Nature or Nurture? Heritability in the Classroom

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Overview: From intelligence to laziness, artistic talent to how likely you are to become bald, people want to know, and debate about, whether traits are passed down from parents ("nature") or affected by environment ("nurture"). In reality, the question is not "nature *or* nurture", but to what extent each affects traits. In this exercise, students will learn about the importance of nature *and* nurture in determining phenotypic differences among individuals by collecting data on themselves and their parents to estimate heritability. With instructor guidance, students will decide the traits that can be easily and reliably quantified (measured) for both themselves and their parents. Students will also develop their own hypotheses about how and why different traits have higher or lower narrow-sense heritability, and factors that could affect those estimates.

Necessary Student Background (pre-teaching)
Some of this is covered below in Teacher Background:

- traits, genotype, phenotype.
- heritability, inheritance, Punnet squares
- graphs of offspring vs. parents for body height, humans and animals

Lesson Concepts:

- Traits can be defined as any aspect of the phenotype that can be measured with a reasonable degree of accuracy and repeatability. Examples of traits include a person's height, the number of siblings they have, their attitudes towards social issues, intelligence, how many minutes it takes them to run a mile, blood pressure, and blood hormone levels.
- The variation of any trait within a population is a result of both genetic differences among individuals ("nature") and the different environments each individual has experienced since conception, and even the environments experienced by their parents ("nurture").
- Narrow-sense heritability is the measure of how much of the phenotypic variance in a population is caused by additive effects of alleles segregating at all genetic loci that affect the trait in question.
- Narrow-sense heritability of a trait indicates its potential to respond to selection (natural, sexual or artificial), at least in the short term (over perhaps 10-30 generations in laboratory studies).
- Narrow-sense heritability of a trait in a population can be estimated as the slope of a least squares linear regression line of offspring average trait value on parental average trait value.
    - Regression analysis is used to describe the relationship between a dependent variable and one or more independent variables. The slope of a linear regression line measures how much the value of the dependent variable changes when a given independent variables is changed by one unit.
    - In this exercise, male and female offspring are analyzed separately to avoid statistical complications caused by sex differences (e.g., men are taller than women, on average).
- Environmental factors (e.g., diet) shared between parents and their offspring often inflate estimates of narrow-sense heritability. The study of heritability in human populations is complicated by this and by various practical considerations.

Grade Span: High School; College lower- or upper-division biology classes, including genetics and evolution

Materials:

- A computer with Internet connection and access to Google Forms (may require creation of a free Google account).
- Teacher computer preferably connected to a projector.
- Each student must be able to fill out the Google Form (can be from a computer or smart phone). Otherwise, teacher can manually input data for students.

Advance Preparation:

Read Teacher Background (below)
Follow instructions in Teacher Packet [link to PDF] to:

- Create a Google Form (which will be modified based on student interactions)
- Learn how to analyze data in the Google spreadsheet, which will be automatically created as responses to the Google Form
- Create instructions for a student report, if so desired

Time: Two to three 50-minute class periods (discussion sections and/or lecture periods)

Grouping: Pairs or groups for discussion, but most work done individually

Teacher Background:

Variation in most phenotypic traits (e.g., height) within a population results from individuals having different genes (nature) **and** from individuals experiencing different environments, currently and as they grew up (nurture). Here it is important to understand that parents provide many important aspects of an individual's "environment." For example, if a woman drinks alcohol heavily prior to conception, during pregnancy, or while nursing, then her child may be affected in various ways, both directly and indirectly (e.g., through changes in the mother's hormone levels). Similarly, obesity during pregnancy can have adverse effects on offspring health. As another example, dietary habits of parents (e.g., eating a lot of junk food) can be passed on to children.

The idea that both genes and environmental factors (including those provided by parents) can affect your traits is formalized in the field of quantitative genetics. This concept can be simply written as $V_P = V_G + V_E$, where V stands for variance (i.e., standard deviation squared) and P = phenotype, G = genotype, and E = environment. Most traits are controlled to some extent by genes, making them "heritable." However, heritability ranges between close to zero and as high as about 0.9 for some human traits. Heritability determines whether and how rapidly the average value of a trait for a population will change (evolve across generations) in response to natural, sexual or artificial selection. These concepts apply to both wild and domestic populations of sexually reproducing plants and animals, including human beings.

