Beyond Seven

Let’s find the SNPs.

Beyond Seven allows students to extend their thinking beyond Mendelian genetics by examining breakthroughs in genetics and genomics research; using the inquiry approach students will understand Isaak Newtons’ familiar expression from 1676 regarding scientific discoveries. “If I have seen further, it is by standing on the shoulders of giants." Through guided inquiry, students will build on their understanding of the genetic concepts emphasizing how biological information is passed from one generation to another.

UF Center for Precollegiate Education and Training
UNIVERSITY of FLORIDA

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Lesson Four Adapted from pbs.org

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Matias Kirst joined the School of Forest Resources and Conservation in 2005 as an Assistant Professor in Quantitative Genetics. In addition to his affiliation to the SFRC, he is also a member of the Plant Molecular and Cellular Biology Program (PMCB) and the University of Florida Genetics Institute (UFGI). His group in Quantitative Genomics Research is part of the Forest Genomics Laboratory. Research is focused in three areas: (1) Fundamental Genomic Research in the genetic regulation of gene expression and gene expression networks; (2) Applied Genomic Research for the discovery of genes, metabolic and regulatory networks that control variation in wood quality, growth and other important traits for the forestry and agronomic industry; and (3) Technology and genomic tool development

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AUTHOR'S NOTE

A visit to the Poplar Forest helped me moved beyond Mendel's seven traits. The research team noted way more than seven traits in poplar plants. Dr. Matias Kirst, who is the professor of genetics and genomics at UF, lectured on the complexity of non-Mendelian traits, and Annette Fahrenkrog, who is a Ph.D student, shared her research on associative genetics. I had heard of Single-nucleotide polymorphisms, but not to the extent covered with the researchers from the School of Forest Resource and Conservation. After learning so much about genetics and genomics study on the Poplar plants, I decided to incorporate my learning into four lessons I hope would benefit teachers and students in moving beyond Mendelian genetics. They extended my scientific thinking, and I would like to do the same by using these four lessons in the Beyond Seven unit exploring quantitative traits.

INTRODUCTION

Gregor Mendel's fundamental theory of heredity involves the passing of discrete units, or what we know now as genes. These genes are passed on from parents to offspring. He focused on pea plants, and allelic makeup (genotype) and physical expression (phenotype). He discovered those pea plants expressed seven phenotypes. His observations could be summarized in two principles: segregation and independent assortment. However, what is influencing those phenotypic expressions? What genes are involved? Does the environment contribute to the phenotypic expression? Let's move beyond the seven traits to understand that the passing of discrete units is really not so discrete. Rather, they are continuously quantitative. Using Quantitative Trait Loci analysis and Associative Genetics, scientists are gaining a greater understanding of how and what genes are controlling specific traits, and the location of SNPs and significance to phenotypic variance.

After the revelation of the Human Genome Project, many researchers started to research genomic studies on various other organisms. This endeavor was the inception in a new era of genomics research. Again supporting Isaac Newton's expression, using the information derived from the project, scientists now have more avenues to analyze the genome and discover more about how our DNA affects who we are. However, Genotyping has been explored in depth while phenotyping is yet investigated.

We know that we are different, but what really make us so different from each other. What exactly is present in our DNA. Looking at DNA sequence from one person to the next, scientists have found that we are quite similar with minimal variations, which make each individual unique from each other. Single-nucleotide polymorphism (SNP) is the most common type of variation in the human genome. It is pronounced "snip". It is a change within single base-pair in a segment of DNA, where a C (cytosine) is replaced with a G (guanine).

Beyond seven is develop with the intention of moving students beyond the seven traits they have learned about genetics in DNA. They will explore their learning in four lessons sequentially. Using Arabidopsis plants, students explore the nature of science through observations of traits to applying cutting-edge technology to extract, sequence their DNA, and analyze their sequence for SNPs. Furthermore, they will acquire critical thinking skills through reading various passages on current biotechnologies and their impact on human health and the environment.

My hope is that students will be thoroughly engaged in learning about the current information about phenotyping and biotechnologies from these four lessons. They will be enticed to know more, which in turns will lead to them applying Isaac Newton's expression and make additional discoveries. They will know the different career paths in the scientific research realms and make more informed decisions about their lifelong careers.

TIPS ABOUT THIS CURRICULUM

Lesson Plan Format: All lessons in this curriculum unit are formatted in the same manner. In each lesson you will find the following components:

KEY QUESTION(S): Identifies key questions the lesson will explore.
OVERALL TIME ESTIMATE: Indicates total amount of time needed for the lesson, including advanced preparation.
LEARNING STYLES: Visual, auditory, and/or kinesthetic.
VOCABULARY: Lists key vocabulary terms used and defined in the lesson. Also collected in master vocabulary list.
LESSON SUMMARY: Provides a 1-2 sentence summary of what the lesson will cover and how this content will be covered. Also collected in one list.
LESSON GOALS: the overall focus of the lesson based on the standard.
STUDENT LEARNING OBJECTIVES: Focuses on what students will know, feel, or be able to do at the conclusion of the lesson.
STANDARDS: Specific state benchmarks addressed in the lesson. Also collected in one list.
MATERIALS: Items needed to complete the lesson. Number required for different types of grouping formats (Per class, Per group of 3-4 students, Per pair, Per student) is also indicated.
BACKGROUND INFORMATION: Provides accurate, up-to-date information from reliable sources about the lesson topic.
ADVANCE PREPARATION: This section explains what needs to be done to get ready for the lesson.
PROCEDURE WITH TIME ESTIMATES: The procedure details the steps of implementation with suggested time estimates. The times will likely vary depending on the class.
ASSESSMENT SUGGESTIONS: Formative assessment suggestions have been given. Additionally, there a summative assessment that can be given. Teachers should feel free to create additional formative and summative assessment pieces.
EXTENSIONS: (ACTIVITIES/LITERATURE) There are many activities and reading sources available to augment and enhance the curriculum. They have been included. If you find additional ones that should be added, please let us know.
RESOURCES/REFERENCES: This curriculum is based heavily on primary sources. As resources and references have been used in a lesson, their complete citation is included as well as a web link if available. All references and resources are also collected in one list.
STUDENT PAGES: Worksheets and handouts to be copied and distributed to the students.
TEACHER MASTERS: Versions of the student pages with answers or the activity materials for preparation.

Collaborative Learning: The lessons in this curriculum have been developed to include many collaborative learning opportunities. Rather than presenting information in lecture format and teacher driven, the activities involve the students in a more engaged manner. For classrooms not accustomed to using collaborative learning strategies, have patience. It can be difficult to communicate instructions, particularly for students who are visual learners. For these students, use of visual clues such as flowcharts and graphics can help them understand how they are to move to different groups.

Groups: Most of the lessons are carried out in groups. While it isn't necessary for students to remain in the same groups the entire unit, if they work well together, it may foster students to think deeper as they are comfortable with their teammates and willing to ask questions of each other.

Inquiry-based: The lessons in the curriculum invite students to be engaged and ask questions. They work through background information in a guided fashion, but are challenged to think beyond what they have read or done. The teacher serves as the facilitator in these activities, not the deliverer of information.

Technology: Lessons have been written to be mindful of varying availability of technology in schools and homes. Some of the lessons would be very well suited to online environments and if your students are able, you might wish to engage in some of the technology modifications.

Content: Often we teach in a manner that is very content heavy. With high-stakes testing the norm, students are pushed to memorize and regurgitate numerous isolated facts. There is so much content that must be covered in a biology class, for example, that often it is difficult to synthesize those discrete facts into a compelling context or a story. This unit provides that opportunity: to take concepts learned such as Mendel's two principles in show them the extent of their application and how researchers contribute to the scientific growing field from prior research.

Implementation notes: This curriculum should be modified and adapted to suit the needs of the teacher and students. To help make implementation easier in this first draft, notes have been included in lessons as needed.

Extensions: Teachers can decide to have students develop a research questions to guide their students towards a research project on the Arabidopsis plants. Students would need to include why this species is widely use in genomic research. They could explore associative genetics by performing PCR on their SNPs to predict the impact of the phenotype on the plants.

Science Subject: Biology

Grade and ability level: 9-12 students in advanced biology

Science concepts: Genetics and DNA

LESSON SUMMARIES

LESSON ONE: I Think Therefore I Am.
In this lesson, students will be scientific investigators exploring phenotypic variation. They should already have basic knowledge of genetics in DNA. They will collaborate in teams of four to five members to observe and record different traits from several Arabidopsis plants from the lab. Using what they learn, they will generate their research questions to explore as an independent study. This lesson will allow students to apply scientific inquiry and build on their conceptual genetics by discussing this question: What contributes more to an organism's traits, genes or the environment?

LESSON TWO: On Shoulders of Giants: Link What?
As a whole class review Gregor Mendel's two principles on segregation and independent assortment. If necessary also discuss meiosis, especially homologous chromosomes and crossing over. In this lesson, students will work collaboratively in groups of four to derive an understanding of gene linkage. Teachers also need to emphasize Non-Mendelian Genetics and how other scientist add to the pre-existing scientific knowledge (theories and laws). As teams, students need to develop an approach to explore whether phenotypic traits are linked or not and share it as a whole class.

LESSON THREE: Wild Thing: What's Your Digits?
Already previewed to discrete unit, students will perform Punnett squares using phenotypic traits from lesson one independently. Also, allow them to practice dihybrid crosses with incomplete dominant alleles with a partner. In this lesson, students will observe trichomes numbers. This factor will help them understand the environmental contribution to genetic phenotypes. They will collect data on Arabidopsis trichomes if they display continuous traits or not. They will work collaboratively in groups of 4 to observe and gather data from four plants (wild type and mutant). Using the collected data compare discrete units and continuous units.

LESSON FOUR: Let's SNIP it Real Good!
Technological advances have allowed scientist to make substantial progress in understanding different organisms' genomes. They have also studied genotyping in detail; however, there is still move discoveries to be made. In this lesson, students will extract and sequence DNA from the Arabidopsis plants. Using already established genome of the plant to determine the location of any SNPs. They will analyze their results and determine the significance of the SNPs to the plants' phenotype. They will apply the same knowledge to predict if such SNP existed in humans, what would be the phenotypic impact.

LESSON SEQUENCING GUIDE

These lessons would benefit students who already have prior knowledge of simple genetics, Mendel's laws, Meiosis, and Protein synthesis. Below is a pacing guide that can be used when planning to use this curriculum.

90 minute periods

	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**
Week	Lesson 1 (90 minutes)	Lesson 2 (90 minutes)	Lesson 4 (90 minutes)	Lesson 4 (90 minutes)	Review (30 minutes) Assess (60 minutes)

VOCABULARY

Traits: character is a feature of an organism

Gene: The physical and functional unit of heredity. It is a segment of DNA that is responsible for the physical and inheritable phenotype of an organism.

Genome: A genome is an organism's complete set of DNA, including all of its genes. Each genome contains all of the information needed to build and maintain that organism. In humans, a copy of the entire genome—more than 3 billion DNA base pairs—is contained in all cells that have a nucleus.

Phenotype: The physical appearance or particular traits of an organism as a result of the interaction of its genotype and the environment, for example skin color, height etc. (*genotype + environment + random variation → phenotype*).

Genotype: The entire set of genes in an organism or a set of alleles that determines the expression of a particular characteristics or traits.

Arabidopsis plant: is a small flowering plant that is widely used as a model organism in plant biology

Genetic Variation: The genes of organisms within a population change

Model Organism: A species that has been widely studied, usually because it is easy to maintain and breed in a laboratory setting and has particular experimental advantages.

Chromosomes: Carry all of the information used to help a cell grow, thrive, and reproduce. They are made up of DNA. Segments of DNA in specific patterns are called genes.

Meiosis: is the process by which one diploid eukaryotic cell divides to generate four haploid cells often called gametes

Crossing Over: process in genetics by which the two chromosomes of a homologous pair exchange equal segments with each other.

Homologous Chomosomes: a chromosome with the same gene sequence as another _(The maternal and paternal **chromosomes** in a **homologous** pair have the same genes at the same loci, but possibly different alleles. A couple of **homologous chromosomes**, or **homologs**, are a set of one maternal and one paternal **chromosomes** that pair up with each other inside a cell during meiosis).

Locus (plural **loci**): Is the specific location or position of a gene's DNA sequence, on a chromosome. Each chromosome carries many genes; humans' estimated 'haploid' protein coding genes are 20,000-25,000, on the 23 different chromosomes.

Mendel's Law of Segregation: States that allele pairs separate or **segregate** during gamete formation, and randomly unite at fertilization

Mendel's Law of Independent Assortment: Formation of random combinations of chromosomes in meiosis and of genes on different pairs of homologous chromosomes by the passage according to the laws of probability of one of each diploid pair of homologous chromosomes into each gamete independently of each other pair.

Genetic Linkage: Is the tendency of alleles that are close together on a chromosome to be inherited together during the meiosis phase of sexual reproduction.

Genetic Markers: Are used to trace or identify specific region of a *gene* (especially one that is associated with an inherited disease) on a chromosome. They are also used to determine a linkage group or a recombination event.

Linkage Disequilibrium: When the frequency of association of their different alleles is higher or lower than what would be expected if the loci were independent and associated randomly.

Ecotype: A group of organisms within a species that is adapted to particular environmental conditions and therefore exhibits behavioral, structural, or physiological differences from other members of the species.

Recombinant inbred lines (RILs): are a collection of strains that can be used to map quantitative trait loci. Parent strains are crossed to create recombinants that are then inbred to isogenicity, resulting in a permanent resource for trait mapping and analysis.

Discrete (discontinuous) traits: phenotype is controlled by one or only a few genes

Continuous (Quantitative) traits: phenotype that depends on the cumulative actions of many genes and the environment

Trichomes: are plant appendages found on the leaves. They look like little hairs.

Frequency Distribution: A statistical description of raw data in terms of the number or frequency of items characterized by each of a series or range of values of a continuous variable.

SNP: **single-nucleotide polymorphism**, or **SNP** (pronounced "snip"). This is a single base-pair change in a segment of DNA—replacement of a C (cytosine) with a G (guanine).

Monozygotic: Twins that arise from a single ovum (egg).

