Santa Cruz-Watsonville Inquiry-Based Learning in Environmental Sciences

An NSF GK-12 Project

Why Do Organisms Vary?

Genetic and Environmental Contributions to Trait Variation

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Field-tested with: 10th grade students in Agriculture and Natural Resources Courses, ESNR Academy, Watsonville High School, Watsonville, CA (Fall, 2010)

Concepts: Variation within populations, evolution, genetics, heritability, environmental effects on organisms' traits

Skills: Performing a long-term, controlled experiment; defining and measuring traits; displaying information graphically (histograms and linear regression)

Module Type: Long-term experiment with associated lectures/discussions

Duration: Approximately 8 weeks

Key materials:

- 2 "Growth, Development, and Reproduction" Classroom Kits from Wisconsin Fast Plants™
- toothpicks and glue/small paint brushes
- watering trays
- flats for seedlings
- 2 fluorescent light fixtures and 4 fluorescent light bulbs
- class set of rulers, calipers, or tape measures
- class set of science notebooks
- class sets of all handouts

Science Education Standards:

National: Science As Inquiry; Life Science

California: Biology-Life Sciences: 7. Evolution (allele frequency), 8. Evolution (genetic change); Investigation and Experimentation

Overview: In this project, students design an experiment to assess how much phenotypic variation in one or more traits results from genetic vs. environmental variation. Students use Wisconsin Fast Plants™ (*Brassica rapa*) to calculate trait heritability and investigate the effect of environmental variation on traits. This project articulates well with lessons on how crop plants were domesticated, natural and artificial selection, and traditional vs. biotechnological methods of modifying the traits of domesticated plants and animals. It could also lead to discussions of how environmental changes will impact organisms, both in terms of immediate, phenotypic changes and long-term evolutionary changes.

This project is an opportunity for students to:

- Understand what traits of living organisms are, why traits vary, and why only traits whose variation is at least partly genetically determined can evolve.
- Design a controlled, long-term experiment and learn how to avoid and account for biases in experimental design and data collection.
- Collect, organize, display, and interpret data in appropriate tables and graphs.

Background for Teachers

Why does variation matter?

The simple observation that not all members of a species are identical is fundamental to genetics, evolution, ecology, and conservation. This module lets students observe how an organism's environment and genes both affect its appearance. Using Wisconsin Fast Plants (http://www.fastplants.org/), which are mustard plants bred especially for the classroom, students breed two generations of a population in a single semester, allowing them to create and analyze a pedigree. At the same time, they manipulate the environment to measure how much environmental variation contributes to variation in the plant's characteristics. The module lets students in vocational courses such as horticulture integrate science content with the practical techniques they have learned, and it may stimulate discussion of traditional breeding vs. genetic modification as methods of altering domesticated organisms.

Science Education Standards Addressed:

California Science Standards:

Biology/Life Science Standards for Grades 9-12 (pp. 45-46)

- 7d: *Students know* variation within a species increases the likelihood that at least some members of a species will survive under changed environmental conditions.

  This module permits students to observe the effects of environmental variability on organisms' traits, which is vital to understanding why environmental changes may threaten some species' survival. It also allows students to observe, experimentally, the fact that some variation in an organism's traits is genetic and thus may be able to respond evolutionarily to environmental changes.

- 8a: Students know how natural selection determines the differential survival of groups of organisms.

  By illustrating how variation is passed from one generation to the next, this module helps students to understand why individuals with traits that allow them to survive and/or reproduce at higher rates than others in their population leave disproportionately high numbers of descendents, who will likely share those traits. This is the mechanism by which natural selection operates.

Investigation and Experimentation Standards for Grades 9-12 (p. 52)

- 1a: Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data.

This module generates data on frequency distributions of traits, as well as the relationship between parental and offspring traits and between trait values and the value of environmental variables. Recording, organizing, analyzing, and displaying these data will allow students to use technologies such as spreadsheets and statistical analysis programs and require them to decide which graphs are most appropriate for several kinds of data.

- 1b: Identify and communicate sources of unavoidable experimental error.

  An investigation of the sources of variation in living organisms provides an ideal context to discuss how experimental error might also contribute to the variability that students observe in their plants.

- 1c: Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.

  Students can be guided through a discussion of what other factors might cause variation in the plants they are raising, besides genetics and the environmental variable they choose to manipulate.

- 1j: Recognize the issues of statistical variability and the need for controlled tests.

  Depending on students' level of statistical knowledge, this module can incorporate formal statistical tests such as linear regression and tests for homogeneity of variance. Students without a background in statistics can still be guided through a comparison of which populations of plants is most variable. As discussed above, the need for controlled tests can be discussed in the context of extraneous sources of variation in the plants' traits and how to avoid biases in the experiment.