The term "heritability" can have several meanings, and is often used semi-colloquially. For purposes of this exercise, it is important to distinguish broad-sense from narrow-sense heritability. (Both of these are generally symbolized as "h^2" in the literature, which can lead to confusion.) Broad-sense heritability is the ratio of total genetic variance/phenotypic variance in a population. This includes non-additive effects of genes, i.e., dominance and epistasis. In general, dominance and epistasis do not contribute much to the resemblance between parents and their offspring because gene combinations are broken up when diploid parents produce haploid gametes (sperm and eggs). Broad-sense heritability is relevant for public policy because (by subtraction) it indicates how much of the variation in a population is environmental in origin, and hence potentially susceptible to manipulation in ways that would benefit human health or society (e.g., by educational or nutritional interventions).

Narrow-sense heritability is always lower than broad-sense heritability, as it equals the ratio of additive genetic variance/phenotypic variance for a given trait in a given population. This measure of heritability indicates, **on average**, how much of the variation in a trait is passed on from parents to their offspring within a specific population. Variances caused by genetic dominance and epistasis are not included in the calculation of narrow-sense heritability because they are not passed on from parents to their offspring. As additive effects of genes are, on average, faithfully passed down from parents to offspring, narrow-sense heritability is useful for predicting how rapidly a population will evolve over several or sometimes many generations. It is a main focus of animal and plant breeders, as well as evolutionary biologists.

All estimates of heritability apply to a particular trait, in given population, and at a certain point in time. Heritability often changes over time as the genetic composition of a population evolves and/or the environment changes. With very strong selection that continues for many generations, it is possible for narrow-sense heritability to be reduced to near-zero, as "good" alleles increase in frequency while "bad" alleles are eliminated from the population. Random mutations and gene flow from other populations would counter this process.

Narrow-sense heritability can be estimated as the slope of a regression of offspring on parents for a specific trait (assuming that you have no epistasis and also no non-genetic maternal or paternal effects and no common family environmental effects). In this exercise, the teacher instructs students to collect data on several traits that they find interesting and are easily measurable with a reasonable degree of accuracy (e.g., height, body mass, preference for sweets by self-assessment or see Possible Extensions). The teacher then performs regression analysis to estimate narrow-sense heritability for these traits.

Regression analyses are widely used for estimating relationships between variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed.

Note: The procedures described above for estimating narrow-sense heritability assume that mating occurs at random within the study population. Therefore, assortative mating (like tends to breed with like) can cause inflated heritability estimates. In many human populations, like tends to marry like with respect to physical characteristics, socioeconomic standing, political views, and so forth. This phenomenon can also cause the slopes of offspring-on-parent values to be higher than expected.

In addition, non-admixed populations can give inflated heritability estimates. If the class is of diverse backgrounds (e.g., including some recent immigrant populations), then you may observe higher estimates than expected because some of the among-population variation (e.g., in dietary preferences or skin color) will be present in the differences among both parents and offspring in your sample.

Also read:

- Quantitative Genetics [http://idea.ucr.edu/documents/flash/quantitative_genetics_1/story.htm]
- Adaptation [http://evolution.berkeley.edu/evosite/evo101/IIIE5Adaptation.shtml]
- Natural Selection [http://evolution.berkeley.edu/evosite/evo101/IIIENaturalSelection.shtml]

Vocabulary for Students: behavior, characteristic, estimate, evolution, genes, environment, heritability, morphology, phenotype, physiology, population, regression, trait, variance

Procedure:

Part 1: Background and Developing Hypotheses

1. Start by asking students to write 5 characteristics that they share in common with one or both of their parents. These traits can be morphological (e.g., height), physiological (e.g., blood pressure, diabetes) or behavioral (e.g., preference for spicy foods or classical music, a conservative political attitude).
2. Ask students to share their list of 5 common characteristics with their partner(s), followed by a whole-group share out. [think-pair-share here and in other places below]
3. Create a list of characteristics on the board (or have students write on the board), separated into morphological, behavioral, and physiological.
4. Discussion: Do these characteristics have anything in common? Which kinds of traits are more likely to be shared between parents and children? Morphological ones? Behavioral ones?
5. Discussion: Why would certain types of traits be more or less "shared" between parents and their offspring? (Get them to think about both genetic and environmental "inheritance.")
6. As a group, agree on 5 to 10 variables to measure. Keep in mind how easy or difficult it will be to get the data -- students will need to contact their biological parents for information. Some preferred variables for inclusion are height, weight (mass), shoe size, preference for salty snacks, preference for sweet snacks, preference for sour foods, preference for coffee, frequency of exercise behavior.
7. After selecting the variables, have students create and write hypotheses about which types of traits (e.g., behavior versus morphology) should have lower or higher heritabilities. Have them briefly explain their reasoning. For some traits, they may not expect any heritability. Have students share their thoughts with their partners.
8. Discussion: Do their hypotheses make sense? Ask how the environment might affect traits differently based on trait type (e.g., behavior vs. morphology). What happens to narrow-sense heritability if the parents and offspring grew up in very different environments? What if they grew up in very similar environments?
9. Have students refine their hypotheses and then make predictions about relative levels of heritability for the specific traits they will be measuring. Note that this is not easy because human reproduction involves ample opportunity for both genetic and non-genetic inheritance! Hence, no well-reasoned hypothesis or prediction should be considered "wrong."
10. Demonstrate filling out the Google Form.
11. **For homework, have students fill out the Google Form you create** (see Teacher Packet link to PDF). Be sensitive to the fact that some students may not want to provide this information, perhaps because they cannot contact or do not know one or both parents. In that case, tell them to enter "-9" (without the quotations) for "missing values" in the Google Form.

Part 2: Data Analysis and Interpreting Results

Prior to the Lesson (teacher prepares ahead of time):

1. Examine the student data and check for obvious errors. Remember to make a copy of the data file before you begin editing! Convey to your students the importance of data quality and verification -- garbage in, garbage out! In an advanced class, you may want to have students participate in this process.
2. Create graphs and analyses directly in the Google spreadsheet where the data reside. Note that you can also export the file in Excel format and edit there or with a graphics/statistics program of your choice.
3. Watch for obvious biological "outliers" that might cause student discomfort or embarrassment (e.g., high body mass caused by obesity). Biological outliers (i.e., unusual data points that are not simply caused by measurement or typographic errors) can be good taking-off points for instruction (including the statistical complications they may cause). However, depending on the class, it may be prudent to delete them before showing the data. If so, then you may want to tell the class that the data have been edited by removing apparent outliers, which is common statistical practice.

In Class:

4. Show the appropriate graphs/analyses to address the predictions.
5. Make sure to go over reading and interpreting the graphs. Why are offspring values on the y-axis (dependent variable)? Why are the parental values on the x-axis (independent variable)? What does one data point represent? What is a line of best fit?
6. Were there any outliers (see also #1 and #3 above)? Go over the data collection process. Are outliers mistakes? How so? How do you deal with these problems?
7. Optional: What is a least-squares linear regression? What are residuals? What are covariates?
8. Discussion: Does the data support student predictions?
9. Provide students with graphs and analysis results by printout or email.
10. **For homework**, have students write a summary or report. One possible format for a report is included at the end of the Teacher Packet.

Part 3: Lesson Summary and Class Discussion

1. Have students share what they learned from the exercise. Were any results surprising or unexpected? If so, then how might you explain the results?
2. Think-pair-share: What do you think about the phrase “nature vs. nurture” now that you have learned that most traits are affected by *both* genes and the environment? What are the implications of your results for human health and public policy? What are some other traits that could be studied?
3. Develop new hypotheses about the relative level of heritability for different types of traits.

Extensions

Preference test for salty or sweet foods: get different kinds of potato chips or nuts with different amounts of sodium on the label. Conduct a blind taste test in class. You can test for repeatability (consistency within individuals, tested at different times) by doing the same test a day/week apart. It would also be possible to get parents to do the same taste-test and let the students know the outcomes.