Understanding Variation in Human Skin Color

Activity
Educator Materials

OVERVIEW

In this activity, students extend the concepts covered in the short film *The Biology of Skin Color* through the application of models and mathematical thinking to explain how the number of genes that affect skin color affects the number of phenotypes and how scientists explore the genetics of skin color.

The Biology of Skin Color walks viewers through the process by which Nina Jablonski came to propose an explanation for why humans living in different parts of the world have different natural skin colors. Specifically, students learn how patterns in variation for the *MC1R* gene provide evidence that dark skin is favored in environments that experience intense UV radiation. As mentioned briefly in the film, however, human skin color is a polygenic trait.

In Part 1 of this activity, a simple mathematical model illustrates an idealized relationship between the number of genes involved in a trait and the number of phenotypes that can occur from combinations of alleles. In Part 2, students learn about the methods geneticists use to identify skin color genes and to estimate heritability.

Additional information can be found on this resource's webpage, including suggested audience, estimated time, and curriculum connections.

KEY CONCEPTS

- Scientists use mathematical models to estimate the number of genes that affect a trait. Many different genes contribute to differences in human skin color.
- Changes to a gene's DNA sequence can affect the translation of the gene into amino acids, and ultimately, the function of a protein and the expression of a trait.
- Both genetics and the environment can affect expression of a trait. Experiments suggest the degree to which differences in traits are inherited. Differences in human skin color are mostly controlled by genetics.

STUDENT LEARNING TARGETS

- Develop mathematical models to explore how the number of genes that influence a trait affects the possible number of phenotypes.
- Explain how scientists estimate the role of genetics and the environment in determining differences in skin color.

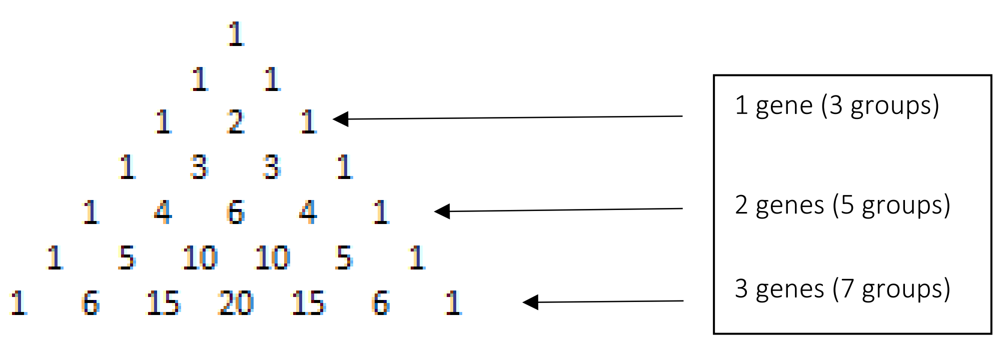
PRIOR KNOWLEDGE

- Students should have a basic understanding of Mendelian genetics, including the terms DNA, gene, and allele, and know that variations in some traits are inherited.
- It would be helpful for students to have prior knowledge of the terms *genotype* and *phenotype* and how to apply the terms to specific examples.
- Students should be comfortable generating and using a mathematical expression with two variables.

TEACHING TIPS

- Have students watch the short (19-minute) film *The Biology of Skin Color* before completing this activity. If you don't have sufficient in-class time, consider assigning it as homework. Have students write down any questions they have while they watch. Run through some of these questions as a warm-up or as a concluding discussion.
- Before beginning the lesson, consider reviewing genes and alleles with students. One way to accomplish this is to ask them in an open-ended class discussion to elicit everything they know about genes and alleles. Write down everything students say so all can see the list. At the end of the brainstorming session, highlight the following overarching concepts:
  - *Genes are inherited.* Genes are located on chromosomes. Chromosomes are inherited in pairs, one from each parent. Different versions of genes are called alleles. A single gene can have many alleles.
  - *Genes affect phenotypes.* Genes code for proteins, which are critical for thousands of functions within cells, or they affect the expression of other genes. The expression and action of proteins result in the distinguishable traits of an organism: its phenotypes.
- Make sure to emphasize the critical point that, while much of the data for skin color presented in this activity focuses on differences among people, comparison of genomic sequences from individuals around the world has revealed that all humans are closely related to one another and that individuals have much in common.
  - Skin color is unusual in comparison with most traits that vary among people. For most traits, there is more variation within populations than between populations, which mirrors the pattern for human genetic variation. However, for skin color, this trend is reversed, which makes people think there is more variation among groups of people than there is.
- Questions 2–5 ask students to answer questions about a simple mathematical model of genotype and phenotype, in which different genotypes result in identical phenotypes (for example, A^1A^0 is equivalent to A^0A^1). If students have covered the concept in mathematics, they may realize that, if they counted the number of possible combinations in each group, the pattern would be like every other row of Pascal's triangle. If you think it is appropriate, tell students that they could use this triangle to predict the number of individuals within each group if there was a cross between two parents that were heterozygous for each allele.