National Science Education Standards:

Standard A for Grades 9-12: Science as Inquiry (p. 173)

As a result of activities in grades 9–12, all students should develop

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

This module requires students to choose appropriate, measurable traits and select variables that can be rigorously manipulated. It gives them the opportunity to design a controlled experiment and generates a large quantity of data for them to analyze and display.

Standard C for Grades 9-12: Biological Evolution (p. 185)

- Species evolve over time. Evolution is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuring selection by the environment of those offspring better able to survive and leave offspring.

This module permits a detailed investigation of the heritability of quantitative traits (those for which variation is continuously distributed). Most traits discussed in high school biology classes are discrete traits, even though most traits of interest in wild and domesticated organisms are quantitative. This module will thus broaden students' understanding of the mechanism by which selection operates.

SCSCPS (http://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf);
NSES (http://www.nap.edu/catalog/4962.html)

Common Student Misconceptions:

Students may have been exposed to the concept of genetics in terms of discrete traits in their previous biology classes (often through discussions of Punnett squares and Gregor Mendel's experiments with pea plants), which can both help and hinder their understanding of quantitative genetics. For some classes, it may be useful to explain that quantitative traits are usually influenced by many loci within the genome, unlike discrete traits, which are usually influenced by one or a few loci. However, this explanation may only further confuse students with less biology background, who would be more successful if they approached the material on its own, without distractions. Evaluating the students' prior biology knowledge may be helpful in deciding how much detail to provide.

Project Description

Materials:

- 2 fluorescent light fixtures (any kind)
- 4 fluorescent light bulbs (any kind)
- 2 "Growth, Development, and Reproduction" Classroom Kits from Wisconsin Fast Plants, available from Carolina Biological Supply or Nasco Science. As of Feb., 2011, these cost $68.95 per "classroom kit," from CBS and $71.75 from Nasco, but each classroom kit is really only enough for 16 students, so most classes will need two. They are available at http://www.carolina.com/product/living+organisms/wisconsin+fast+plants/kits/wisconsin+fast+plant+growth+development+reproduction+kit.do?sortby=ourPicks and http://www.enasco.com/product/SB41046M.
    - Each kit contains:

- 1 pack of 200 Standard Wisconsin Fast Plant Seeds
- 1 packet (1 oz.) Osmocote fertilizer pellets
- 2 watering trays
- 2 watering mats
- 70 wicks
- 2 anti-algal squares
- 8 watering pipettes
- 1 L potting soil
- 1 package dried bees
- 16 4-cell quads (for growing plants, can be reused)
- 16 support stakes
- 16 support rings
- Growing instructions

Depending on class size, it may be helpful to have extras of the following items:

- Watering trays (can buy with the kits or make out of a plastic tupperware, with a hole in the top to allow the watering mat to hang down; please see photo)
- Watering mats (a.k.a. capillary mats; can order with the kits or buy at a gardening store, although we had a hard time finding them locally)
- Anti-algal squares (will need one per tray; can order extras with kits)
- Watering pipettes (only 8 come with each classroom kit, and it's best if every student has his/her own; can buy plastic transfer pipettes at drugstore)

Do-It-Yourself Watering Trays:

A slot cut into the edge of the container lid allows the capillary matting to hang down into the water.

Class sets of the following:

- Flats for growing plant seedlings (order extras with kits or buy at gardening store)
- Small paint brushes for pollination (4 per student; for use if dried bees don't work)
- If using dried bees for pollination, you will also need sharp toothpicks and glue to make beesticks
- Rulers, calipers, or tape measures, depending on traits students choose to measure
- Small envelopes (4 per student) for collecting seeds
- Science notebooks (1 per student) for recording data and observations
- Class sets of all handouts

Preparation:

In our class, each student was responsible for a single "quad" containing four plants, so they could work largely individually. Depending on the class and the students' interests, it may be necessary for the teacher to build a lighting system for the plants ahead of time (although it won't technically be necessary until the plants have germinated and start to photosynthesize). For some classes, however, this can be a good way to get students with hands-on, mechanical skills more involved in the project. The fluorescent lights should be 5-10 cm above the plants; this can be achieved by simply placing the light fixtures on two stacks of books or by constructing a more complicated setup, depending on time, materials, and student interest.

The plants should be watered with water that does not contain chlorine, so if the tap water in your area is chlorinated, it may be necessary to leave trays filled with water out overnight before using them to water any plants. This will allow the chlorine to evaporate. Alternatively, you can use deionized water.