Epigenetics: is the study of heritable changes in gene expression or above genetics. It refers to external modifications to DNA that turn genes "on" or "off." These modifications do not change the DNA sequence, but instead, they affect how cells "read" genes.

NEXT GENERATION SUNSHINE STATE STANDARDS – SCIENCE

Benchmark	**Lesson**			
	1	**2**	**3**	**4**
SC.912.L.16.1 Use Mendel's laws of segregation and independent assortment to analyze patterns of inheritance.		**X**	**X**	
SC.912.L.16.2 Discuss observed inheritance patterns caused by various modes of inheritance, including dominant, recessive, codominant, sex-linked, polygenic, and multiple alleles.	**X**	**X**	**X**	
SC.912.L.15.15 Describe how mutation and genetic recombination increase genetic variation.	**X**	**X**		
SC.912.L.16.16 Describe the process of meiosis, including independent assortment and crossing over. Explain how reduction division results in the formation of haploid gametes or spores.		**X**		
SC.912.L.16.10 Evaluate the impact of biotechnology on the individual, society and the environment, including medical and ethical issues.				**X**
SC.912.L.16.4 Explain how mutations in the DNA sequence may or may not result in phenotypic change. Explain how mutations in gametes may result in phenotypic changes in offspring.				**X**
SC.912.N.1.6 Describe how scientific inferences are drawn from scientific observations and provide examples from the content being studied.	**X**			**X**
SC.912.N.2.4 Explain that scientific knowledge is both durable and robust		**X**		

and open to change. Scientific knowledge can change because it is often examined and re-examined by new investigations and scientific argumentation. Because of these frequent examinations, scientific knowledge becomes stronger, leading to its durability.				
SC.912.N.3.1 Explain that a scientific theory is the culmination of many scientific investigations drawing together all the current evidence concerning a substantial range of phenomena; thus, a scientific theory represents the most powerful explanation scientists have to offer.		**X**		
SC.912.N.1.1 Define a problem based on a specific body of knowledge, for example: biology, chemistry, physics, and earth/space science, and do the following: 1. pose questions about the natural world, 2. conduct systematic observations, 3. examine books and other sources of information to see what is already known, 4. review what is known in light of empirical evidence, 5. plan investigations, 6. use tools to gather, analyze, and interpret data, 7. pose answers, explanations, or descriptions of events, 8. generate explanations that explicate or describe natural phenomena (inferences), 9. use appropriate evidence and reasoning to justify these explanations to others, 10. communicate results of scientific investigations, and 11. evaluate the merits of the explanations produced by others.	**X**	**X**	**X**	

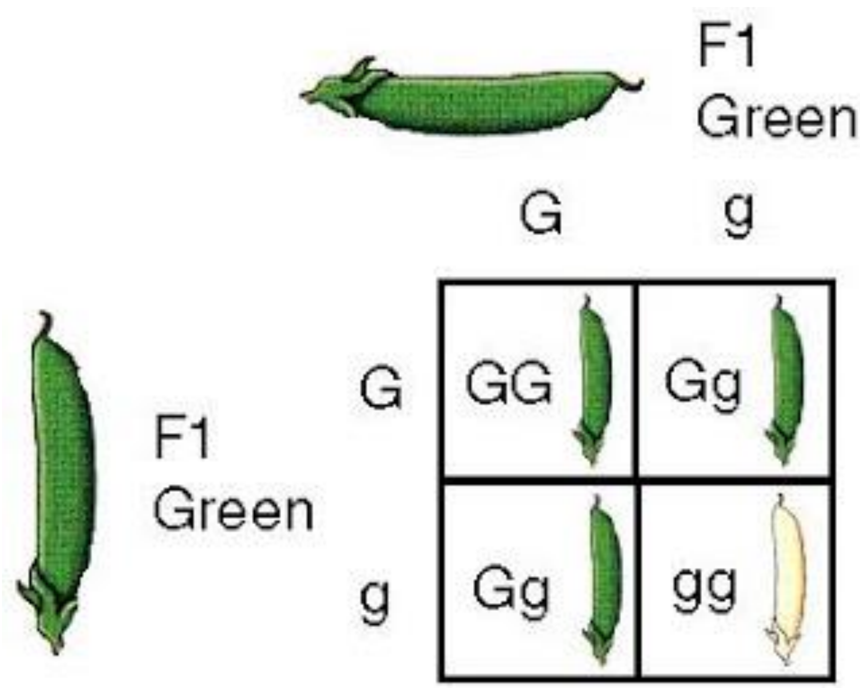
BACKGROUND INFORMATION

General background information is given here. More detail is provided in the individual lessons as needed as well in the student information in each lesson.

In 2011, scientists revealed the successful completion of the Human Genome Project. The project allow researchers to establish the order of the three billion DNA base pairs that compose the tens of thousands of genes in the human genome. However, the project was the inception in a new era of genomics research. Again supporting Isaac Newton's expression, "If I have seen further, it is by standing on the shoulders of giants." Using the information derived from the project, scientists now have more avenues to analyze the genome and discover more about how our DNA affects who we are.

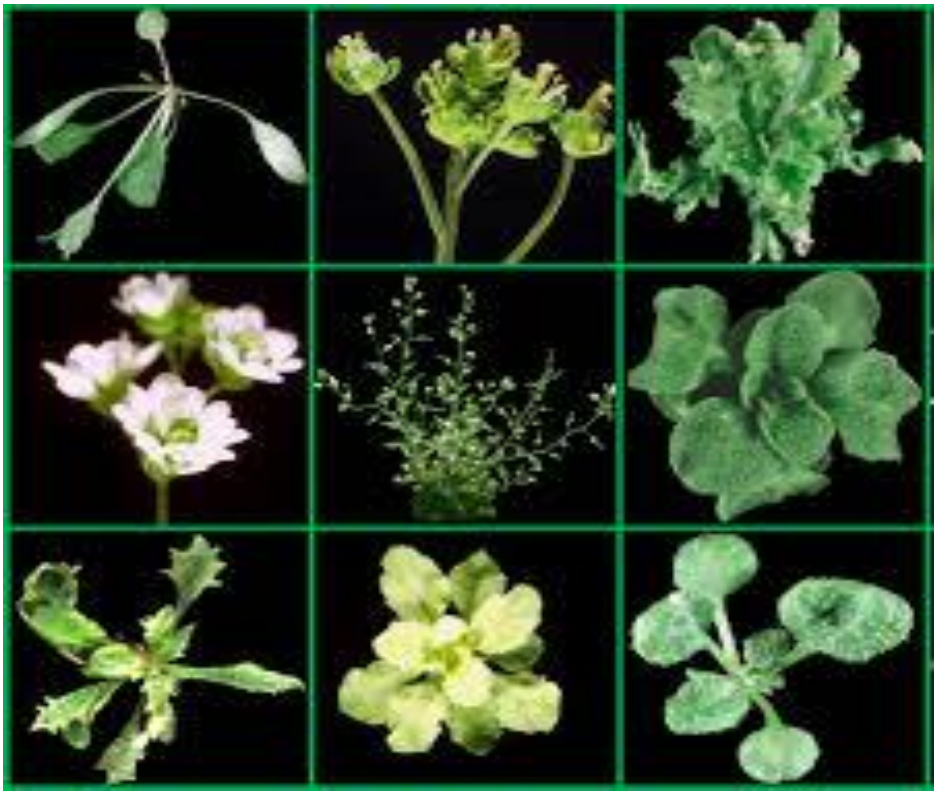
The "Beyond Seven" four lessons will focus on more than simple genetics. Students will need to have a grasp of simple genetics before moving on with the four lessons in this unit. To summarize, customarily, students learn about genetics through gamete formation during the meiotic process. These gametes have ***discrete traits*** and the students can use Punnet Square to show that. They can track the effect of a single gene expressing the discrete traits.

• **Single trait-** a trait controlled by a single gene that has two alleles.



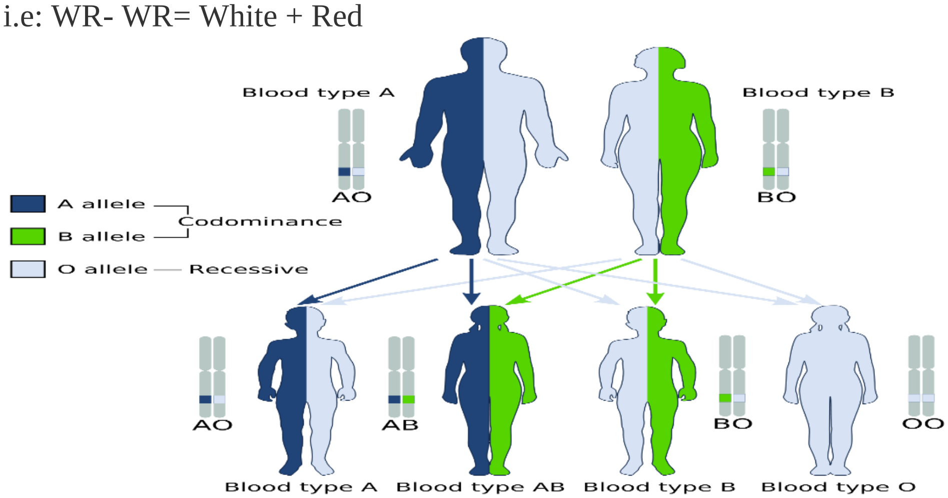
a.

However, most traits are the results of numerous genes interacting coined ***continuous*** *or* ***quantitative traits***. These genes work together and Punnett Squares can help students predict the probability of discrete traits in offspring of homozygous parents. Students can use the traits from the Arabidopsis plants from this unit to test their own predictions.

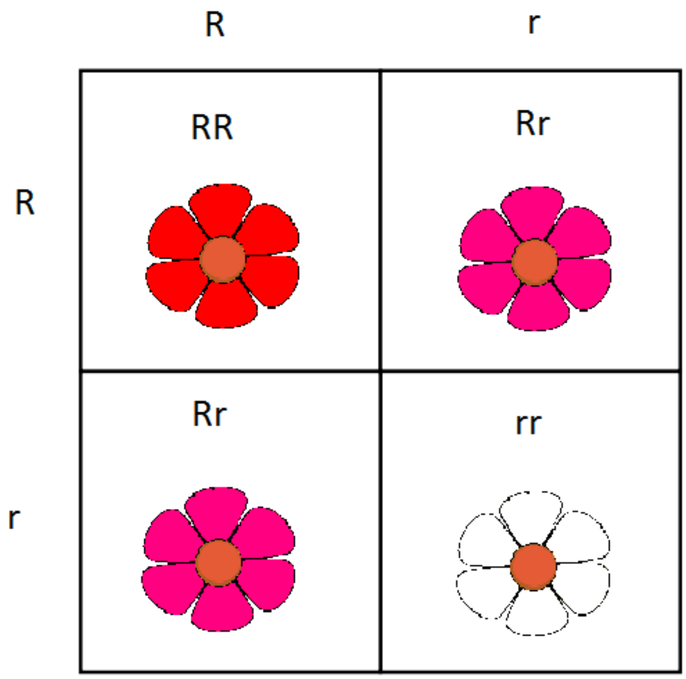
b. 

With the understanding of inheritance through discrete traits, teachers need to now help their learners grasp that quantitative traits are inherited in the same fashion. However, these genes work together to generate a particular trait. Below are examples of **Non-Mendelian** genetics

- **Codominant**- Describes two or more alleles that are equally dominant.
  i.e: WR- WR= White + Red

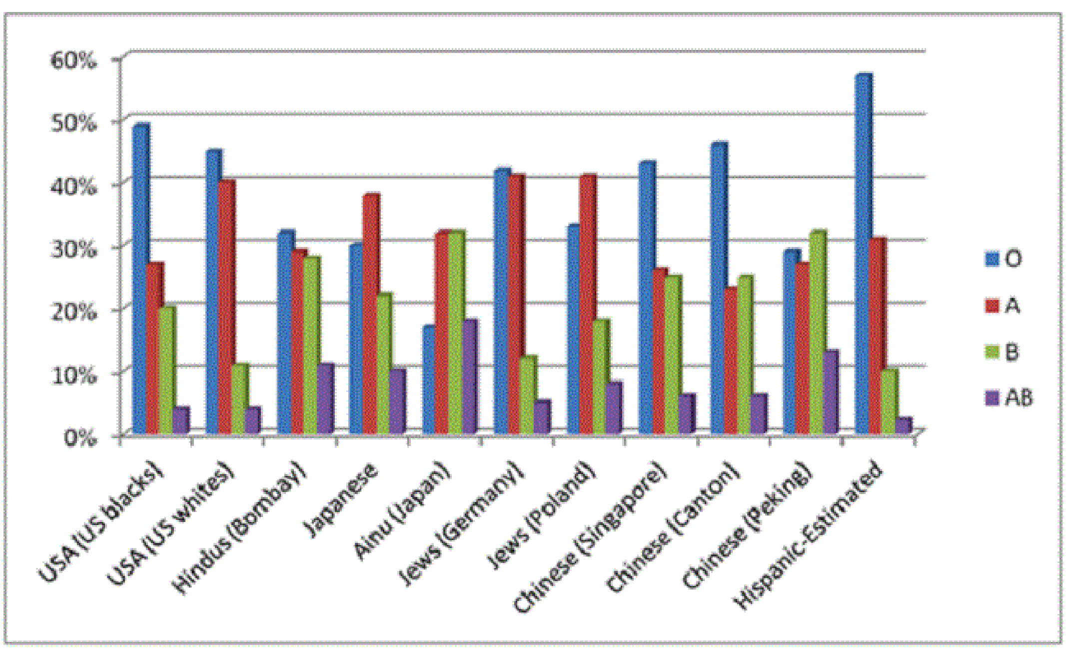
c. 

- **Incomplete Dominance-** The blending of the alleles that gives rise to the phenotype using a combination of the both traits.