Pascal's Triangle



You may consider collaborating with a math teacher to reinforce the concepts of probability that can accompany learning about Pascal's triangle.

- After completing Part 1, you may want to share the following with students:
  - Studies of the genetics of skin color reveal that the assumption that all the genes that affect skin color contribute equally to pigmentation is *not* supported by evidence. Alleles at some genes have a much larger impact than others.

- Scientists attempting to estimate someone's skin pigmentation group from bones or other forensic evidence have used data from 36 SNPs, with prediction accuracies ranging from 96% for dark to black skin to 72% for light skin ([Walsh et al. 2017](#)).

ASSESSMENT GUIDANCE

Answers to the questions in the "Student Handout" will vary depending on students' experiences and knowledge. Sample responses to the questions are provided below. These sample answers may include more detail than would be provided by most students. They are meant to give you additional information that you may want to discuss with students.

PART 1: Using a Model to Understand Skin Color Genetics

1. Table 1 shows all the genotypes possible when there are one, two, or three genes contributing to skin color in our model. Complete the table by determining the number of unique phenotypes for two genes.
   - You can use colored pens or pencils to circle, or otherwise indicate, the genotypes that correspond to each unique phenotype.
   - It may help to add up the number of pigment alleles (A^1, B^1, or C^1) present in a genotype. Genotypes with the same number of pigment alleles will have the same phenotype.

   The following table shows how the genotypes can be categorized into unique phenotypes based on the number of pigment alleles.

Scenario	Genotypes with 0 pigment alleles	Genotypes with 1 pigment allele	Genotypes with 2 pigment alleles	Genotypes with 3 pigment alleles	Genotypes with 4 pigment alleles	Genotypes with 5 pigment alleles	Genotypes with 6 pigment alleles	Number of Unique Pheno-types
1: One gene (*A*)	A^0A^0	A^1A^0 A^0A^1	A^1A^1	none	none	none	none	3
2: Two genes (*A*, *B*)	$A^0A^0B^0B^0$	$A^0A^1B^0B^0$ $A^0A^0B^0B^1$ $A^1A^0B^0B^0$ $A^0A^0B^1B^0$	$A^0A^1B^0B^1$ $A^1A^1B^0B^0$ $A^0A^1B^1B^0$ $A^1A^0B^0B^1$ $A^0A^0B^1B^1$ $A^1A^0B^1B^0$	$A^1A^1B^0B^1$ $A^0A^1B^1B^1$ $A^1A^1B^1B^0$ $A^1A^0B^1B^1$	$A^1A^1B^1B^1$	none	none	5
3: Three genes (*A*, *B*, *C*)	$A^0A^0B^0B^0C^0C^0$	$A^0A^1B^0B^0C^0C^0$ $A^0A^0B^0B^1C^0C^0$ $A^0A^0B^0B^0C^0C^1$ $A^1A^0B^0B^0C^0C^0$ $A^0A^0B^1B^0C^0C^0$ $A^0A^0B^0B^0C^1C^0$	$A^0A^1B^0B^1C^0C^0$ $A^0A^1B^0B^0C^0C^1$ $A^1A^1B^0B^0C^0C^0$ $A^0A^1B^1B^0C^0C^0$ $A^0A^1B^0B^0C^1C^0$ $A^0A^0B^0B^1C^0C^1$ $A^1A^0B^0B^1C^0C^0$ $A^0A^0B^1B^1C^0C^0$ $A^0A^0B^0B^1C^1C^0$ $A^1A^0B^0B^0C^0C^1$ $A^0A^0B^1B^0C^0C^1$ $A^0A^0B^0B^0C^1C^1$ $A^1A^0B^1B^0C^0C^0$ $A^1A^0B^0B^0C^1C^0$ $A^0A^0B^1B^0C^1C^0$	$A^0A^1B^0B^1C^0C^1$ $A^1A^1B^0B^1C^0C^0$ $A^0A^1B^1B^1C^0C^0$ $A^0A^1B^0B^1C^1C^0$ $A^1A^1B^0B^0C^0C^1$ $A^0A^1B^1B^0C^0C^1$ $A^0A^1B^0B^0C^1C^1$ $A^1A^1B^1B^0C^0C^0$ $A^1A^1B^0B^0C^1C^0$ $A^0A^1B^1B^0C^1C^0$ $A^1A^0B^0B^1C^0C^1$ $A^0A^0B^1B^1C^0C^1$ $A^0A^0B^0B^1C^1C^1$ $A^1A^0B^1B^1C^0C^0$ $A^1A^0B^0B^1C^1C^0$ $A^0A^0B^1B^1C^1C^0$ $A^1A^0B^1B^0C^0C^1$ $A^1A^0B^0B^0C^1C^1$ $A^0A^0B^1B^0C^1C^1$ $A^1A^0B^1B^0C^1C^0$	$A^1A^1B^0B^1C^0C^1$ $A^0A^1B^1B^1C^0C^1$ $A^0A^1B^0B^1C^1C^1$ $A^1A^1B^1B^1C^0C^0$ $A^1A^1B^0B^1C^1C^0$ $A^0A^1B^1B^1C^1C^0$ $A^1A^1B^1B^0C^0C^1$ $A^1A^1B^0B^0C^1C^1$ $A^0A^1B^1B^0C^1C^1$ $A^1A^1B^1B^0C^1C^0$ $A^1A^0B^1B^1C^0C^1$ $A^1A^0B^0B^1C^1C^1$ $A^0A^0B^1B^1C^1C^1$ $A^1A^0B^1B^1C^1C^0$ $A^1A^0B^1B^0C^1C^1$	$A^1A^1B^1B^1C^0C^1$ $A^1A^1B^0B^1C^1C^1$ $A^0A^1B^1B^1C^1C^1$ $A^1A^1B^1B^1C^1C^0$ $A^1A^1B^1B^0C^1C^1$ $A^1A^0B^1B^1C^1C^1$	$A^1A^1B^1B^1C^1C^1$	7