Timeline:

Day 0: Introductory lecture (45 min)
Day 0 or 1: Brainstorming session on which traits to measure and which environmental variable to manipulate (20-30 minutes, can be combined with first planting if time allows)
Day 1: Plant seedlings of parental generation (45 min. – 2 hours, depending on students' behavior; our class was very unruly, so it took close to 2 hours)
Day 4: Thinning plants (20-30 min.)
Between Day 3 and Day 12: First day of trait measurements (45 minutes)
Between Day 13 and Day 15: Flowering observations (15-20 minutes per period)
Between Day 15 and Day 17: Pollination (45 minutes; with possible follow-up pollinations on later days, 15-20 minutes)
Between Day 18 and Day 34: Seed pod development observations (15-20 minutes per

period)
Day 35: Remove plants with mature seed pods from water (30 minutes)
Day 40: Harvest seeds (30 minutes)
Day 41: Plant second generation of seeds (45 minutes – 2 hours)
Between Day 42 and Day 51 Second day of trait measurement (45 minutes)
Day 52: Data analysis (at least 45 minutes, can be expanded to cover several class periods)

Procedure:

Students conduct two overlapping experiments to determine whether observable traits are influenced more by genetics or by the environment.

The breeding experiment runs for the duration of the module. It measures the contribution of genetics to the traits students select for analysis. Students begin by selecting one or more traits to analyze, and plant a set of seeds. When these plants reach adulthood, the students measure the traits they selected. They cross their plants with those of other students to generate a second generation of seeds with known parentage, harvest the seeds, plant them, and grow them to adulthood. This generates a pedigree, and allows students to measure the same traits they had measured previously in their original plants' offspring. They use linear regression to see how similar parents and their offspring are and calculate each trait's heritability, which is a measure of how much variation in a trait is caused by genes. This part of the experiment provides information about the degree to which these traits would have the potential to evolve in response to artificial or natural selection.

The environmental influence experiment is conducted on the second generation of plants, and begins as soon as the offspring seeds are ready for planting. Teachers should choose a student whose plants have produced an unusually large number of "sibling" seeds (i.e., seeds from the same cross). Students choose an environmental variable to control and plant these genetically similar ("sibling") seeds under varied conditions. They record the effects of this variation on the same traits they are measuring in the breeding experiment. Again, when the offspring generation reaches adulthood, students use linear regression to see how much the environmental variable affected the selected trait.

Starting Point For Inquiry:

Day 1 (whole class period): Introductory lecture (see attached) on traits, variation within populations, natural and artificial selection, heritability, and the effect of the environment on organisms' phenotypes. Discuss genetic and environmental causes variation in human traits (e.g. hair color) or the traits of domestic animals (dogs are a good example, but schools with many students from agricultural backgrounds may have more success with farm animals).

Question Generation and First Planting:

Day 2 (whole class period): Students should be guided to choose a trait to measure, and an environmental variable (e.g., fertilizer levels) whose effect they wish to assess, and levels of that variable should be varied among the plants. We had the most success in measuring plant height and number of leaves, and we varied fertilizer levels (from 1-4 pellets in the four cells of each quad). Please see instruction handout.

Plant seedlings of the parental generation. Each student should have one "quad," containing four cells, and each cell should have a unique identifier of some kind. Planting three seeds per cell usually ensures at least one will germinate.

Testing, Observing and Recording Variation:

Days 3-12 (at least one whole class period for trait measurement): Students make observations and collect data on plants as they grow. Variable traits include plant height, number of leaves, number of hairs on leaf margins, number of flower buds, time to development of first flower bud, and many others. Students should be guided to choose the traits they will measure and analyze.

Day 4 (about 20-30 minutes): Students pull out all but one plant per cell.

Days 13-15 (about 15-20 minutes per class period): Plants begin to flower; students should make observations of their plants in their science notebooks.

Days 15-17 (at least one whole class period): Pollination. Students pair up and make reciprocal crosses using either dried bees or paintbrushes. It is vital that the students record which plants they crossed, so that the parentage of the seeds used in the next generation will be known.

Days 18-34 (about 15-20 minutes per class period): Fertilization occurs and seed pods develop. Students should make observations of the rate at which this occurs for each plant in their science notebooks.

Day 35 (about 30 minutes): Remove plants with mature seed pods from water and allow to dry out.

Day 40 (whole class period): Harvest seeds from dried-out seed pods, place seeds from each plant in individual envelopes marked with the parents of those seeds, thereby conserving the pedigree.