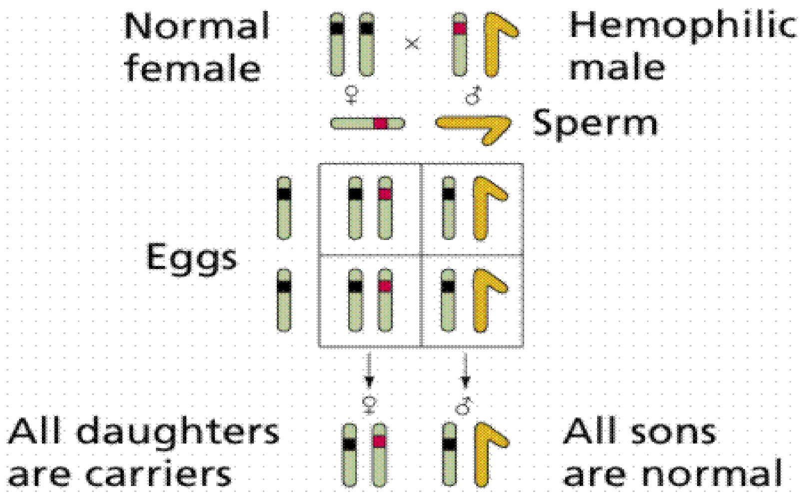
d.

• **Blood Type**- Contains three different alleles, two copies of which exist in all human body cells.



e.

• **Sex Linked Gene**s- concerning characteristics that are determined by genes carried on the sex chromosomes. (X & Y) f.



Besides the examples mentioned above, many more phenotypes do not follow Mendel's two laws: segregation and independent assortment. The truth remains, his laws are correct and did explain how genetics works. The genotypic ratios follow Mendel's first law, but not the phenotypes do not. However, real life is just a bit more complex than peas. So both genotypes and phenotypes do not really follow Mendel's second law. Also, mitochondrial inheritance, which is solely maternally inherited; linkage, where two genes that are close together physically, and linkage disequilibrium, where two alleles that are not inherited separate.

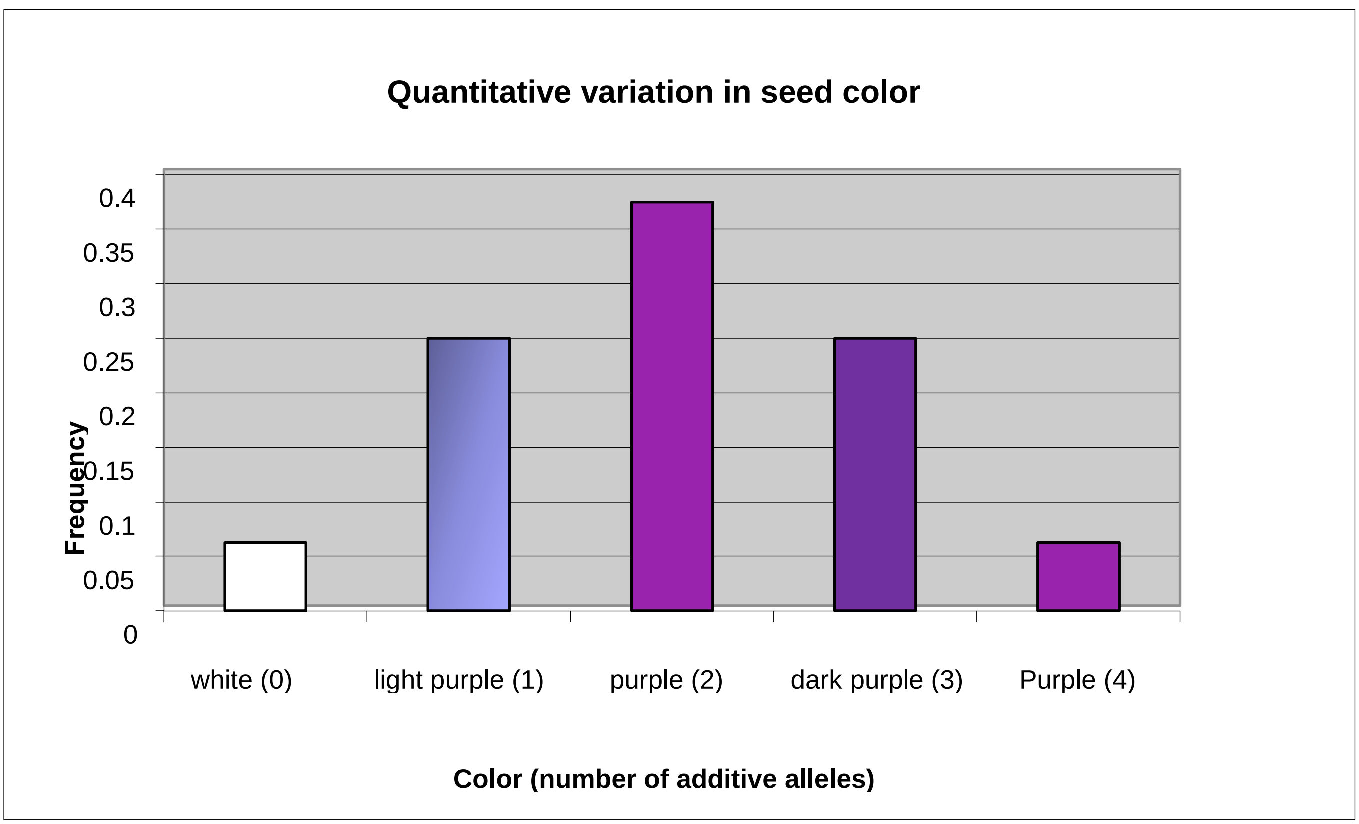
For example, consider this case of an incomplete dominance using this dihybrid cross using two heterozygous **AaBb x AaBb,** where **A and B** are *Purple* factors for color, and **a and b** are *white* factors for leaf color to predict the offspring ratios.

Egg/Sperm	ab	aB	Ab	AB
ab	**aabb** (white)	**aaBb** (light purple)	**aAbb** (light purple)	**aAbB** (purple)
aB	**aaBb** (light purple)	**aaBB** (purple)	**aABb** (purple)	**aABB** (dark purple)
Ab	**Aabb** (light purple)	**AabB** (purple)	**AAbb** (purple)	**AABb** (dark purple)
AB	**AaBb** (purple)	**AaBB** (dark purple)	**AABb** (dark purple)	**AABB** (purple)

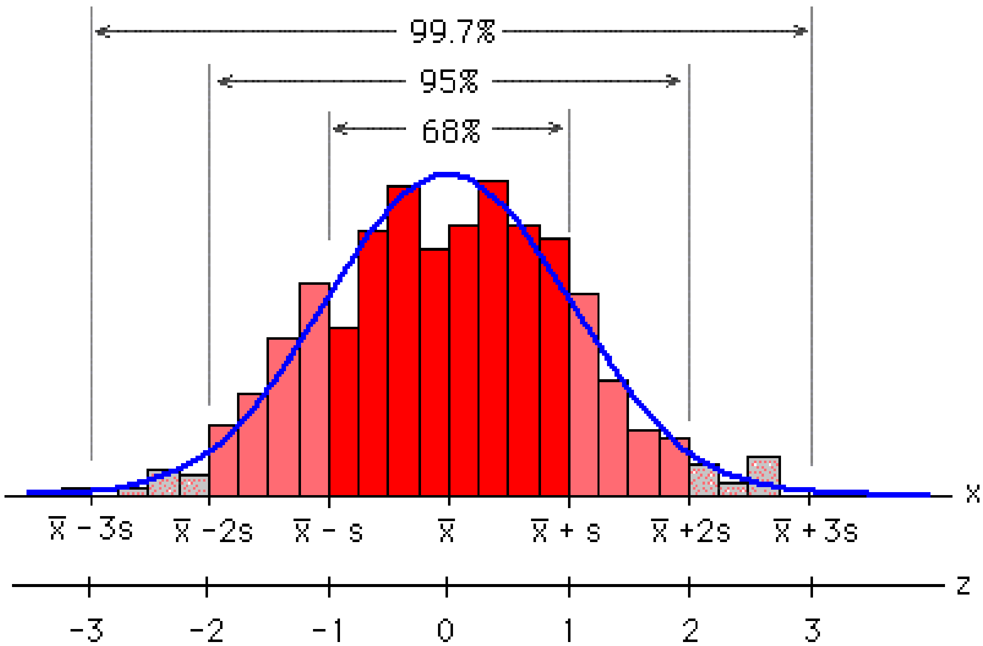
The Punnett square above of the case above would yield the results with the additive alleles below. Additive alleles are change the phenotype in an additive way, they behave similar to incomplete dominance

Color (# of additive red alleles)	Number of individuals	Frequency
White (1)	1	0.0625
Light purple (1)	4	0.25
Purple (2)	6	0.375
Dark purple (3)	4	0.25
Purple (4)	1	0.0625
Total	16	1.0000

Using the frequency to create a standard curve, the contributing additive genes to the polygenic trait can be found by looking at the mean of the distribution. If the two additive alleles impact the phenotype equally, then the mean will be the genes involved.



You can read additional literature on this topic with real world application, which will be included as part of the reference list. However, I would like to summarize using quantitative traits using the bell curve showing that the mean is the number of genes controlling the traits, while the width show the phenotypic variance. Statistically, if using two sets of data, and one has a wider range of numbers, it will have a greater variance, so standard deviation could be calculated. Hence, using this graph, the phenotypic variance is a product of both genetics and the environment, or P=G+E



g.

References

Picture a: https://missingbrains.com/2013/10/24/how-it-works-mendelian-inheritance/

Picture b. https://abrcoutreach.osu.edu/trained-educational-kits

Picture c. https://en.wikipedia.org/wiki/Dominance_(genetics)#Co-dominance

Picture d. http://evolution.about.com/od/Evolution-Glossary/g/Incomplete-Dominance.htm

Picture e. http://www.thrombocyte.com/most-common-blood-type/

Picture f. https://www2.estrellamountain.edu/faculty/farabee/biobk/BioBookhumgen.html

Picture g. http://www.math.armstrong.edu/statsonline/3/ex3.b.3.html

LESSON ONE: I THINK THEREFORE I AM.

KEY QUESTION(S): Are organisms' traits determined more by genes or environment?

OVERALL TIME ESTIMATE:

- Advanced Preparation: 15-30minutes (Reviewing contents and copies)
- Student Procedure: 60-90 minutes

LEARNING STYLES: Visual, auditory, and tactile

VOCABULARY:

Traits: character is a feature of an organism

Gene: The physical and functional unit of heredity. It is a segment of DNA that is responsible for the physical and inheritable phenotype of an organism.

Genome: A genome is an organism's complete set of DNA, including all of its genes. Each genome contains all of the information needed to build and maintain that organism. In humans, a copy of the entire genome—more than 3 billion DNA base pairs—is contained in all cells that have a nucleus.

Phenotype: The physical appearance or particular traits of an organism as a result of the interaction of its genotype and the environment, for example skin color, height etc. (genotype + environment + random variation → phenotype).

Genotype: The entire set of genes in an organism or a set of alleles that determines the expression of a particular characteristics or traits.

Arabidopsis plant: is a small flowering plant that is widely used as a model organism in plant biology

Genetic Variation: The genes of organisms within a population change

Model Organism: A species that has been widely studied, usually because it is easy to maintain and breed in a laboratory setting and has particular experimental advantages.

LESSON SUMMARY: In this lesson, students will be scientific investigators exploring phenotypic variation using Arabidopsis as a model organism. They should already have basic knowledge of genetics in DNA. They will collaborate in teams of four to five members to observe and record different traits from several Arabidopsis plants from the lab. Using what they learn, they will generate their research questions to explore as an independent study. This lesson will allow students to apply scientific inquiry and build on their conceptual knowledge on genetics by discussing this question: What contributes more to an organism's traits, genes or the environment?

STUDENT LEARNING OBJECTIVES:
The student will be able to...

1. Describe the characteristics of a model organism
2. Explain why Arabidopsis is a model organism in biomedical research
3. Describe traits and phenotype
4. Explain what cause variation in organisms.
5. Make observation and inferences.
6. Explain that observed traits (phenotype) are controlled by genotype interacting with the environment.
7. Develop research questions.

STANDARDS:
SC.912.L.16.2
SC.912.L.15.15
SC.912.N1.1
SC.912.N.1.6

MATERIALS:

- 1 copy of *Teacher Guide: I Think Therefore I am*
- 1 copy of *A Model Organism*
- 1 copy of *Arabidopsis*
- Post it Chart paper
- 1 copy of *Student Worksheet 1: Traits and Phenotype* per student
- 1 copy of *Student Worksheet 2*: *Variation of Traits* per student

BACKGROUND INFORMATION: Teachers are encouraged to read the Teacher guide and the student information prior to the activity. This lesson has two activities leading students through the scientific inquiry process, and help them understand that an organism's trait is determine by the both genes and the environment.

ADVANCE PREPARATION:

1. Make copies of all the handouts
2. Explore the suggested website in the references for Lesson One

I THINK THEREFORE I AM

Teacher Guide: Lesson One

Teacher Background: Understanding of phenotypic expression of traits, and the role of environment and genotype.

Procedure and Discussion Questions With Time Estimates:

1. **(5 min)** Engage students: Pointing to the already populated Arabidopsis for this lesson, survey the students on their knowledge of the plants. Tell them that the plants will be part of their scientific investigation for the next four lessons. Tell them that these plants are model organisms, then ask them, what is a model organism?
2. **(5 min)** Allow students to share their response as a whole class
3. **(2 min)** Ask a student to read the handout on: A Model Organism.
4. **(5 min)** Ask students to pair share on the characteristics of a model organism and share with the whole class.
5. **(3 min)** Ask another student to read the handout on: Model Organism for Biomedical Research-Arabidopsis.
6. **(5 min)** Ask the students to write 3-5 reasons why Arabidopsis is a model organism?
7. **(5 min)** Allow students to pair share their responses and ask for 2-3 pairs to share their partner's answers with the class.
8. **(5 min)** Ask students to write the list of vocabulary words for Lesson One in their notebook.
9. **(15 min)** Have students assemble in groups of 4. Provide them with plants from both Wildtype and Mutant Arabidopsis and Worksheet 1. Have a member of the group read the paragraph about trait and phenotype, then ask them to discuss the following questions and record their answers on the Post it Chart paper:

Discussion

1. How much of who you are have you inherited from your parents (genes)? How much from your parents?

2. Observing the plants assigned to your group, how much do you think are from their genes? How much from the environment? What inferences can you make about the environmental traits on plants?

