels
   6 – remove three 2 x 2 blocks from above the wheels

   If at any time the modification is not possible, then your Legocarnivora has died.

5. Build Offspring 2 and run it down the ramp. Measure the distance it rolls from the bottom of the ramp and record this in the data table. Repeat for a second trial. Average your results.

6. Recreate the parental Legocarnivora. Flip the coin and roll the die to determine the modifications needed to create Offspring 3 from the parental Legocarnivora.

7. Build Offspring 3 and run it down the ramp. Measure the distance it rolls from the bottom of the ramp and record this in the data table. Repeat for a second trial. Average your results.

Part C: Additional Generations

1. From the three offspring, identify the Legocarnivora that travelled the furthest (on average). This will become the new parent.

2. Repeat steps 1 through 7 of Part B, recording your data for each trial for a total of ten generations. Note which of your Leogcarnivora travels the furthest.

3. Record the mass of your farthest travelling Legocarnivora.

Observations:

Data Table

Legocarnivora	Coin Toss	Die Roll	Number of front blocks	Number of rear blocks	Distance Rolled Trial 1	Trial 2	Mean
Parent	N/A	N/A	2	2	____	____	____
Generation 1							
Offspring 1	____	____	____	____	____	____	____
Offspring 2	____	____	____	____	____	____	____
Offspring 3	____	____	____	____	____	____	____
Generation 2							
Offspring 1	____	____	____	____	____	____	____
Offspring 2	____	____	____	____	____	____	____
Offspring 3	____	____	____	____	____	____	____
Generation 3							
Offspring 1	____	____	____	____	____	____	____
Offspring 2	____	____	____	____	____	____	____
Offspring 3	____	____	____	____	____	____	____
Generation 4							
Offspring 1	____	____	____	____	____	____	____
Offspring 2	____	____	____	____	____	____	____
Offspring 3	____	____	____	____	____	____	____
Generation 5							
Offspring 1	____	____	____	____	____	____	____
Offspring 2	____	____	____	____	____	____	____
Offspring 3	____	____	____	____	____	____	____

Generation 6							
Offspring 1	_____	_____	_____	_____	_____	_____	_____
Offspring 2	_____	_____	_____	_____	_____	_____	_____
Offspring 3	_____	_____	_____	_____	_____	_____	_____
Generation 7							
Offspring 1	_____	_____	_____	_____	_____	_____	_____
Offspring 2	_____	_____	_____	_____	_____	_____	_____
Offspring 3	_____	_____	_____	_____	_____	_____	_____

Analysis and Conclusions:

1. a) Which arrangement of wheels produced the Legocarnivora that travelled the furthest? This is the optimum design.
   b) In which generation did this occur?

2. Is this what you expected to occur? Why or why not?

3. What factor(s) do you think affect the distance the Legocarnivora will travel?

4. a) Of the factor(s) identified, which is environmental in nature?
   b) What effect would a change in the environmental factor have on the optimum design of the Legocarnivora?
   c) Design an experiment to test your prediction.

5. a) Suppose the parent selected in each generation was the one that travelled the shortest distance. How would this affect the optimum design of the Legocarnivora?
   b) Design an experiment to test your prediction.

6. Why were you use the Legocarnivora that travelled the furthest as the new parent for the next generation?

7. Did any of your Legocarnivora die? How is the death of your Legocarnivora an analogy for what happens in nature?

8. How does variation provide the raw material for natural selection?

Appendix 5b: Natural Selection in Legocarnivora Answer Key

1. a) The farthest travelling Leogcarnivora will generally have more blocks on the front than the rear, or more blocks on the rear than on the front.
   b) Answers will vary, but will usually be in a later generation.

2. Answers will vary.

3. The mass of the Legocarnivora and the angle of the ramp will affect the distance travelled.

4. a) The environmental factor is the angle of the ramp.
   b) Answers will vary.
   c) The experimental design should include changing the angle of the ramp and running the experiment again for a few generations.

5. a) Answers will vary.
   b) The experimental design should include running the experiment again for a few generations, but selecting for the Legocarnivora travelling the shortest distance.

6. In nature, the best adapted survive and reproduce. The Legocarnivora that travelled the furthest in each generation was the one that was selected for It was best adapted, so it was the one that “reproduced”.

7. Yes, some Legocarnivora died. Answers will vary, but should indicate that in nature, sometimes mutations cause variations that are not favourable to the survival of an organism.

8. Individuals with variations that make them better adapted to their environment survive and reproduce in greater numbers than those without such adaptations. Over generations, the number of individuals in a population with the favourable adaptation will increase.

Appendix 6: Investigating Variation (BLM)

Introduction
Many traits have variations within a population. Some variations may increase or decrease an organism's chance of survival in an environment. In this investigation, you will examine variation in the length of dried beans.

Materials (per group)
50 dried beans (e.g. kidney, navy, pinto…)
ruler with mm markings

Procedure
1. Obtain a sample of 50 dried beans. Identify the largest and smallest beans in the sample.

2. Measure the length of the smallest bean to the nearest millimetre. Record its length in the first row of length column and add a tally mark on the data table.

3. Measure the length of the largest bean to the nearest millimetre. To the length column of the data table, write the intermediate bean lengths. Then record the length of the largest bean in the final row of the length column and add a tally mark.