Day 41 (whole class period): Plant seeds from second generation in two parallel experiments. The breeding experiment will determine the heritability of the traits measured in the parental generation, while the environmental-influence experiment uses multiple seeds from the same cross (i.e., genetically similar individuals) under different circumstances (like different amounts of fertilizer) to assess the effect of varying levels of the environmental variable chosen by the students on those same traits.

Days 42-51 (at least one whole class period for trait measurement): Students make general observations of their plants' growth and development. It is important that students measure the same traits as in the parental generation, when the plants are the same age that their parents were.

Analyzing and Presenting Final Results:

Day 52 (most of one class period for data analysis): For the breeding experiment, perform a parent-offspring regression for each trait measured, using data from the whole class. Make a scatter plot where you graph the average value of the trait among all the offspring of a cross on the y-axis and the average value of that trait in the parents on the x-axis. You can use Microsoft Excel or a statistics program to perform a linear regression, an analysis that draws the line of best fit through the points (see attached appendix for detailed instructions using Excel). Most programs will provide the slope of the line, which represents the quantity (change in y)/(change in x). That is, larger slopes represent "steeper" lines and generally indicate stronger effects of the x-variable on the y-variable. In a parent-offspring regression, the slope of the regression line is the heritability, or the percentage of the phenotypic variation in the trait that is caused by genetic variation.

For the environmental variation experiment, regress the plants' trait values on the value of the environmental variable. Discuss what regression is and what the data indicate.

Assessment Methods:

1. Worksheets in which students graph new data using techniques learned with their Fast Plants data (see attached examples).

2. Review students' science notebooks and assign grades based on how carefully they documented their methods and observations, how well they recorded and organized their data, and how many hypotheses they developed and whether they referred to them later.

3. Lab reports or poster presentations of findings. Students could work in groups, each of which might be responsible for analyzing a different trait.

Special Notes to Teachers:

One major caveat teachers should bear in mind when implementing this module is that the growth times given in the Wisconsin Fast Plants manual are approximate. Students' plants may vary substantially in when they germinate, how quickly they grow, and when they flower. As long as students keep careful records, it's fairly easy to adjust the procedure for delays or accelerations in plant development, but if students fail to keep track of what steps they have already performed with their plants, it may be difficult for them to produce usable data. Emphasizing careful data collection and checking to make sure students are actually writing down their data is essential. We also found that student data sheets were frequently lost or destroyed if they left the classroom. Issuing the students "science notebooks," which were kept in a locked cabinet in the classroom, helped to resolve this issue.

Another potential problem arises when students are absent on key project days. Asking other students to care for or take data on absent students' plants ensures that all students can contribute data to the final analyses.

Appendices (Handouts)

A. Introductory Lecture:

- **"Why do individuals of the same species look different from one another?"**
- **Key Concepts and Skills: Quantitative Trait Variation and Controlled Experiments**
- **Glossary**

C. Assessment Materials:

1. **Questions for Understanding: Graphing Traits** (We used this worksheet to assess students' understanding of how to represent the data they were generating and why traits must be heritable to evolve.)
2. **Linear Regression in Microsoft Excel** (These instructions are for the Macintosh version of Excel from 2008. They may vary slightly from other versions, but the general idea should be similar.)

Why do individuals of the same species look different from one another?

Genetic and Environmental Contributions to Phenotypic Variation

*Words in **bold type** are defined in the attached list of vocabulary words.*

Look around the room. You and everyone else in your class are members of the same **species**, but you don't all look alike. Some of you are taller than others, and you may have differently colored hair or eyes. All these characteristics are called **traits**, and when we describe the version of a trait an individual has, we call that description the **trait value**. A trait value can be a number (someone can be **1.57** m tall) or a verbal description (a person can have **blue** or **brown** eyes).

Individuals of other species have traits that vary, too. In nature, some trait values may help the individuals that help them survive or reproduce better than other individuals of their species. This process is called **natural selection**, and over long periods of time, it can change which trait values are most common in a species. If this happens, we say the species has **evolved**. Humans can also control how some species evolve, however, by using the variation that occurs naturally in the plants or animals we have domesticated. For example, a farmer who wanted larger cows might only allow the largest cows in his or her herd to breed. This process is known as **artificial selection**, but it works essentially the same way as natural selection.

Here's another good example of artificial selection. Did you know that broccoli, cabbage, kohlrabi, and brussels sprouts are all the same species? Many years ago, farmers domesticated a species of wild cabbage called *Brassica oleracea* (Figure 1). In this plant, different individuals varied in the sizes of their leaves, buds, flowers, and other body parts. Broccoli is the result of farmers breeding only the plants with the biggest flower clusters. Similarly, cabbage resulted from artificial selection for shorter shoots, kohlrabi from selection for larger stems and leaf bases, and brussels sprouts from selection for larger lateral buds (buds on the side of the plant's stem).