3. Are genes or environment more important at certain times in their lives? During germination, reproduction, or death?

10. **(10 min)** Have each group select a spokesperson to share their answers with the rest of the class.
11. **(5 min)** Using what you have learned about traits and phenotype, select a trait from your list and develop a research question that can be answered through experimentation.
12. **(10 min)** Ask students to analyze their team picture and note similarities and differences. Ask them to explain what would cause the differences? (Variation)
13. **(5 min)** Wrap-up the lesson by asking students to summarize what they have learned in and have 1-2 of them share with the rest of class.
14. Assign the students the ReadingWorks on *Variation on Traits* as Homework: http://www.readworks.org/passages/variation-traits

ASSESSMENT SUGGESTIONS:

- Student worksheets can be checked for completion.

EXTENSIONS:

Homework: Read and Answer the questions on Variation of Traits from http://www.readworks.org/passages/variation-traits

RESOURCES/REFERENCES:

- Genotype/Phenotype: https://www.youtube.com/watch?v=lal1aaf14PQ
- Mutations-Power of mutations: https://www.youtube.com/watch?v=GieZ3pk9YVo
- Genetics vs. Environment https://www.youtube.com/watch?v=y6rGht8s9E8
- ReadingWorks Vriation on Traits: http://www.readworks.org/passages/variation-traits

A Model Organism

What are model organisms?

A species that has been widely studied, usually because it is easy to maintain and breed in a laboratory setting and has particular experimental advantages.

- ✓ Model organisms are non-human species that are used in the laboratory to help scientists understand biological processes.
- ✓ They are usually organisms that are easy to maintain and breed in a laboratory setting.
- ✓ For example, they may have particularly robust embryos[?] that are easily studied and manipulated in the lab, this is useful for scientists studying development.
- ✓ Or they may occupy a pivotal position in the evolutionary tree, this is useful for scientists studying evolution.[?]

Why are model organisms useful in genetics research?

- ✓ Many model organisms can breed in large numbers.
- ✓ Some have a very short generation time, which is the time between being born and being able to reproduce, so several generations can be followed at once
- ✓ Mutants allow scientists to study certain characteristics or diseases. These are model organisms that have undergone a change or mutation[?] in their DNA[?] that may result in a change in a certain characteristic.
- ✓ Some model organisms have similar genes[?] or similar-sized genomes[?] to humans.
- ✓ Model organisms can be used to create highly detailed genetic maps:
    - Genetic maps are a visual representation of the location of different genes on a chromosome[?], a bit like a real map but one where the key landmarks are areas of interest in the genome.
    - For example, areas of DNA that differ between individuals in the same species (SNPs[?]) or genes.

Retrieved from http://www.yourgenome.org/facts/what-are-model-organisms

National Institutes of Health
Model Organisms for Biomedical Research

Model Organisms for Biomedical Research

Arabidopsis

http://luirig.altervista.org/schedenam/fnam.php?taxon=Arabidopsi

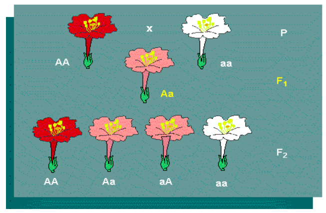
Arabidopsis thaliana is a small flowering plant that is widely used as a model organism in plant biology. Arabidopsis is a member of the mustard (Brassicaceae) family, which includes cultivated species such as cabbage and radish. Although not of major agronomic significance, Arabidopsis offers important advantages for basic research in genetics and molecular biology:

- Approximately 115 Mb of the 125 Mb genome has been sequenced and annotated (Nature, 408:796-815; 2000).
- Extensive genetic and physical maps of all 5 chromosomes are available.
- The life cycle is short--about 6 weeks from germination to seed maturation.
- Seed production is prolific and the plant is easily cultivated in restricted space.
- Transformation is efficient utilizing Agrobacterium tumefaciens.
- A large number of mutant lines and genomic resources is available.
- A. thaliana is studied by a multinational research community in academia, government and industry.

Such advantages have made Arabidopsis a model organism for studies of the cellular and molecular biology of flowering plants. The Arabidopsis Information Resource (TAIR) collects and makes available the information arising from these efforts.

Retrieved from http://modelorganisms.nih.gov/arabidopsis/index.html

Traits and Phenotype



What are Traits?

Traditionally in the science realm, traits and phenotype are used interchangeably. Looking at the list of key terms in today's lesson contains both terms. They both essentially describe an organism's characteristics, such as color, height, shape etc. However, an organism's genotype is clearly affected by its genes. The environment has an impact on an organism's trait.

Collaborative Activity



Using your assigned plants: List 5 genotypic traits and 3 traits influenced by the environment

1. ______________________
2. ______________________
3. ______________________
4. ______________________

1. ________________________
2. ________________________
3. ________________________

Picture 1 Team 1

http://dianechamberlain.com/2014/11/story-weekend-identical-twins/

Picture 2 Team 2

http://www.thinglink.com/scene/620337131042111489

Picture 3 Team 3

https://allyouneedisbiology.wordpress.com/2015/12/13/parthenogenesis-reptiles-insects/

Picture 4 Team 4

https://www.google.com/search?biw=1280&bih=611&tbm=isch&sa=1&q=same+plant+with+variation&oq=same+plant+with+variation&gs_l=img.3...295553.299954.0.300907.0.0.0.0.0.0.0.0..0.0....0...1c.1.64.img..0.0.0.eSXSbdP7oF8#imgrc=zUsNdAcpv0d5UM%3A

Picture 5 Team 5

https://www.google.com/search?biw=1280&bih=611&tbm=isch&sa=1&q=clone+with+variation&oq=clone+with+variation&gs_l=img.3...489801.492118.0.492571.0.0.0.0.0.0.0.0..0.0....0...1c.1.64.img..0.0.0.iq8qSaMCaww#imgrc=MrDAmjZS-Sw8VM%3A

LESSON TWO: ON SHOULDERS OF GIANTS: LINK WHAT?

KEY QUESTION(S): What are linked genes and how might we find them?

OVERALL TIME ESTIMATE:

- Advanced Preparation: 30-60 minutes (Reviewing contents and copies)
- Student Procedure: 90 minutes

LEARNING STYLES: Visual, auditory, and tactile

VOCABULARY:

Chromosomes: Carry all of the information used to help a cell grow, thrive, and reproduce. They are made up of DNA. Segments of DNA in specific patterns are called genes.

Meiosis: is the process by which one diploid eukaryotic cell divides to generate four haploid cells often called gametes

Crossing Over: process in genetics by which the two chromosomes of a homologous pair exchange equal segments with each other.

Homologous Chomosomes: a chromosome with the same gene sequence as another (The maternal and paternal **chromosomes** in a **homologous** pair have the same genes at the same loci, but possibly different alleles. A couple of **homologous chromosomes**, or **homologs**, are a set of one maternal and one paternal **chromosomes** that pair up with each other inside a cell during meiosis).

Locus (plural **loci**): Is the specific location or position of a gene's DNA sequence, on a chromosome. Each chromosome carries many genes; humans' estimated 'haploid' protein coding genes are 20,000-25,000, on the 23 different chromosomes.

Mendel's Law of Segregation: States that allele pairs separate or **segregate** during gamete formation, and randomly unite at fertilization

Mendel's Law of Independent Assortment: Formation of random combinations of chromosomes in meiosis and of genes on different pairs of homologous chromosomes by the passage according to the laws of probability of one of each diploid pair of homologous chromosomes into each gamete independently of each other pair.

Genetic Linkage: Is the tendency of alleles that are close together on a chromosome to be inherited together during the meiosis phase of sexual reproduction.

Genetic Markers: Are used to trace or identify specific region of a gene (especially one that is associated with an inherited disease) on a chromosome. They are also used to determine a linkage group or a recombination event.

Linkage Disequilibrium: When the frequency of association of their different alleles is higher or lower than what would be expected if the loci were independent and associated randomly.

Ecotype: A group of organisms within a species that is adapted to particular environmental conditions and therefore exhibits behavioral, structural, or physiological differences from other members of the species.

Recombinant inbred lines (RILs): are a collection of strains that can be used to map quantitative trait loci. Parent strains are crossed to create recombinants that are then inbred to isogenicity, resulting in a permanent resource for trait mapping and analysis.

LESSON SUMMARY: As a whole class review Gregor Mendel's two principles on segregation and independent assortment. If necessary also discuss meiosis, especially homologous chromosomes and crossing over. In this lesson, students will work collaboratively in groups of four to derive an understanding of gene linkage. Teachers also need to emphasize Non-Mendelian Genetics and how other scientist add to the pre-existing scientific knowledge (theories and laws). As teams, students need to develop an approach to explore whether phenotypic traits are linked or not and share it as a whole class.

STUDENT LEARNING OBJECTIVES:

The student will be able to...

8. Explain meiosis, independent assortment of homologous chromosomes, and recombination during the event of crossing-over.
9. Describe Mendel's principles of inheritance
10. Differentiate between laws and theories
11. Explain how genetic recombination increase genetic variation
12. Describe that that linked genes are located on the same chromosome
13. Explain that genes are located closer together on the same chromosome have a greater degree of linkage.
14. Recognize that traits of linked genes are inclined to be inherited together.
15. Understand that traits that tend to show up together are signs of genetic linkage.
16. Understand how Mendel's principles contribute to genomic study

STANDARDS:

SC.912.L.16. 1

SC.912.L.16. 2

SC.912.L.16.16

SC.912.L.15.15

SC.912.N.1.6

SC.912.N.2.4

SC912.N3.1

SC912.N3.4

MATERIALS:

- 1 copy of *Teacher Guide: On the Shoulders of Giants: Link What?*
- Envelope of Cut-out: *Key Terms*
- Envelope of Cut-outs: *Chromosomes Handout*
- 1 copy of *Handout 1: Incomplete Dominance*
- 1 copy of *Handout 2, 3 and 4: Genetic Linkage*
- 1 copy of *Handout 5*: *Linkage Disequilibrium*
- Student Worksheet: *Recombinant Inbred Lines*

BACKGROUND INFORMATION: Teachers are encouraged to read the Teacher guide and the student information prior to teaching Lesson Two. This lesson explores students understanding of gene linkage using Cut-outs. However, teachers should ensure that their pupils have a solid understanding of meiosis, especially crossing over and independent assortment. In addition, they should also review basic Punnett square and Non-Mendelian genetics.

ADVANCE PREPARATION:

3. Make copies of all the handouts
4. Prepare Vocabulary cards (laminate if you want to reuse)
5. Prepare envelopes of Cut-out chromosomes per pair of students
6. Explore the suggested website in the references for Lesson Two

ON SHOULDERS OF GIANTS: LINK WHAT?

Teacher Guide: Lesson Two

Teacher Background: Review meiosis-crossing Mendel's law of inheritance. A few suggested linked are listed on the resource/references section.

Procedure and Discussion Questions With Time Estimates:

15. **(5 min)** Have students sit in pairs. Give each student a random card (term or definition). Tell them to get up and find their match and to remain with that person. **Post answer key to self-correct.** Have them read their key terms and meaning to the class.
16. **(7 min)** Engage students: Have students work in pairs to answer these two questions.
    a. How are you different from your partner? How are you similar?
    b. How would these characteristics be in comparison to identical twins?
17. **(4 min)** Allow students to share their response as a whole class
18. **(7 min)** Ask for a volunteer to draw a Venn diagram comparing a theory and a law on the board. Whole class instruction. The other students will need replicate the diagram in their notebook.
    a. define a theory
    b. define a law
    c. compare/contrast (***reinforce that one will never become the other, but theories are modifiable)***
19. **(7 min)** allow the students to watch the video clip on meiosis and independent assortment https://www.youtube.com/watch?v=-Zzp3mLlycM. Tell them to summarize their understanding in one to two sentences in their notebook.
20. **(5 min)** Show the students the *Handout 1*: Do these flowers follow Mendel's laws?
21. **(2 min)** Share out: What makes you "unique"?
22. **(5min)** Allow students to observe the population of Arabidopsis and record any variation in their notebooks.
23. **(5 min)** Watch the video clip on crossing over and recombination https://www.youtube.com/watch?v=pdJUvagZjYA
    Ask the students to discuss how (crossing-over) genetic recombination increase genetic variation?
24. **(15-20 min)** Have students pair up for this activity: Give each student an envelope with a pair of chromosomes and a pair scissors and glue stick.
    a. Demonstrate crossing over using their chromosomes: 1) create an X shape using their two pieces. 2) Then cut a segment of one chromatid and glue it on their partner's chromosomes

b. Repeat the same process by repopulating again with another (pair-team) of different chromosomes from their partner and a different segment. (examine their chromosomes for different colors)
c. Allow them to propagate again with another member different from the second partner with a different segment.
d. Ask the students to compare their chromosomes with their partner and describe what had happened? How does it compare to the original chromosomes.

Emphasize that In vitro, this recombination process occurs randomly. However, you use the cut-out to help them visualize crossing over and recombination genetic materials.

25. **(3 min)** Have students discuss in pair if they knew which alleles they donated to what their partner (color-traits). How did they know? Would they know if it occurs randomly? Could some genes linked with others be passed together during the activity? How can they know if it happen in vitro . ***Emphasizing gene linkage and the use of genetic markers.***
26. **(3 min)** Ask students to switch partner and repopulate again with someone they have not had contact with during the previous activity. Ask them what is the probability that they received the same size gene from their different partners? ***Showing linkage disequilibrium.***
27. **(10 min)** Post a copy of *Handout 2 and 3* to show students ***how and why genes are linked***. Ask them to explain what they are observing? Then give students *Handout 4* to answer the questions
28. **(2 min)** Ask the students if they think the location of the genes will remain if they continue to populate? Post a copy of *Handout 5* to show them linkage disequilibrium.
29. **(10 min)** Ask students to regroup in 4 and pick up their Arabidopsis plant for observation and record any changes in their notebooks. Give each student a copy of the worksheet on RILs to read and discuss the questions
30. **(5 min)** review the lesson's goal with students about gene and ask them if Mendel was wrong? How have Mendel's principle contribute to the genetics studies?

ASSESSMENT SUGGESTIONS:

- Check Handout #4 and Student worksheet on RILs for completion.