2. Describe the basic relationship between the number of unique skin color phenotypes generated in the model and the number of genes responsible.
The number of skin color groups goes up as the number of genes involved in skin color increases.

3. Look at the number of unique phenotypes for one gene and two genes. The number of unique phenotypes for three genes is seven. Develop a mathematical expression to summarize the number of phenotypes (*P*) that can form from *N* number of genes.
P = 2N + 1

4. Based on the mathematical expression, predict how many distinct phenotypes would result from six genes, each with two alleles, according to the model.
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5. Studies into the genetics of human skin color have concluded that at least 169 genes affect human pigmentation (Bajpai et al. 2023). Based on the mathematical expression you developed, and assuming that each of the 169 genes has two alleles, how many unique phenotypes would be generated? Show your work.
P = 2(169) + 1 = 339 distinct phenotypes

PART 2: Searching for Skin Color Genes

6. To search for genes involved in determining skin color, scientists look for SNPs associated with different skin color phenotypes. SNPs are variations at a single nucleotide within the genome. How can a change in a single nucleotide be responsible for differences in skin color or the function of a gene in general?
DNA is transcribed into mRNA that is "read," three nucleotides (a codon) at a time, by tRNA, which translates the codons to amino acids. Amino acids are strung together into a polypeptide, which is eventually processed into a functional protein. If a change to a single DNA nucleotide results in an mRNA codon corresponding to a different amino acid, then the overall structure and function of the protein might be changed. Students may also mention that a change in a regulatory sequence could alter the amount of protein being produced.

7. Why are identical twins a good source of data for studies into the heritability of a trait?
Since they have identical genes, any differences in phenotype will be due to environmental differences.

8. Support this claim using evidence from the information provided: Differences in human skin color are caused primarily by differences in genetics.
The value for heritability for skin color is reported to be 0.83. A heritability of 1.0 means all differences are because of genetics, and a value of 0.0 means all differences are because of the environment. 0.83 is closer to 1.0 than to 0.0, so the claim ("Differences in human skin color are caused primarily by differences in genetics") is supported.

9. We know that multiple genes (some with many different alleles) contribute to skin color, but genes alone do not account for the diversity of pigmentation we see among humans; environmental factors play a role. Propose an explanation for how one of these factors could alter the expression of skin color genes.
An environmental factor such as diet, environment during development, or any one of many other factors might inhibit or promote the activity of the proteins associated with pigment expression. Students may also mention how sun exposure can affect tanning, which is a temporary change in skin color. Sun exposure increases the amount of ultraviolet light striking skin cells, which causes DNA damage, which in turn results in changes in the expression of many genes.

REFERENCES

Bajpai, Vivek K., Tomek Swigut, Jaaved Mohammed, Sahin Naqvi, Martin Arreola, Josh Tycko, Tayne C. Kim, Jonathan K. Pritchard, Michael C. Bassik, and Joanna Wysocka. 2023. “A genome-wide genetic screen uncovers determinants of human pigmentation.” *Science* 381, 6658: eade6289. https://doi.org/10.1126/science.ade6289.

Clark, P., A. E. Stark, R. J. Walsh, R. Jardine, and N. G. Martin. 1981. “A twin study of skin reflectance.” *Annals of Human Biology* 8, 6: 529–541. https://doi.org/10.1080/03014468100005371.

Klug, W. S., M. R. Cummings, and C.A. Spencer. *Concepts of Genetics*. New York: Pearson, 2006.

Sturm, R. A. 2009. “Molecular genetics of human pigmentation diversity.” *Human Molecular Genetics* 18, R1: R9–R17. https://doi.org/10.1093/hmg/ddp003.

The 1000 Genomes Project Consortium. 2015. “A global reference for human genetic variation.” *Nature* 526, 7571: 68–74. https://doi.org/10.1038/nature15393.

Walsh, S., L. Chaitanya, K. Breslin, C. Muralidharan, A. Bronikowska, E. Pospiech, J. Koller, et al. 2017. “Global skin colour prediction from DNA.” *Human Genetics* 136, 7: 847–863. https://doi.org/10.1007/s00439-017-1808-5.

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