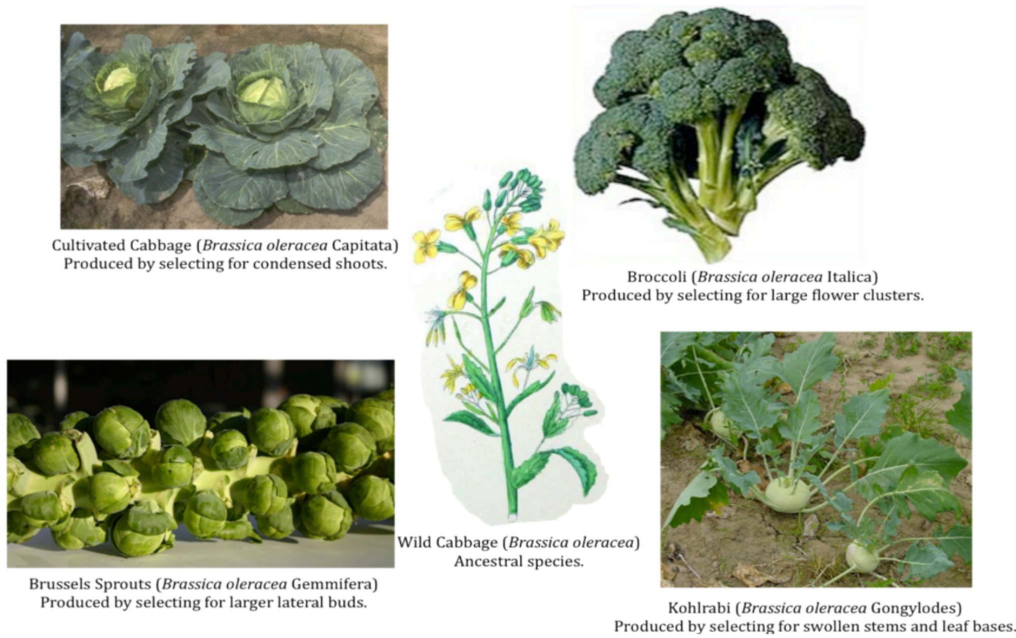


Figure 1: Wild cabbage gave rise to broccoli, cauliflower, kale, collard greens, Brussels sprouts, kohlrabi, and cabbage. Farmers used the natural variation in this plant's traits to develop several varieties of crop plants that now appear completely different from one another and their ancestor (all images from the public domain; information from Freeman & Herron 2007)

The trait value an individual has for a given trait is determined by two main factors:

1) the genes the individual's parents pass down to it, and
2) the environment the individual has experienced during its life.

This semester, we'll measure variation in two traits of Fast Plants, a variety of the mustard plant *Brassica rapa*, which has been artificially selected to grow especially quickly in the laboratory. We'll also perform an experiment to determine how strongly genes and the environment affect each trait.

Key Concepts and Skills: Quantitative Trait Variation and Controlled Experiments

Traits where the trait value is a number and the **frequency distribution** is fairly smooth are called **quantitative traits**. Examples in humans include height and weight. In contrast, traits that can't be described by numbers or don't have smooth frequency distributions are called **discrete traits**. Examples in humans include gender (male or female) and handedness (left or right). Most traits are quantitative traits, so those are the kinds of traits we'll be discussing.

Variation within a species in the value of a trait is the "raw material" for both natural and artificial selection. If a trait isn't variable, it can't evolve. The variation we see in wild and domesticated species has two sources: the genetic variation passed down from the previous generation (the parents of the current individuals) and effects due to the environment.

One example of an environmental effect might be fertilizer level. Plants that are given more fertilizer will likely grow larger, regardless of what genes they have.

However, variation caused by the environment does not contribute to evolutionary change, either by natural or artificial selection. You might say that this kind of variation is "invisible" to selection, because selection can only work on traits that are passed down from parents to offspring.

Remember the example of the farmer who wanted to get larger cows by allowing only the largest cows in his or her herd to breed? If body size in cows were only due to some environmental variable, such as how much food the cows ate, this technique wouldn't work. In that case, a large cow and a large bull would be no likelier to produce a large calf than would a small cow and a small bull. The body size of the calf would depend only on how much food the farmer gave it.

Before trying to use artificial selection to cause some desired evolutionary change, farmers and ranchers need to determine whether that trait is influenced mostly by the environment or mostly by genetics.