RESOURCES/REFERENCES:

- Meiosis: https://www.youtube.com/watch?v=D1_-mQS_FZ0
- Meiosis and independent assortment: https://www.youtube.com/watch?v=-Zzp3mLIycM
- Crossing over and recombination: https://www.youtube.com/watch?v=pdJUvagZjYA
- Handout 1, 2,3: http://learn.genetics.utah.edu/content/pigeons/geneticlinkage/

- Genetic Linkage: http://www.nature.com/scitable/topicpage/thomas-hunt-morgan-genetic-recombination-and-gene-496
- RILs: https://www.youtube.com/watch?v=SNvG_CqFvVY

Key Terms:

Linkage Disequilibrium	When the frequency of association of their different alleles is higher or lower than what would be expected if the loci were independent and associated randomly.
Genetic Markers	Are used to trace or identify specific region of a gene (especially one that is associated with an inherited disease) on a chromosome. They are also used to determine a linkage group or a recombination event.

Genetic Linkage	Is the tendency of alleles that are close together on a chromosome to be inherited together during the meiosis phase of sexual reproduction.
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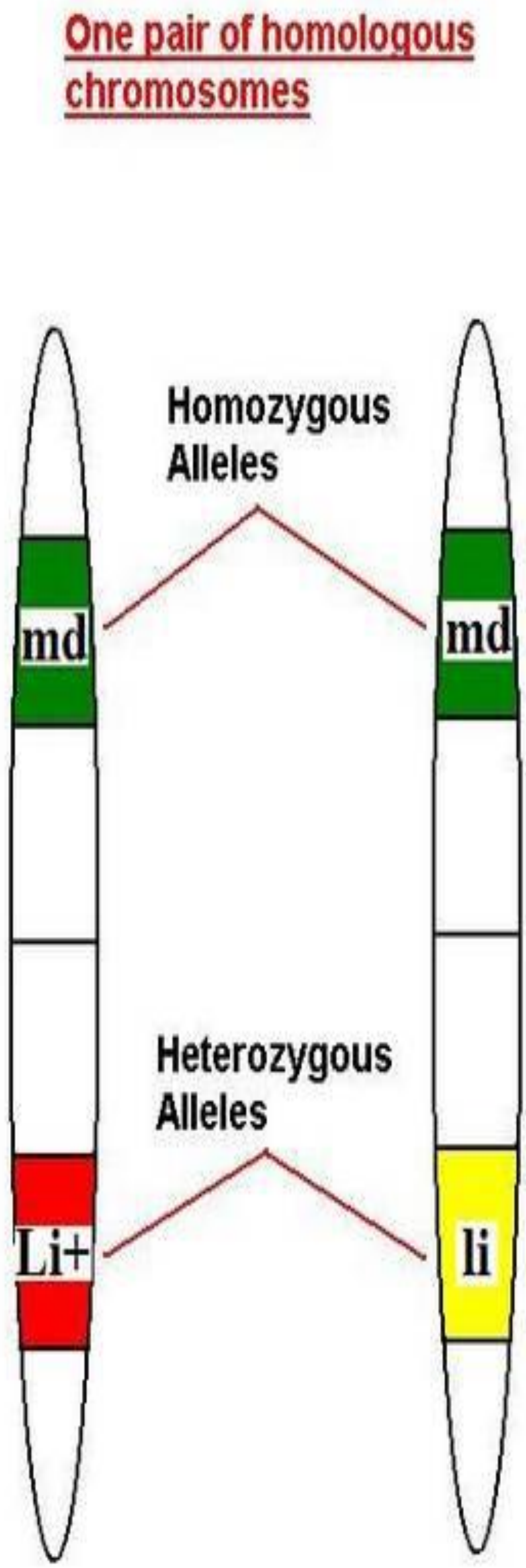
Homologous Chomosomes	A chromosome with the same gene sequence as another _(The maternal and paternal chromosomes in a homologous pair have the same genes at the same loci, but possibly different alleles. A couple of homologous chromosomes, or homologs, are a set of one maternal and one paternal chromosomes that pair up with each other inside a cell during meiosis).
Crossing Over	Process in genetics by which the two chromosomes of a homologous pair exchange equal segments with each other.

Meiosis	Is the process by which one diploid eukaryotic cell divides to generate four haploid cells often called gametes.
Chromosomes	Carry all of the information used to help a cell grow, thrive, and reproduce. They are made up of DNA. Segments of DNA in specific patterns are called genes.

Genetic Markers	Are used to trace or identify specific region of a gene (especially one that is associated with an inherited disease) on a chromosome. They are also used to determine a linkage group or a recombination event.
Linkage Disequilibrium	When the frequency of association of their different alleles is higher or lower than what would be expected if the loci were independent and associated randomly.
	A group of organisms within a

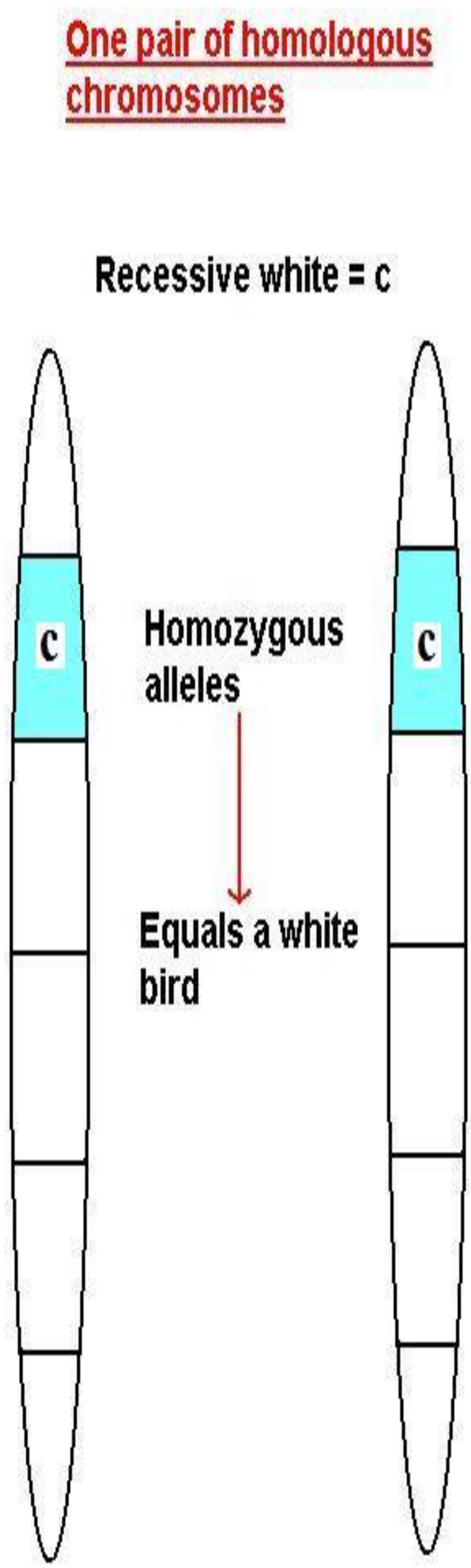
Ecotype	species that is adapted to particular environmental conditions and therefore exhibits behavioral, structural, or physiological differences from other members of the species.
Recombinant inbred lines (RILs)	Are a collection of strains that can be used to map quantitative trait loci. Parent strains are crossed to create recombinants that are then inbred to isogenicity, resulting in a permanent resource for trait mapping and analysis.

PAIR 1 (MEMBER 1)



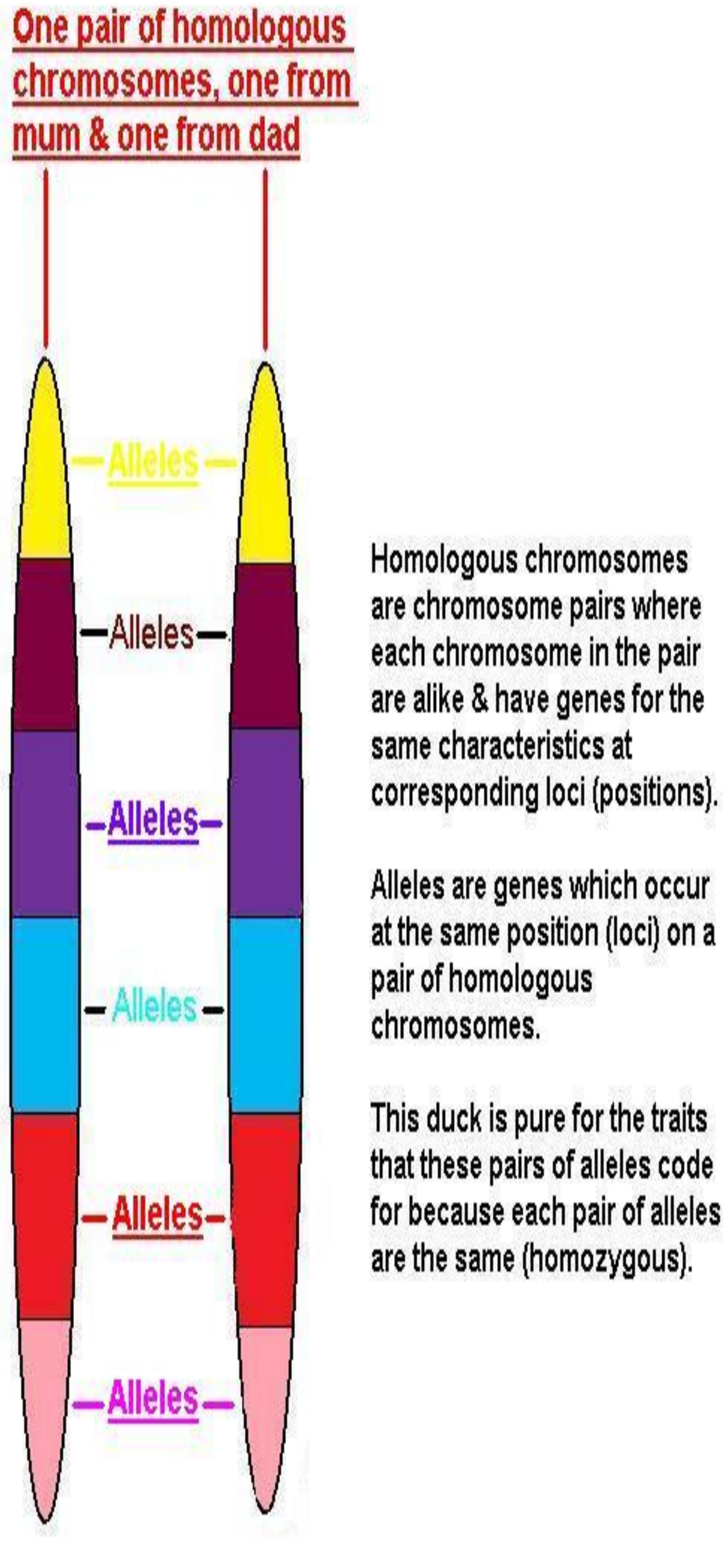
http://forum.backyardpoultry.com/viewtopic.php?f=16&t=7997538

PAIR 1 (MEMBER 2)



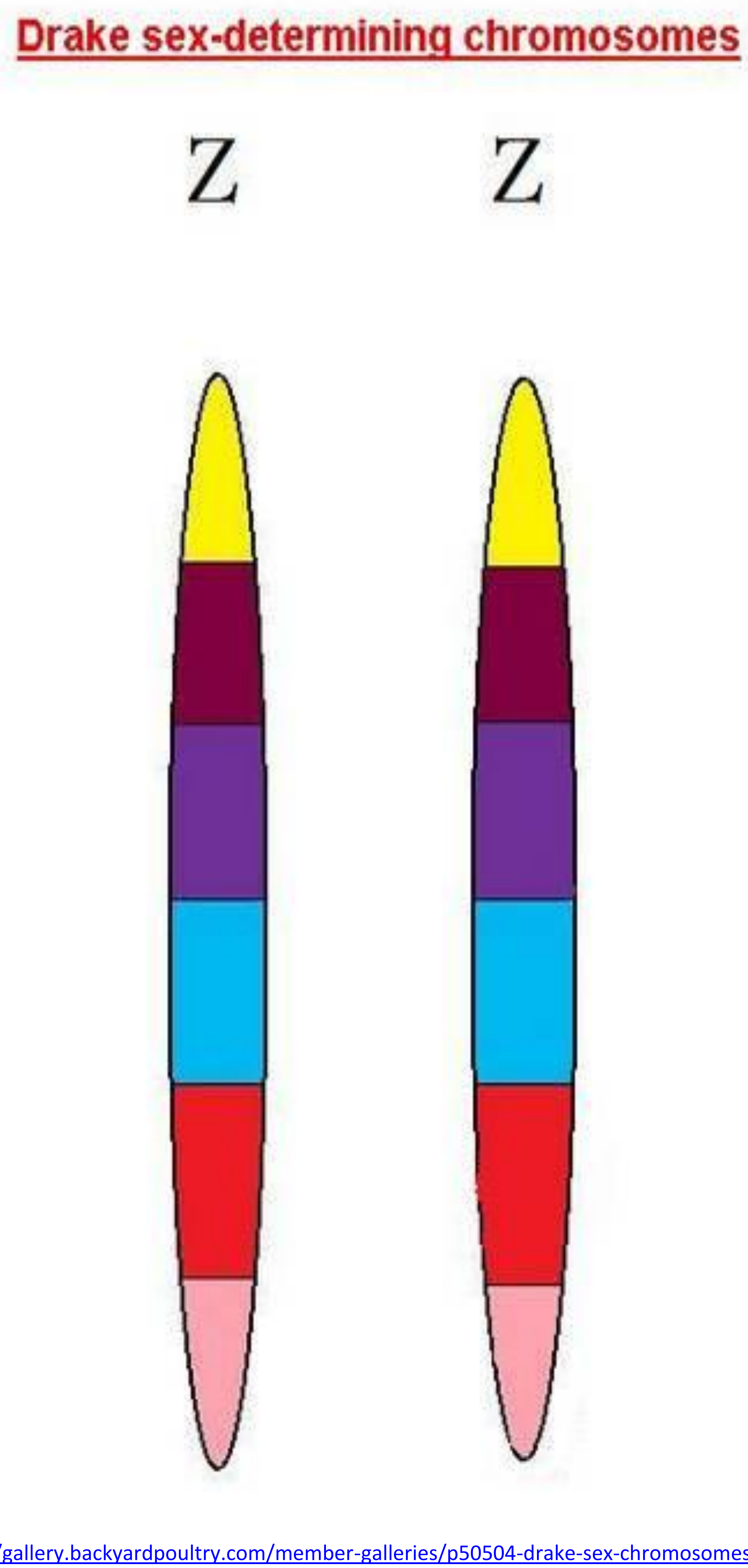
http://forum.backyardpoultry.com/viewtopic.php?f=16&t=7997538

