Content Connections
Genetics

Introduction

The STeLLA program intentionally places student thinking at the foreground of student learning. The purpose of this document is to support and further your own understanding about your students' possible ideas about genetics and ways these ideas may influence their ability to develop a conceptual understanding about how DNA can influence the traits that an organism shows. You can use it to develop your knowledge and skill in anticipating and responding to student ideas and confidently guiding student learning.

The content is written with you, the teacher, in mind. It presents subject matter knowledge that is tied to the lessons you will be teaching in the spring semester of the STeLLA program. It provides a rationale for sequencing and structuring student learning experiences to address shortcomings in typical instruction that have been shown to lead students to miss some important conceptual links between their understanding of genetics and how DNA influences the traits of an organism. Common student ideas are described throughout this document. Although these common student ideas are scientifically inaccurate, these ideas, when surfaced and made explicit to students, can be used as building blocks to a more meaningful and scientifically accurate understanding of the science content.

Next Generation Science Standards

To ensure that a genetics unit builds toward a conceptual understanding of the ideas, it is important to consider the three-dimensional learning experiences that will help students best develop their understanding. To that end, the *Next Generation Science Standards* are one option that can be used as a guide for developing lessons. The next few pages show the applicable standards from the *NGSS* for a genetics unit.

In developing the Content Connections sessions, we did not consider all performance expectations on these pages but focused on the following:

- HS-LS1-1: Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
- HS-LS3-1: Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.
- HS-LS3-2: Make and defend a claim based on evidence that inheritable genetic variations may result from (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, ~~and/or (3) mutations caused by environmental factors~~. (Note that we expect a focus on environmental factors to be in a later unit of instruction.)

We also see great potential for incorporating *HS-LS3-3: Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population* into a unit such as this one; however, we did not explicitly do so.

As you teach the Natural Selection lessons, look for opportunities to make explicit to students the science ideas embodied in the disciplinary core ideas, the crosscutting concepts, and the science and engineering practices. Although "asking questions and defining problems" and "constructing explanations and designing solutions" are practices that are the focus of the performance expectations, there are many opportunities to make others explicit, such as "developing and using models". In considering crosscutting

concepts, both “cause and effect” and “structure and function” are prominent concepts that should be made explicit to students.

Common Student Idea #1

Proteins are responsible for only some of the characteristics of organisms, while DNA or genes are responsible for others.

This common idea represents students’ incomplete ideas about how DNA is expressed in cells. All cells in an organism have the same genetic information in the form of DNA. During the processes of transcription and translation, some genes are transcribed into RNA and translated into proteins. These proteins are responsible for the physical traits, the physiology, and the behavior of organisms. This is true in humans, in other animals, and in plants.

Proteins are often considered the work horses of the body. They have many general functions, including enzymatic reactions, structural functions, transport of materials, immune support, pigmentation, and many others. Because of the variety of proteins, the characteristics that an organism has are a direct result of the DNA and genes that are expressed in the organism’s body.

This idea also shows the incomplete ideas students have about the structure of genetic material. Genes are made up of DNA, rather than being a separate entity. Genes are segments of DNA that code for specific proteins in cells. They are the basic units of heredity. This is an opportunity to highlight the crosscutting concept of “structure and function” because understanding that relationship can help students develop a deeper conceptual understanding of how DNA relates to genes and proteins.

Common Student Idea #2

Organisms eat proteins; they do not make proteins.

Some students think of the protein that humans eat in meats and other foods and do not associate those food items as having been living organisms. They do not connect the idea that a steak was once a living cow or that beans were once part of a living plant. As a result, they do not think of proteins as something that bodies make. In fact, proteins are responsible for the characteristics of bodies, behavior of organisms, and the physiology and functioning in organisms.

Proteins carry out instructions, tasks like building a new copy of a cell or repairing damage. Most proteins have very specific functions, so if a cell needs to do something new, it must make a new protein to do this job. Similarly, if a cell needs to do something faster or slower than before, it makes more or less of the responsible protein. Genes have the information about which proteins to make and in what amounts. Interestingly, only 1/60th of our entire genome (all the DNA in a cell) codes for making proteins. The rest of the DNA helps direct when and where in the body each protein will be used. This means that the collection of all the DNA in a cell, the genome, gives biological instructions for an organism’s distinct traits, passed from parent to offspring.

Common Student Idea #3

Offspring inherit characteristics from just one parent, either the mother, the same-sex parent, or some solely from the mother and others solely from the father.

Genes are located on chromosomes. Organisms that reproduce sexually have two sets of chromosomes—one set inherited from each parent. For example, humans have two sets of 23 chromosomes, for a total of 46 chromosomes. Dogs have 78 chromosomes, two sets of 39 chromosomes. Each cell in all organisms of a given species has the same number of chromosomes (two copies of each chromosome), except for sex cells (sperm and eggs) which have half the number of chromosomes compared to other cells (one copy of each chromosome).

In thinking about traits inherited from parents, sometimes a particular trait seems to be from one parent and not the other. To explain this, it is important to look at the different forms of the gene that determine the trait. The variations are called *alleles*. The two alleles that an individual has for a gene—one on each chromosome—may be the same or different. The trait that an individual shows depends on which alleles that individual received from its parents.

This is one opportunity to use the science and engineering practice of "developing and using models" because that can help students have a visual representation of how an embryo receives genetic information from its parents. In using models, be sure to support students in understanding what different parts of the model represent as well as the strengths and limitations of the model.