Over the course of the next two months, we'll perform two experiments to determine whether the traits you measured today in your plants are influenced more by genetics or by the environment. One experiment will measure the contribution of genetics to these traits. You'll cross your plants with those of other students to generate seeds and then grow those seeds to adulthood, generating a pedigree and allowing you to measure the same traits in your plants' "children" that you measured in your plants today. You'll then use a statistical analysis called linear regression to see how similar parents and their offspring are, which is a measure of how much variation in a trait is caused by genes. This will help us understand to what degree these traits would have the potential to evolve in response to artificial or natural selection.

The second experiment will use several seeds from the same cross ("siblings") to measure the effect of the environment on the same traits you measured today. Because siblings share a lot of the same genes, using them removes most of the variation due to genetics. You'll grow different siblings in different environments and then use linear regression again to see how much the environmental variable you changed affects their traits.

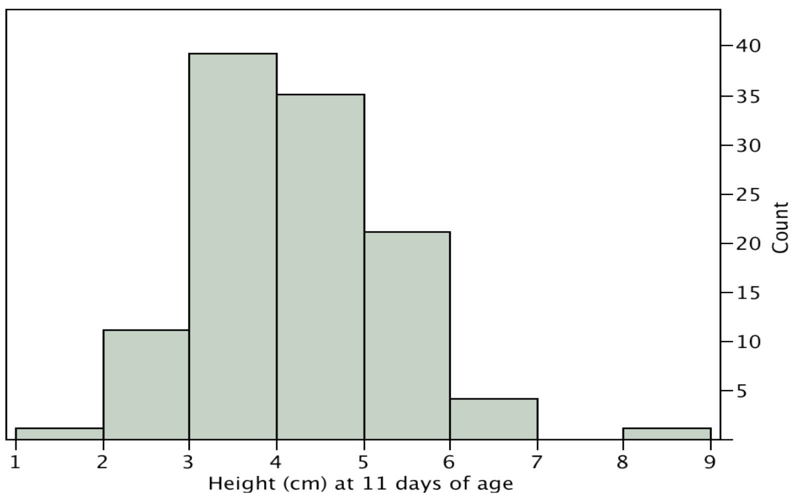
Glossary

Artificial Selection: The process by which humans try to cause a desirable change in the most common value of a trait in some domesticated species. Usually, this means only breeding individuals who have the desired trait values.

Discrete Trait: A trait where the trait value is usually not a number and there are only a few possible versions of the trait. Examples include gender, handedness, and blood type.

Evolution: Change in which values of a trait are most common in a species, as a result of natural or artificial selection.

Histogram: A type of graph that is often used to show variation in the values of a trait within a population or species. The x-axis (horizontal line) usually shows different possible values of the trait, while the y-axis (vertical line) usually represents how many individuals have each value. See the example below:



Another way to describe what this graph illustrates is as a **frequency distribution**. The word "distribution" here refers to the range of trait values occurring in the population. The word "frequency" indicates that we are illustrating how frequently each trait value occurs.

Natural Selection: The process by which certain values of a trait make an individual more likely to survive or reproduce in nature. For example, plants that grow to be taller might receive more sunlight than shorter plants, which would allow them to produce more seeds.

Phenotype: The physical attributes of an organism.

Quantitative Trait: A trait where the trait value is a number and a frequency distribution for that trait in the species where it occurs forms a smooth curve. This happens because there are many possible trait values. Examples include height, weight, and arm length.

Species: A group of individuals who are all capable of reproducing with one another but cannot reproduce with members of other species. For example, humans can reproduce with other humans but not with chimpanzees, the living species that is most closely related to us.

Trait: Any measurable or observable characteristic that is part of a living organism's phenotype. For example, hair color, eye color, height, and weight are all human traits.

Trait Value: A description of which version of a trait an individual has. For example, a person could be 1.6 m tall or have black hair.

Questions for Understanding: Graphing Traits

Please complete these questions and turn them in during your next class.

Based on the following information, answer questions 1-3 and draw a histogram of the frequency distribution on the axes provided:

Ms. Smith asked every student in her 10th grade class how many pets he or she had. Two students answered that they had no pets, 5 students said they had 1 pet, 6 students said they had 2 pets, 4 students said they had 3 pets, 2 students said they had 4 pets, and 1 student said he had 6 pets.

1. Which variable (number of students or number of pets) should be on the x-axis (the horizontal line)?

2. Which variable (number of students or number of pets) should be on the y-axis (the vertical line)?

Histogram: Number of Pets per Student in Ms. Smith's 11th Grade Class

3. Bonus Question: Do you think "number of pets" is likely to be a trait with the potential to *evolve* in response to natural or artificial selection? Explain why or why not.