PAIR 2 (MEMBER 1)



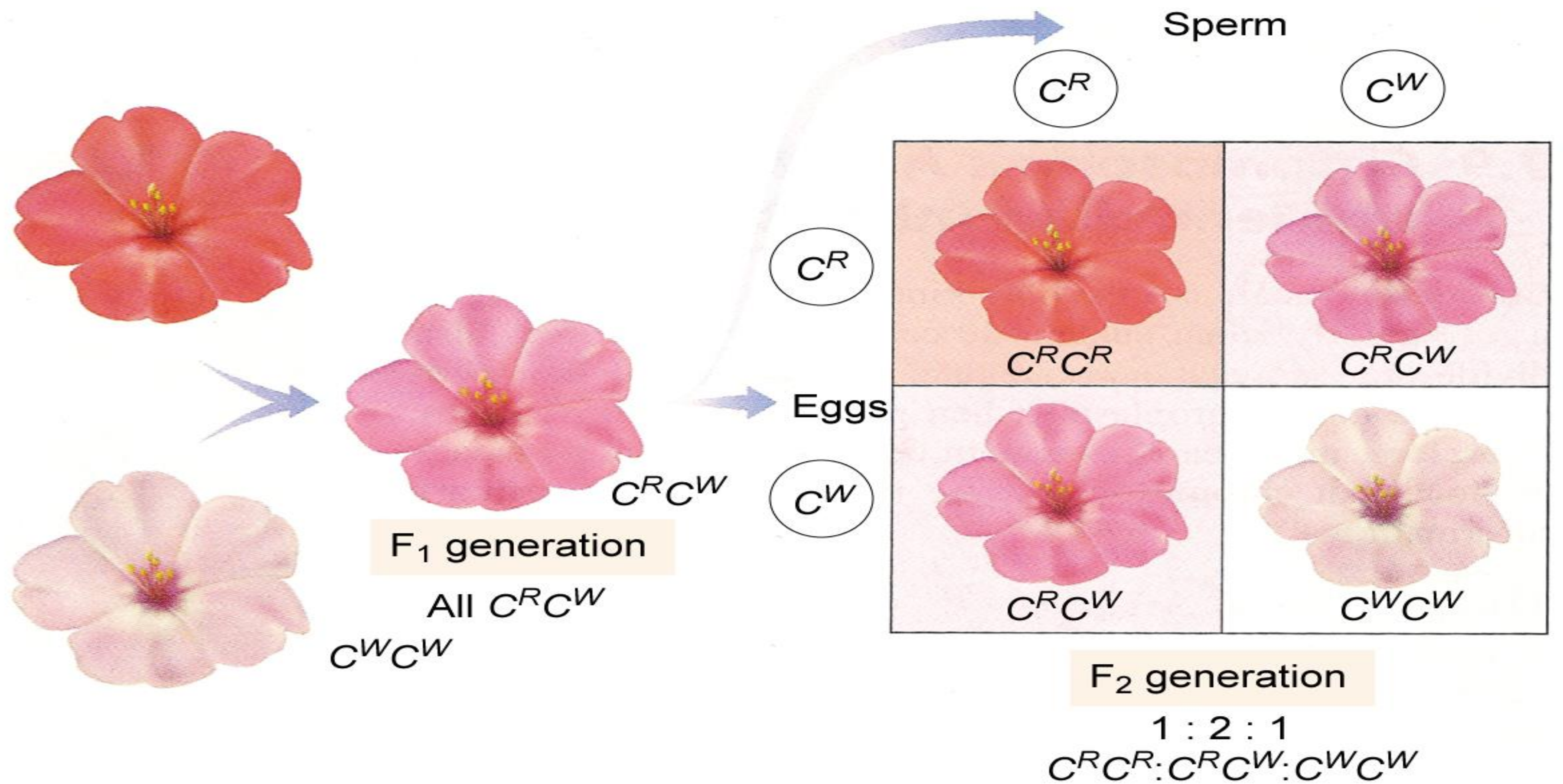
http://forum.backyardpoultry.com/viewtopic.php?f=16&t=7997538

PAIR 2 (MEMBER 2)



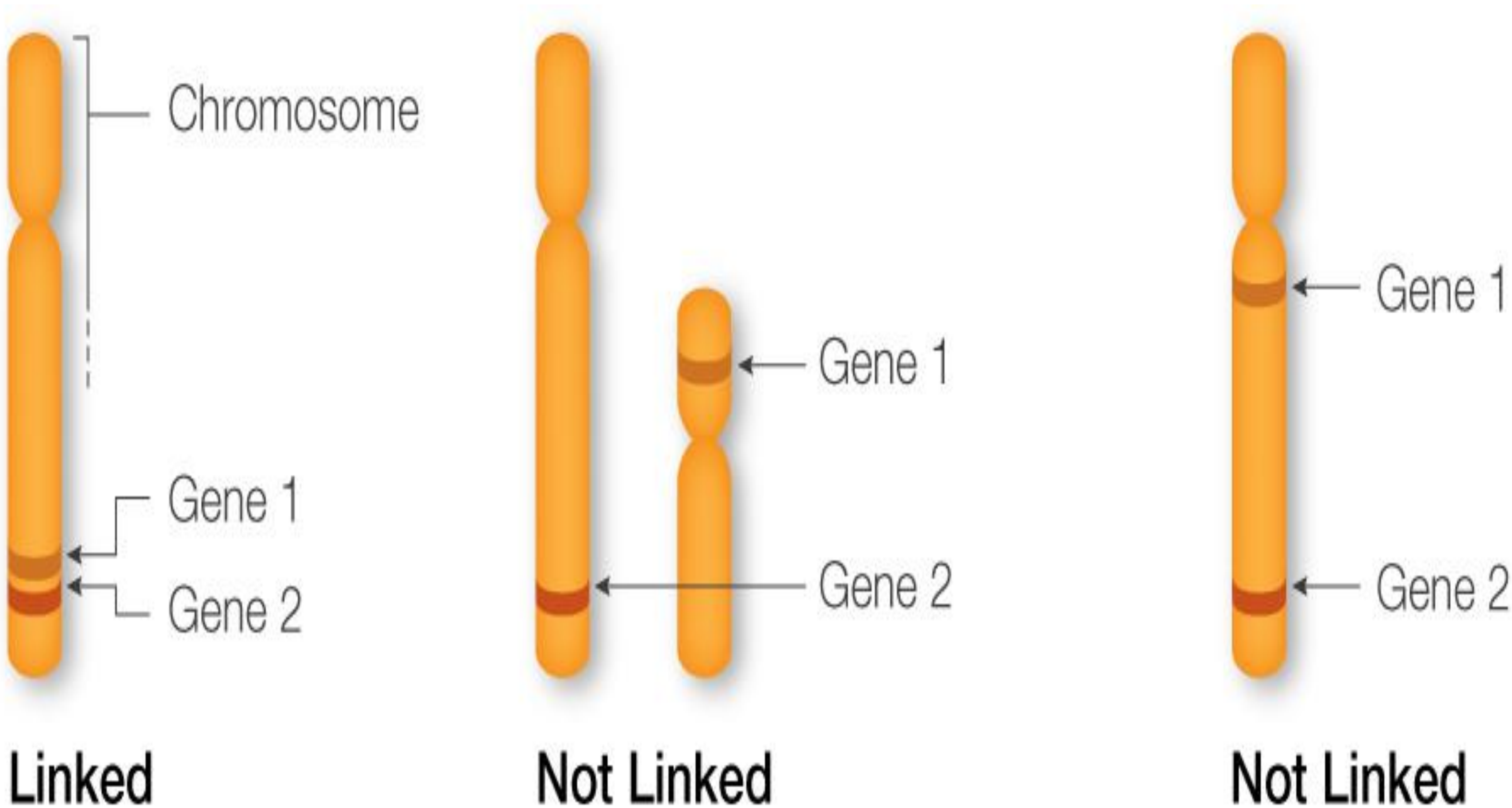
http://gallery.backyardpoultry.com/member-galleries/p50504-drake-sex-chromosomes-1.html

Handout 1



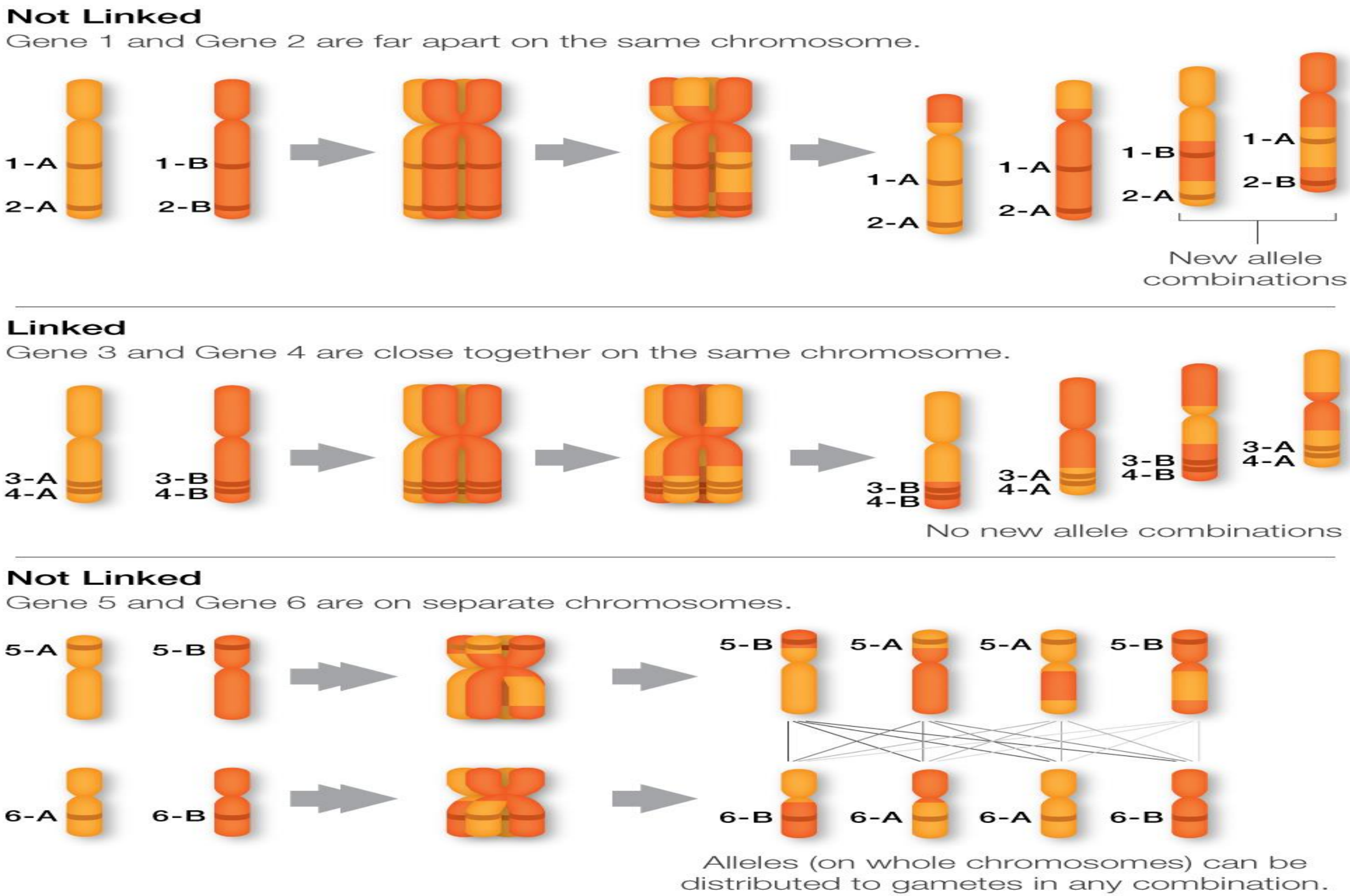
https://online.science.psu.edu/biol011_sandbox_7239/node/7346

Handout 2



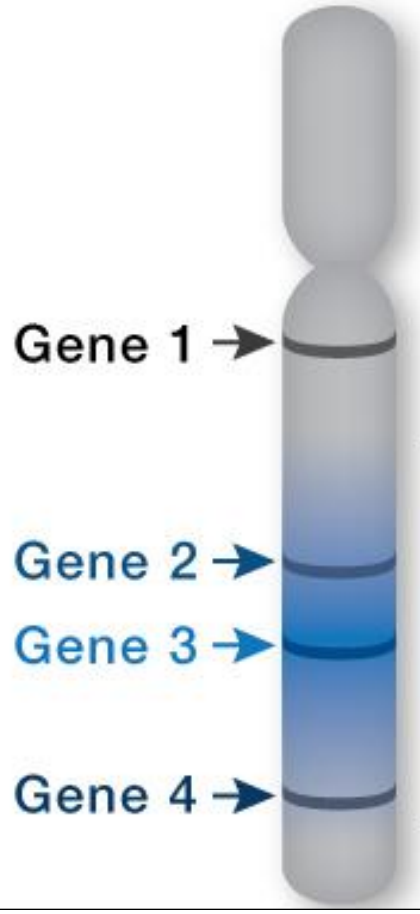
http://learn.genetics.utah.edu/content/pigeons/geneticlinkage/

Handout 3



http://learn.genetics.utah.edu/content/pigeons/geneticlinkage/

Handout 4



Which genes are inherited together?