4. Measure and tally the remaining 48 beans in your sample.

5. Count the tally marks for each length and record the amount in the Group Total column.

6. Determine the class total for each length and record the amount in the Class Total column.

Data Table

Length (mm)	Tally	Group Total	Class Total

Analysis and Conclusions

1. Was there variation in the lengths of the dried kidney beans? Use specific data to support your answer.

2. Prepare a graph of the class results. Plot the class total on the y-axis and the length on the x-axis.

3. What advantage is there for using the class results rather than your group results?

4. If larger seeds were a selective advantage, would this be stabilizing, directional or disruptive selection? Explain your answer.

Appendix 7a: Case Study - Where Did All the Four-Leaf Clovers Go? (BLM)

Part A: Introduction

A team of biologists was conducting a long-term study of wildflower distribution in a meadow in a provincial park. A variety of wildflower species were present such as white clover (*Trifolium repens*), columbine (*Aquilegia canadensis*), and harebell (*Campanula rotundifolia*). During the initial sampling of the plant populations, the biologists noted that the white clovers were usually of the three-leaf variety, but occasionally some four-leaf clovers were found. Four-leaf clovers are a naturally occurring variation of the three-leaf type. Two-leaf and five-leaf variations also occur, but these are extremely rare.

One year, the Parks Branch decided to create a new picnic area near the study site. Over the course of several years, the team of biologists noted that the wildflower population in the study area began to change. As more people began to visit the meadow, the number of four-leaf clovers began to decline to the point that they had virtually disappeared from the site. The research team was puzzled. Where did all the four-leaf clovers go?

Part A: Questions

1. What do you think has happened to the four-leaf clovers?
2. Can you design an investigation to test your hypothesis?

Part B: Mystery Solved!

The research team determined that the four-leaf clovers had been picked by the picknickers over several years. The team had fenced in an area to protect the clover from tourists, but even then, the four-leaf variety was found on extremely rare occasions. The collecting had taken its toll. In the meadow, it was maladaptive to be four-leafed, but the three-leaf clovers were left alone.

Part B: Questions

1. What happened to the gene pool of the clover to explain why the four-leaf variety almost disappeared?
2. Which type of selection was occurring in the meadow? Explain your answer.
3. Sketch a graph showing the initial distribution of leaf variation in *Trifolium repens.* Indicate the number of leaves on the x-axis, and the number of plants on the y-axis.
4. Sketch a graph showing the leaf variation in *Trifolium repens* several years later. Indicate the number of leaves on the x-axis, and the number of plants on the y-axis.

Appendix 7b: Answer Key to Where Did All the Four-Leaf Clovers Go?

Part A

1. The four-leaf clovers were being picked by the picnickers.
2. Possible answers could include interviewing picknickers to see if they are picking the clovers, enclosing an area in the meadow with a fence to prevent the tourists from getting at the clover and see if the four-leaf type returns…

Part B

1. The gene pool gradually changed in favour of the three-leaf type.
2. Stabilizing selection was taking place. The normal three-leaf type was being selected for and the extreme variation (four-leaf) type was being selected against.
3. The frequency peaks at the three-leaf variety, and curves indicating some at four-leaf variety and very few at two- and five-leaf varieties.
4. The frequency peaks at the three-leaf variety, and now shows only a few of the four-leaf variety, and very few at two- and five-leaf varieties.

Appendix 8a: Case Study - Population Bottlenecks and Endangered Species (BLM)

Introduction

Whooping cranes are an endangered species that nest in the Wood Buffalo Park of the Northwest Territories. While populations of whoopers were never large, their numbers declined rapidly in the early 1900's due to hunting and habitat destruction due to agriculture. In 1941 there were only about 15 whooping cranes left in the world. In the 1940's various agencies in Canada and the US joined together in an effort to save the birds from extinction.

Wildlife refuges and national parks now protect the bird's summer breeding area in NWT and wintering grounds in Texas. Captive breeding programs have been established in some zoos (including the Calgary Zoo). By the winter of 2004-05 the crane population had climbed to 472 captive and wild birds, 217 of which nest in Wood Buffalo National Park.

Conservation efforts are hampered by a number of factors. About 15% of eggs laid in wild are infertile, possibly as a result of inbreeding. The success rate of nesting pairs fledging a chick is only about 50%. Disease is a problem in some captive breeding populations. Severe climactic events including hurricanes in Texas and late-spring blizzards in the NWT breeding grounds can lead to increased mortality. While their numbers have increased due to conservation efforts, whooping cranes will always be threatened with extinction.

Questions

1. The whooping cranes are an example of an endangered species that has passed through a population bottleneck. Explain how a population bottleneck can alter the genetic variation in the gene pool of a species.

2. Describe the effect of the population bottleneck on the potential of the whooping cranes to adapt to environmental changes and evolve.

3. How could the population bottleneck affect the ability of the whooping cranes to recover from near extinction?

4. Why should we bother trying to protect and conserve an endangered species?

Appendix 8b: Answer Key to Population Bottlenecks and Endangered Species

1. Because the population reaches such a low number of individuals in a population bottleneck, only a few individuals contribute genes to the entire future population of the species. Much genetic variation within the species is lost, and allelic frequencies change significantly in the remaining gene pool.

2. The lack of genetic variation reduces the ability of the whooping cranes to adapt to environmental changes. There is little variation upon which natural selection can act.

3. No matter how many whooping cranes there are, the species will always be at risk of extinction. Their genetic homogeneity makes them potentially more sensitive to disease and genetic conditions associated with inbreeding.

4. Answers may vary and include points such as:
   - Humans caused to whooping crane numbers to decline due to hunting and destroying their habitat.
   - Our actions caused the whooping crane's gene pool to become a gene puddle.
   - The human population has become so large and is consuming so many resources that we are forcing our neighbours out of their homes.
   - We should practice good stewardship and preserve our world for future generations.