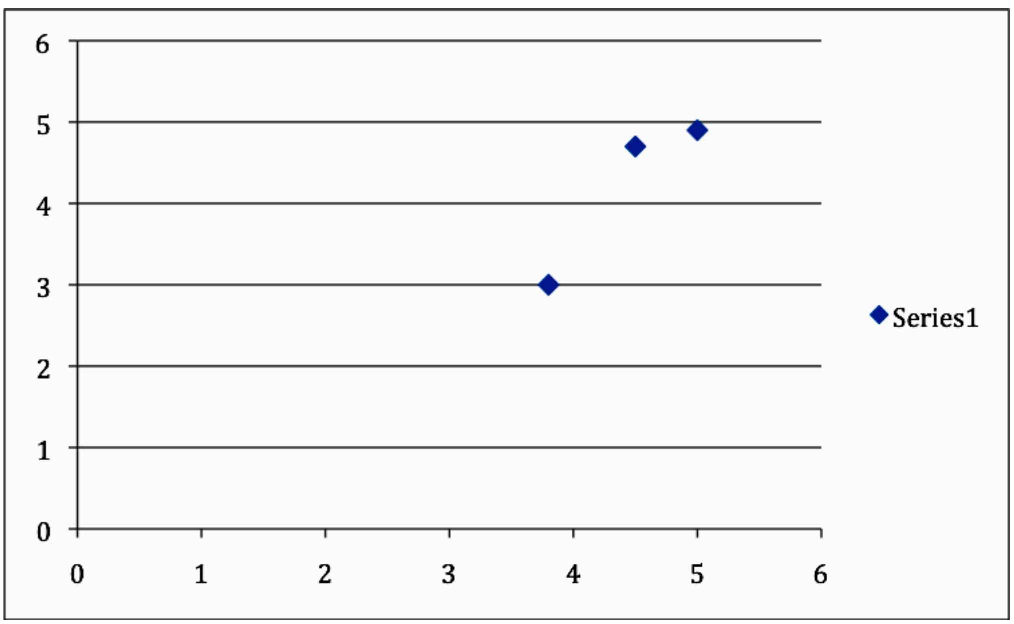
Linear Regression in Microsoft Excel

1. Make two columns of data. One should contain the mid-parent values (the average value of a trait in the parents) for a given cross, while the other contains the average offspring values of the same trait. Make sure the columns are aligned so that each row corresponds to a single cross. See the example below:

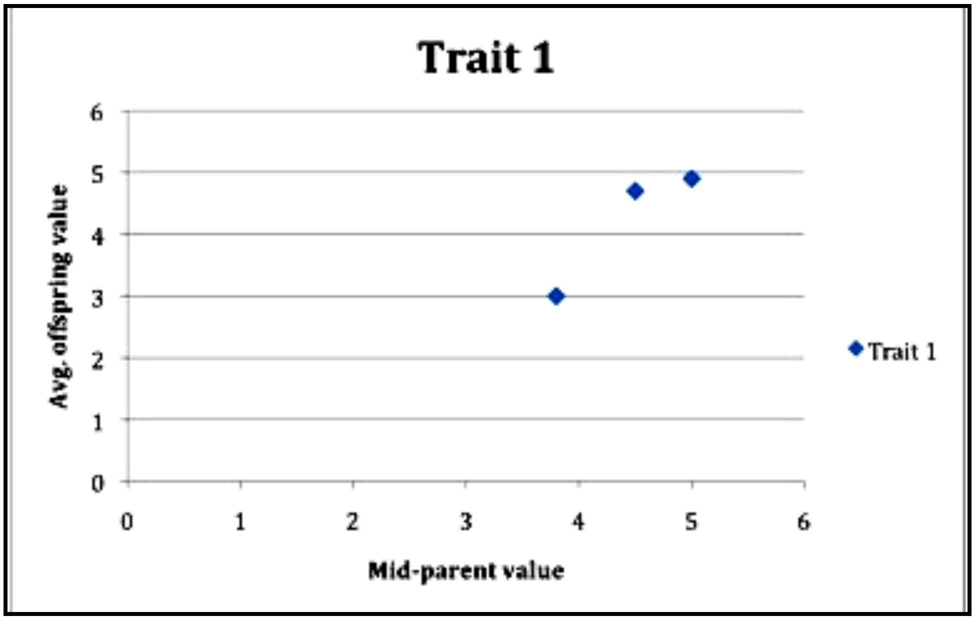
Mid-parent value	Avg. offspring value
5.0	4.9
3.8	3.0
4.5	4.7

Pairs of numbers highlighted the same color should be from the same cross. It is most conventional to put the column that will represent the x-variable on the left and the column that will represent the y-value on the right.