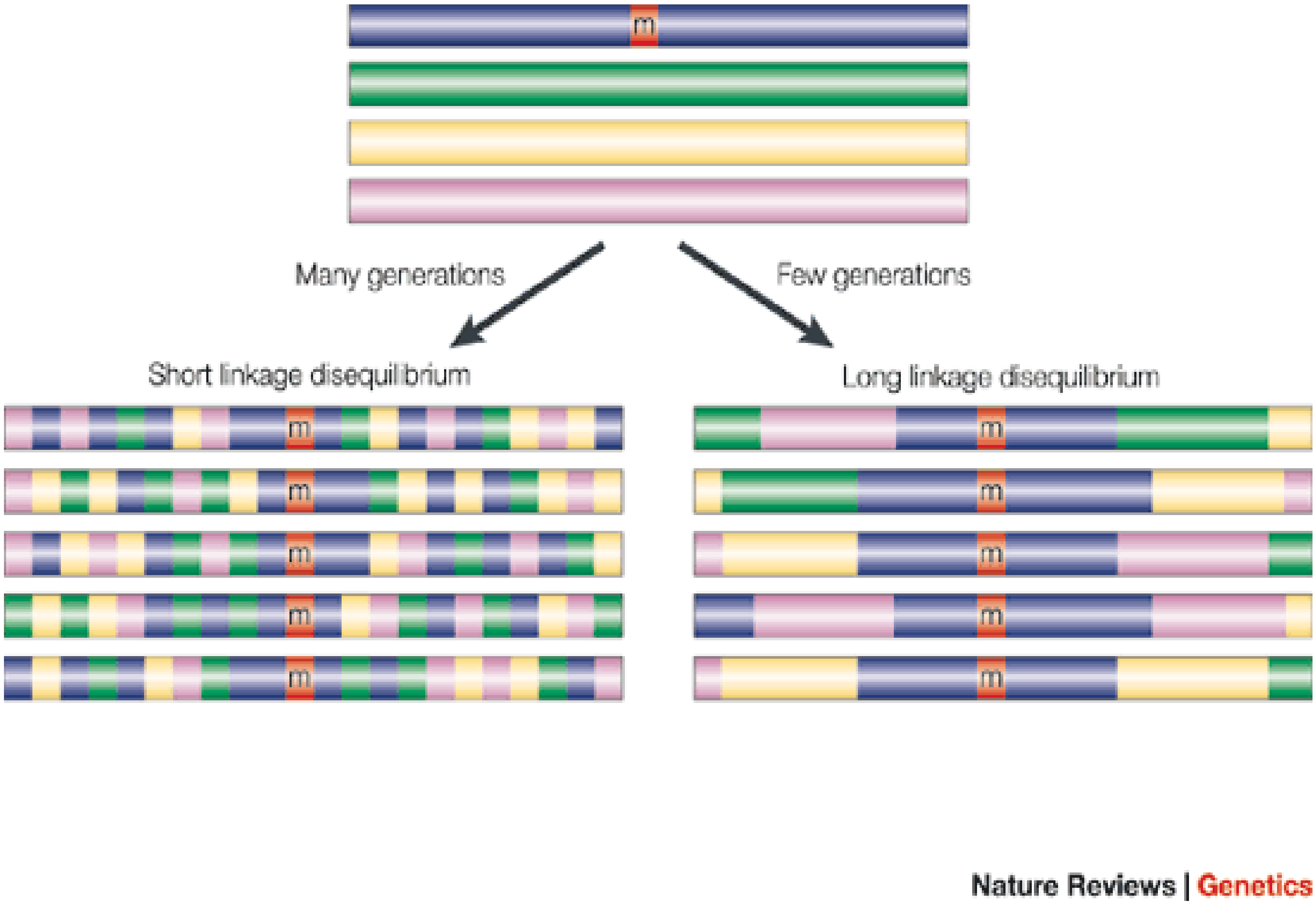
How do you know?

What inferences can you make on the organism's traits based on the location of the genes?

Link What? Can these genes assort independently? Does Mendel's law apply here?

http://learn.genetics.utah.edu/content/pigeons/geneticlinkage/

Handout 5

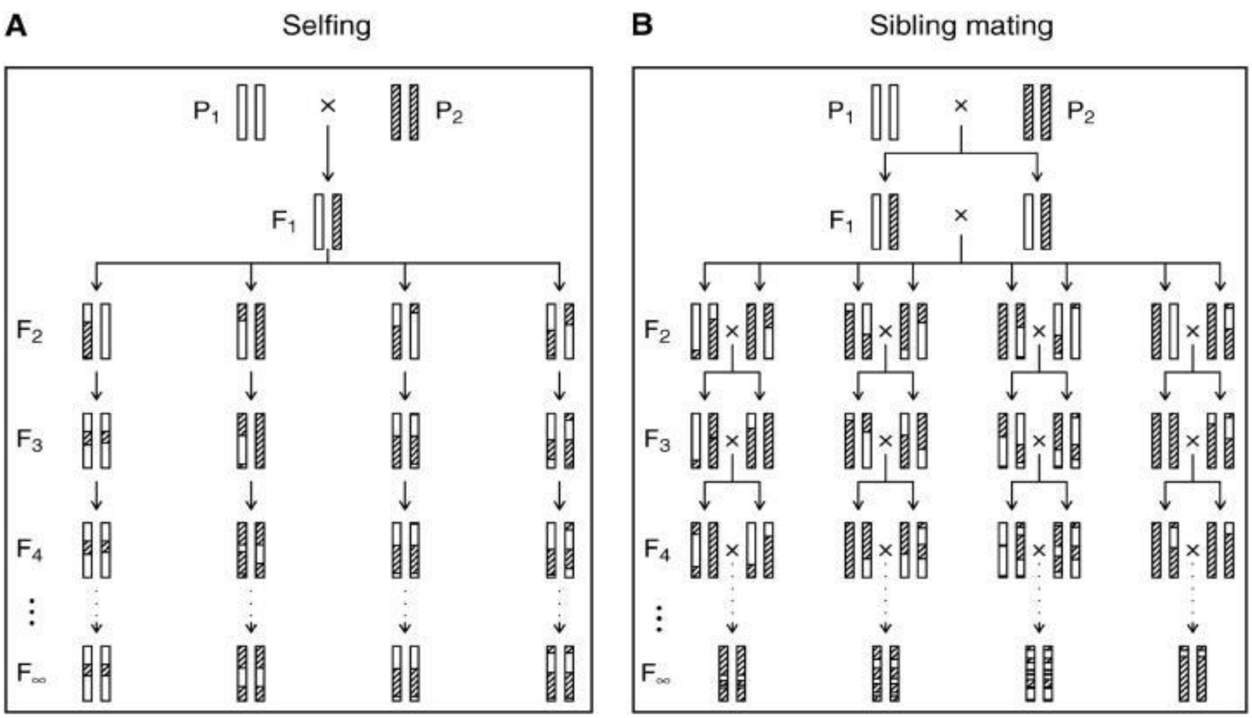


http://www.nature.com/nrg/journal/v2/n11/fig_tab/nrg1101-891a_F1.html

Recombinant Inbred Lines (RILs)

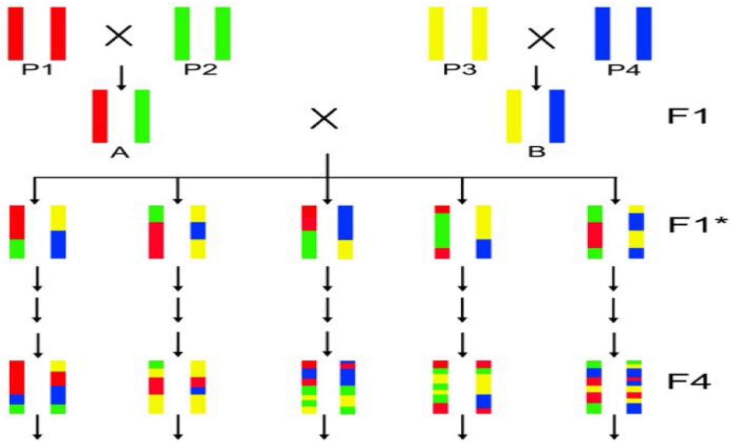
In **Lesson One**, we discussed that Arabidopsis as a model organism and the characteristics of model organisms. Scientists can use this method called RILs to study gene linkage. What is RILs? How does it help scientist determine linkage?

RECOMBINANT inbred lines (RILs) can serve as useful tools for genetic mapping. RIL " is formed by crossing two inbred strains followed by repeated selfing or sibling mating to create a new inbred line whose genome is a mosaic of the parental genomes" (Broman, 2005). Scientists use this method to mimic the minimal genetic variance that occurs in clones, any variance detected is a product of the environment, which is referred to as **ecotypes**. Figure 1 demonstrate the process. When a heterozygous organism undergoes selfing, half of its offspring become homozygous, if the selfing process continues then the probability increases.



Note: Figure from Broman, K. W. (2005). The genomes of recombinant inbred lines. *Genetics*, *169*(2), 1133-1146.

Let's assume our Arabidopsis plants started with some amount of heterogeneity. So the RILs would be similar to F2 in the figure above.



http://bioinfosu.okstate.edu/MG/MGW1/MG11131.html

Discussion Questions

1. What is selfing? How does it help in the development of RILs

2. How difficult would it be to develop RILs in plants that undergo cross-pollination?

3. **Referring to your assigned plants**, what are some environmental (ecotypes) factors that could cause variations in Arabidopsis?

4. What traits might favor cooler or warmer climates, vs. those of wetter/drier climates?

5. Do you think some of these traits are linked? If so, I could you investigate the linkage?

LESSON THREE: WILD THING: WHAT'S YOUR DIGITS?

KEY QUESTION(S): Are trichomes traits discrete or continuous, and how can students know?

OVERALL TIME ESTIMATE:

- Advanced Preparation: 15-30 minutes
- Student Procedure: 90 minutes

LEARNING STYLES: Visual, auditory, and tactile

VOCABULARY:

Discrete (discontinuous) traits: phenotype is controlled by one or only a few genes

Continuous (Quantitative) traits: phenotype that depends on the cumulative actions of many genes and the environment

Trichomes: are plant appendages found on the leaves. They look like little hairs.

Frequency Distribution: A statistical description of raw data in terms of the number or frequency of items characterized by each of a series or range of values of a continuous variable.

LESSON SUMMARY: Already previewed to discrete unit, students will perform Punnett squares using phenotypic traits from lesson one independently. Also, allow them to practice dihybrid crosses with incomplete dominant alleles with a partner. In this lesson, students will observe trichomes numbers. This factor will help them understand the environmental contribution to genetic phenotypes. They will collect data on Arabidopsis trichomes to determine if they expressed continuous traits or not. They will work collaboratively in groups of 4 to observe and gather data from four plants (wild type and mutant). Using the collected data compare discrete units and continuous units.

STUDENT LEARNING OBJECTIVES:
The student will be able to...

17. Manipulate the Punnett squares
18. Distinguish between discrete and continuous traits
19. Gather and analyze on Arabidopsis
20. Predict outcomes based on prior knowledge observations, and research
21. Form conclusions based on collected data

STANDARDS:
SC.912.L.16.1
SC.912.L.16.2
SC.912.N.1.1

MATERIALS:

- 1 copy of *Teacher Guide: Wild Thing: What's Your Digits*
- Handout #1: P*unnett squares and Non-Mendelian Genetics Practice*
- Handout #2: *Reading on discrete and continuous traits*
- *Picture #1*
- Magnifying glass (Class set)
- Handout #3: *Quantifying Trichomes*

BACKGROUND INFORMATION: Teachers are encouraged to read the Teacher guide and the student information prior to teaching Lesson Two. In this lesson, students manipulate Punnett squares, dihybrid crosses before advancing towards an understanding of continuous traits.

ADVANCE PREPARATION:

1. Make copies of all the handouts
2. Explore the suggested website in the references for Lesson Three

WILD THING: WHAT'S YOUR DIGITS

Teacher Guide: Lesson Three

Teacher Background: Review Punnett square and dihybrid crosses.

Procedure and Discussion Questions With Time Estimates:

31. **(3 min)** Have students work independently to complete the **first** Punnett Square on *Worksheet 1*
32. **(10 min)** Engage students: Have students work in pairs to answer these two questions.
    a. How does using a Punnett square demonstrate Mendel's Law of Segregation?
    b. Allow students to complete *Handout #1* in pairs.
33. **(5 min)** Share out, what is happen on problem #2-5 of *Handout #1* (***see if they can differentiate between discrete and continuous traits***)
34. **(12 min)** Allow students to work in their group or team of 4 to read and complete *Handout #2*
35. **(5 min)** Share out their answers to the questions at the end of *Handout #2*.
36. **(5 min)** Project a *Picture #1* of trichomes to the students and ask them to locate and observed them on their plants. .
37. **(50 min)** Allow students to **collect and record** data on their Arabidopsis plants using Handout #3: *Quantifying Trichomes*
38. **(10 min)** Allow students to share their conclusions about trichomes, whether the results showed discrete or continuous traits.

ASSESSMENT SUGGESTIONS:

- Completed Handout #3.

EXTENSIONS:
Homework: Read and Answer the questions on Variation of Traits from http://www.readworks.org/passages/variation-traits

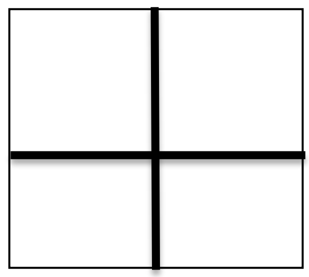
RESOURCES/REFERENCES:

- Two Types of Traits: *eebweb.arizona.edu/courses/ecol223/ECOL223%203-20.pdf*
- *Quantitative Traits:* https://www.ndsu.edu/pubweb/~mcclean/plsc431/quantgen/qgen1.htm

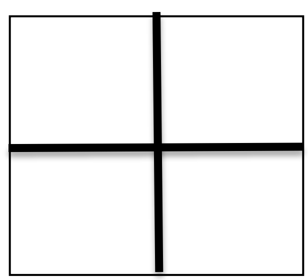
Handout #1

Punnett squares and Non-Mendelian Genetics Practice

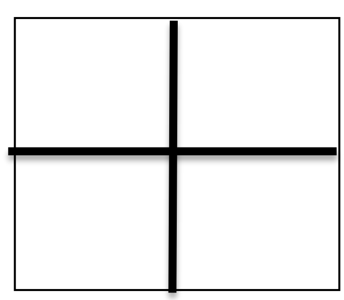
1. B= Brown eyes b= blue eyes Mom= Bb and Dad= BB What are the eye color possibilities of their offspring?