Common Student Idea #4

An individual's characteristics are the result of "blending" from each parent.

and

Common Student Idea #5

Traits are the result of single genes.

Each parent contributes an allele for a gene. The trait that shows up when there are two different alleles is dominant, and the other trait, that appears only if there are two of that same allele, is recessive. This is Mendel's principle of dominance, which says that an organism with at least one dominant allele will display that trait. It is common practice to represent a dominant allele by a capital letter and a recessive allele by a lowercase letter.

We now know that this principle of dominance does not extend to many genes and a dominant and recessive relationship between alleles is more the exception than the rule. In general, there are almost no characteristics that are coded for by only one gene. Most traits are complex and involve multiple genes. For example, we know now that there are as many as 100 different genes involved in skin color. Because of the number of genes—and therefore proteins—that play a role in the color of skin, it is not possible to use a simple dominant and recessive relationship to predict the trait.

Furthermore, there are environmental factors that affect many traits. Although there are a few traits that are determined solely by genes, such as blood type, most traits are affected by the environment. In humans, for example, we may inherit a susceptibility to a disease rather than the disease itself. Depending on the lifestyle choices that we make and the type of environment we live in, we may develop the disease or not.

Common Student Idea #6

Dominant traits are more common in a population.

Students sometimes interpret the term *dominant* as being more prevalent in a population. However, *dominant* refers only to an allele's expression over another allele. There are a number of dominant traits that are quite rare in a human population. For example, polydactyly, or having more than the typical number of fingers or toes, is the result of a dominant trait. However, polydactyly occurs in only 0.31–6.18 births in 1,000, depending on ethnic background. This means it is very rare for a person to have the gene mutation that causes polydactyly, even though it is dominant. This may be an opportunity for students to calculate the prevalence of certain traits in the population compared to others that are less rare. This can lead to deeper understanding of what *dominance* means compared to *prevalence* while supporting students in using science practices.

Common Student Idea #7

Organisms have genes for particular traits, such as "disease genes."

This common student idea often persists because of imprecise language usage. We often make comments such as, "He has the cystic fibrosis gene" or "She had the gene for blue eyes." In fact, people have the same genes. They also have two alleles for each gene. The difference comes in the particular alleles that a person inherits from their parents. A person might inherit alleles that lead to cystic fibrosis or blue eyes, which leads to the particular expression of the trait.

Common Student Idea #8

If there is a one in four chance of having a particular trait and a couple's first child shows the trait, the next three have a reduced chance of showing that trait.

Having a one in four chance does not mean that one out of four children will show a particular trait. It means that each child has a 25 percent chance of showing that trait. The chance each child has is independent of the others. Similarly, every child has a 50 percent chance of being a boy and a 50 percent chance of being a girl. Even if a couple has seven boys in the family, the next child still has a 50 percent chance of being a boy.

If you choose to have students develop abilities related to the science and engineering practice "using mathematics and computational thinking," this is an opportunity to help them understand how to calculate probabilities. For example, students could consider a family who has three boys and is having a fourth child. That child has a 50 percent chance or ½ chance of being a boy. However, students can also develop an understanding of the chances of having four boys. To do this, they would multiply:

$$½ \times ½ \times ½ \times ½ = 1/16$$

For each pregnancy, there is a ½ chance of having a boy. Multiple together ½ for each of four pregnancies and you arrive at 1/16. This means that there is a 1 in 16 chance, or 6.25 percent chance, of having four boys.

Common Student Idea #9

All mutations are harmful.

A mutation is a change in the DNA of an organism. Many mutations are a change to a single nucleotide in the DNA that does not cause any harm to the individual. Some of these mutations occur in places along the DNA that do not code for proteins and as a result do not have any effect on the individual. In other cases, the mutation might occur within a gene but in the third position of a codon. This third spot in each codon is called the *wobble base* because in many cases there can be several different nucleotides at the position that code for the same amino acids. In this way, a change in a wobble base might not change the amino acid and therefore no differences would be expressed in the protein.

In other cases, a mutation can be beneficial. For example, a mutation might encode a change in a gene that leads to resistance to a disease. In this case, the particular allele could become "selected for" in a population over time. Individuals in the population who carry the mutation will survive and pass it on to their offspring. It is often the environment in which an organism lives that determines if a mutation is beneficial or harmful. As a result, mutations can be a way of helping organisms adapt to their environments. A discussion of mutations is an excellent time to make the crosscutting concept of "cause and effect" explicit to students. In addition, this is an opportunity to help students determine evidence that would support an explanation about the role of mutation in variation as well as considering whether mutations are positive, negative, or neutral.

It is also important to realize that mutations often represent preexisting variations in a population. Some of these are favored by changing environmental conditions. Over many generations, the favored variations become more prevalent in the population. However, if the environment changes, a particular mutation may no longer be favored and may disappear over time.

Precise Use of Genetic Terms

The use of precise language is important when teaching genetics to help students avoid some of the common student ideas addressed in this document. Students are often confused among terms, such as *gene*, *trait*, *allele*, *chromosome*, *DNA*, *amino acid*, and *protein*. By carefully using the words in reference to specific components and being precise about language, it will support students in understanding the different parts of genetic processes.

Furthermore, it can often be tempting to use the word *normal* in relation to a wild-type, or most common, trait. Avoid using this word as it implies that other traits are "abnormal." In general, it is useful to refer to particular alleles by carefully describing the trait, such as the eye color allele. In referring to diseases, one is affected or unaffected by the disease.