2. Highlight the data and use the "charts" menu at the top of the page to choose "XY Scatter." Choose the option in which the points are not connected by any lines. A graph similar to the one below should be generated:

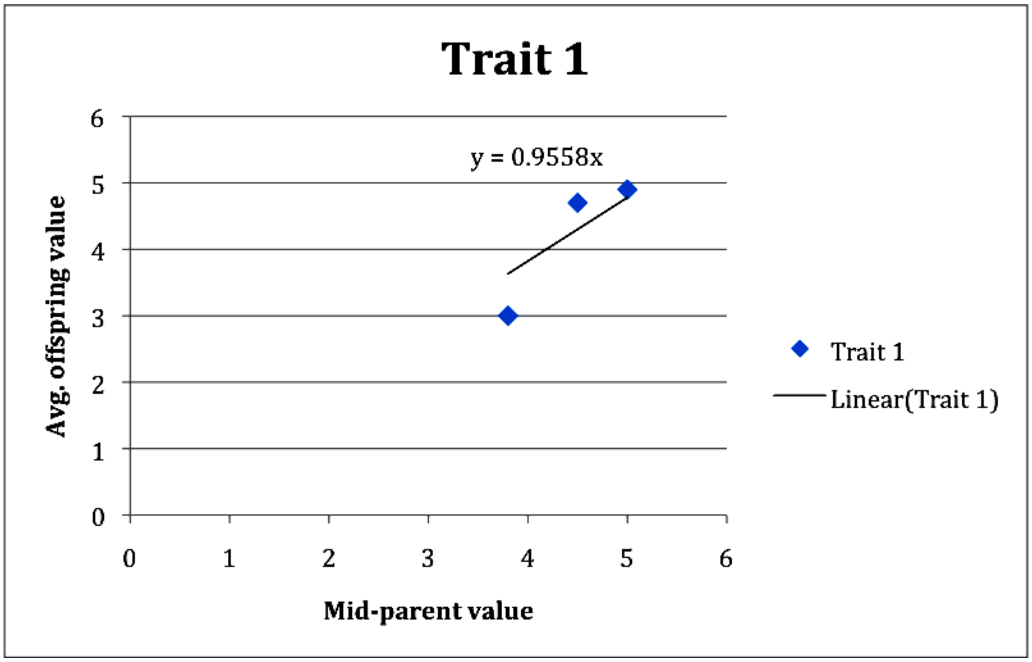


3. You can right-click (PC) or control-click (Mac) on various parts of the graph to edit them. You can also use the formatting palette in the toolbox to add axis labels and change general aspects of the graph's appearance. Here is an example of what the graph might look like after this process:



4. Right-click (control-click) on one of the data points. A menu will pop up that offers the option to "Add Trendline." Click on this option. Excel will automatically perform a simple linear regression, fitting the line that best represents the relationship between the y and x variables suggested by the data.

5. Under the "Options" menu in the "Format Trendline" dialog box, click on "Display equation on chart." This will show an equation of the form $y = mx + b$ that corresponds to the line. In this format, m represents the slope of the line, and b represent the y-intercept (the value of y that corresponds to an x-value of 0). In parent-offspring regression, it makes sense to set the intercept to zero (if the trait is absent in the parents, it is usually also absent in the offspring). You can do this by checking the box next to the "Set Intercept" option and typing "0." This should produce a graph similar to the one on the following page:



Here, 0.9558 is the slope of the regression line for the three sample points on the graph. If this were a real population, it would indicate that "trait 1" had very high heritability – approximately 96% of its variation caused by genes.

6. The same procedure can be used to produce regression lines for the environmental variable you manipulated. In that case, though, it may not make sense to set the y-intercept to zero. Students and teachers should discuss this and make the decision that best reflects the biology of the plants and the variable they manipulated. Also, the slope of a regression line only represents heritability in the special case of parent-offspring regression. In other types of regression, it indicates the strength of the effect of the x-variable on the y-variable.

Reference List

Carolina Biological Supply Company. 2001. *Wisconsin Fast Plants Growing Instructions*. North Carolina: Carolina Biological Supply Company.

Freeman, S. and J.C. Herron. 2007. *Evolutionary Analysis*. 4th ed. New Jersey: Pearson Prentice Hall.

National Science Education Standards: http://www.nap.edu/catalog/4962.html

Science Content Standards for California Public Schools: http://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf

Wray, N. & Visscher, P. 2008. Estimating trait heritability. *Nature Education* 1(1).