2. In humans, hair type is determined by incomplete dominance. Some people have curly hair (CC), some people have straight hair (SS), and heterozygotes have wavy hair (CS). What would occur if a person with wavy hair had a baby with a person with straight hair? Draw the Punnett square and identify the genotypes and phenotypes of their offspring.



3. Type A and Type B blood are codominant to each other. They are both dominant over Type O blood. Using the Punnett square show all the possible blood types for the offspring produced by a type "O" mother and an a Type "AB" father.



4. A tall Yellow pea plant (TTGG) is crossed with a short green pea plant (ttgg). What would the resulting offspring look like? How many are tall and yellow?

____________ X ____________

5) If two Heterozygous Red and White flowers are crossed, where **R** and **W** are Red determinants, and **r** and **w** are white determinants. What would be the resulting offsprings?

____________ X ____________

_____ Red _____ light Pink _____ dark Pink _____ White

Summary

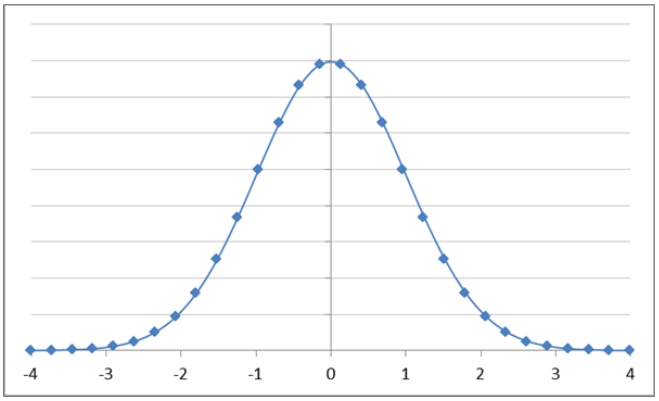
Which examples show discrete or continuous traits? How do you know?

Handout #2

Description of Quantitative Traits

All of the traits that we have studied to date fall into a few distinct classes. These classes can be used to predict the genotypes of the individuals. For example, if we cross a tall and short pea plant and look at F_2 plants, we know the genotype of short plants, and we can give a generalized genotype for the tall plant phenotype. Furthermore, if we know the genotype we could predict the phenotype of the plant. These type of phenotypes are called **discrete or discontinuous traits**.

Other traits do not fall into discrete classes. Rather, when a segregating population is analyzed, a continuous distribution of phenotypes is found. An example, is ear length in corn. Black Mexican Sweet corn has short ears, whereas Tom Thumb popcorn has long ears. When these two **inbred lines are crossed, the length of the F_1 ears are intermediate** to the two parents. Furthermore, when the F_1 plants are inter-mated, the distribution of ear length in the F_2 ranges from the short ear Black Mexican Sweet size to the Tom Thumb popcorn size. The distribution resembles the **bell-shaped curve** for a normal distribution.



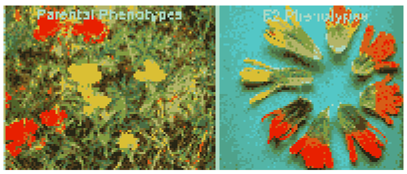
http://www.tushar-mehta.com/excel/charts/normal_distribution/

These types of traits are called **continuous traits** and cannot be analyzed using the same approach as discrete traits. Because continuous traits are often measured and given a quantitative value, they are often referred to as **quantitative traits**, and the area of genetics that studies their mode of inheritance is called **quantitative genetics**.

Many important agricultural traits such as crop yield, weight gain in animals, fat content of meat are quantitative traits, and much of the pioneering research into the modes of inheritance of these traits was performed by agricultural geneticists. Many human phenotypes such as IQ, learning ability and blood pressure also are quantitative traits. **These traits are controlled by multiple genes, each segregating according to Mendel's laws. These traits can also be affected by the environment to varying degrees**.

Here are some images of quantitative traits in plants:

This image demonstrates the variation for flower diameter, number of flower parts and the color of the flower *Gaillaridia pilchella*. Each trait is controlled by a number of genes and is a quantitative trait.



The two photographs above demonstrate variability for Indian Paintbrush flower color. The parents in the left photo are either yellow or reddish orange. The F_2 individuals though show a distribution of colors from yellow to reddish orange. This range of phenotypes is typcial of quantitative traits. This should be compared to flower color of Mendel's peas where the F_2 individuals were either purple or white, the two parental phenotypes.

https://www.ndsu.edu/pubweb/~mcclean/plsc431/quantgen/qgen1.htm

(Contents are modified to suit students' needs)

Discussion

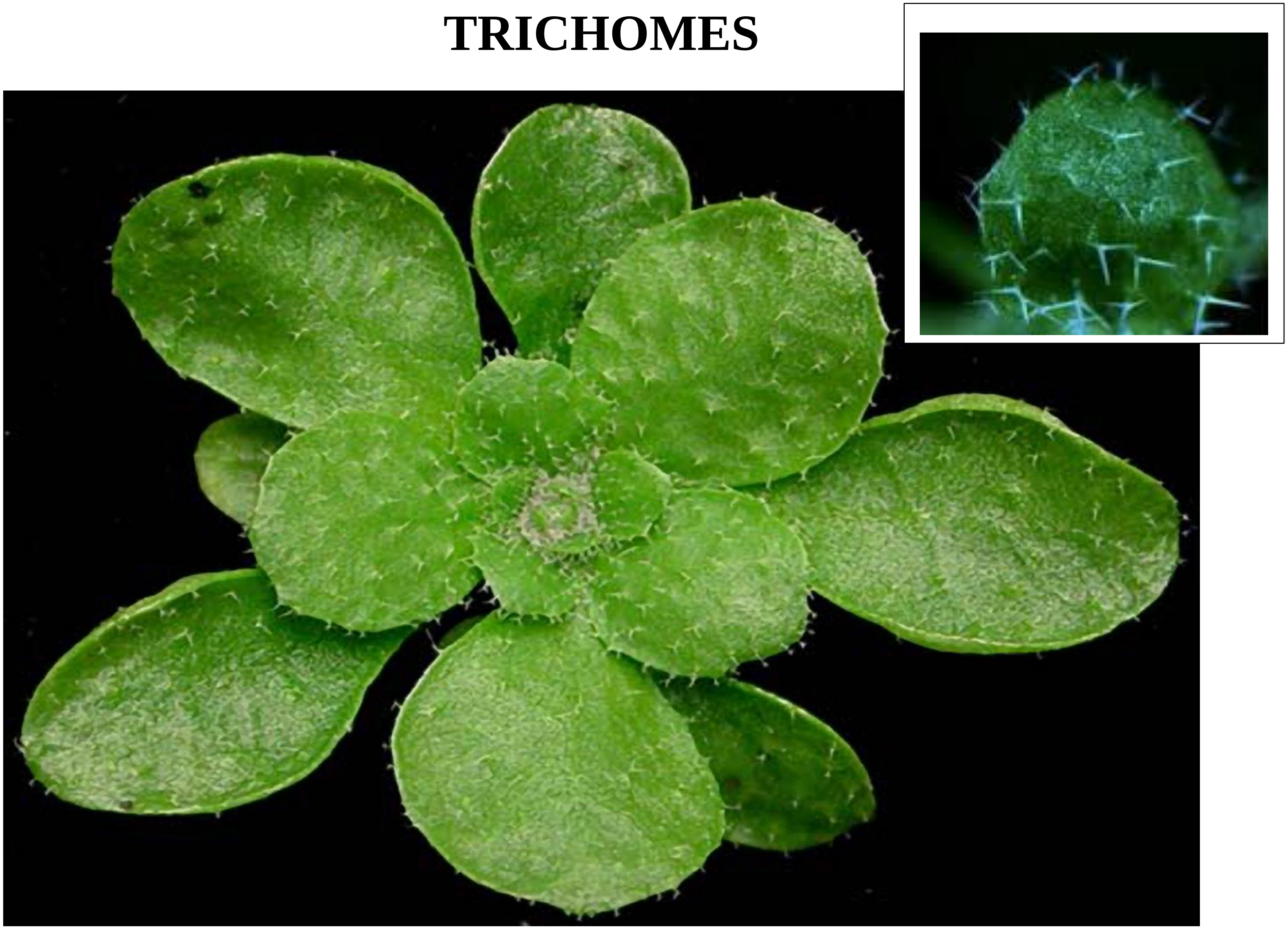
1. How can you differentiate between discrete and continuous traits?

2. Which type of traits support Mendel's Law of Segregation?

3. Which type of traits do not abide by Mendel's Law of Independent Assortment? Justify your answer.

4. Looking at your Arabidopsis plants, select one discrete trait and one continuous trait.

TRICHOMES



http://www.rawscience.tv/can-epigenetics-help-crops-adapt-to-climate-change-not-gmos/

Quantifying Trichomes Lab

Objectives

Counting trichomes on Arabidopsis RILs to determine if they contain continuous traits or not.

Pre-Lab Questions

1. Why would a plant have trichomes?

2. Could it be beneficial to have them in some environments over others?

3. Looking at your plants, would there be different numbers of trichomes on small leaves vs. larger leaves?

4. How can you investigate the answer to question #3?

Materials- Plants and magnifying glass

Procedures

1. Sit with your team in a designated area to count the trichomes from your assigned RILs
2. Make sure you count from ONE plant at a time.
3. Do not count the cotyledons –start with the first (**true** leaf in the plant)
4. Have another team member replicate your results (count again)
5. Record your results on the data table below
6. Graph your results using the **frequency distributions** of #RILs and Trichome # and interpret the data.

Analysis

1. Why do scientists collect data?

2. What tools do they use to make sense of the data or look for patterns?

3. Compare your results with another group. What are similar/different?

Data Collection Table

Team Names: ____ Date: ________________

RILs #	Assigned Pot #	Individual plant #	Trichome # (Count 1)	Trichome # (Count 2)	Trichome Agreed Upon #
	1				
	2				
				Average	

RILs #	Assigned Pot #	Individual plant #	Trichome # (Count 1)	Trichome # (Count 2)	Trichome Agreed Upon #
	1				
	2				
				Average	

Analysis continues: students will use graph paper to graph their results.

Math Tips: When data vary, but still fall within a common range, the average, mode, and range can be calculated. Average is already part of the data collection table. Mode is the number frequently stated. The range is highest number minus the lowest, which tell you how far the values are spread apart, and the variance describes the spread of the numbers.

Title: ___________________________

4. A bell-shaped curve show normal distribution frequency. What would a frequency distribution look like if a trait is discontinuous?

5. Continuous traits would have a frequency distribution reflecting wide ranges of numbers amongst the RILs. In contrast, discrete traits shows narrower ranges amongst the values. Based on your graph, are the traits discrete or continuous? How do you know?

6. Use this table to write the class average and graph the results

# of RILs	**Average of Trichomes**

7. Based on the patterns of these results what conclusions can you draw about the trichomes traits?

LESSON FOUR: LET'S SNP IT REAL GOOD!

KEY QUESTION(S): Can a single base-pair change really make a difference?

OVERALL TIME ESTIMATE:

- Advanced Preparation: 30-60 minutes
- Student Procedure: 90 minutes

LEARNING STYLES: Visual, auditory, and tactile

VOCABULARY:

SNP: **single-nucleotide polymorphism**, or **SNP** (pronounced "snip"). This is a single base-pair change in a segment of DNA—replacement of a C (cytosine) with a G (guanine).

Deletion: removal of one or more nucleotides from a DNA sequence, which may alter the reading frame

DNA: Deoxyribonucleic acid is a nucleic acid containing the genetic instructions used in the development and functioning of all known living organisms.

Insertion: addition of one or more nucleotides in a DNA sequence, which may alter the reading frame

Monozygotic: Twins that arise from a single ovum (egg).

Epigenetics: is the study of heritable changes in gene expression or above genetics. It refers to external modifications to DNA that turn genes "on" or "off." These modifications do not change the DNA sequence, but instead, they affect how cells "read" genes.

LESSON SUMMARY: Let's SNP it Real Good!
Technological advances have allowed scientist to make substantial progress in understanding different organisms' genomes. They have also studied genotyping in detail; however, there is still move discoveries to be made. In this lesson, students will extract and sequence DNA from the Arabidopsis plants. Using already established genome of the plant to determine the location of any SNPs. They will analyze their results and determine the significance of the SNPs to the plants' phenotype. They will apply the same knowledge to predict if such SNP existed in humans, what would be the phenotypic impact.

STUDENT LEARNING OBJECTIVES:

The student will be able to...

22. Extract DNA from Arabidopsis leaves
23. Simulate DNA sequencing using known genome
24. Align and analyze sequences to determine location of SNPs
25. Synthesizing information to make conclusions.
26. Apply scientific knowledge to make inferences
27. Explain the impact of biotechnology on society.

STANDARDS:

SC.912.L.16.10

SC.912.L.16.4

SC.912.N.1.6

MATERIALS:

- 1 copy of *Teacher Guide: Let's SNP It Real Good!*
- Envelope of Cut-out: *DNA Sequence (Reference and Alignment)*
- Handout: *Biotechnological Advances*
- Teacher Key: *DNA Sequence (Reference and Alignment)*
- Computer Access per team

BACKGROUND INFORMATION: Teachers are encouraged to read the Teacher guide and the student information prior to teaching Lesson Four. This lesson allows students to extract DNA and simulate sequencing to locate SNPs. Ensure that they are already previewed to the central dogma in biology.

ADVANCE PREPARATION:

3. Make copies of all the handouts
4. Prepare envelopes of Cut-out Arabidopsis genome (Made Up)
5. Explore the suggested website in the references for Lesson Four
6. Computer and Internet access are available

LET'S SNIP IT REAL GOOD!

Teacher Guide: Lesson Four

Teacher Background: Review the central dogma of biology.

Procedure and Discussion Questions With Time Estimates:

39. **(10 min)** Allow students to watch the first 7 mins of video clip and answer these questions. If time permits they can continue it later_it is about 14 minutes
    a. Does the environment has anything influence on our genetic makeup
    b. Should the other twin really worry about getting cancer?
    c. How can scientist amplify DNA?
    d. Can our behavioral choices impact our genes?
    e. How is epigenetics different from ecotypes from our previous lesson?
40. **(50 min)** Use the protocol that come with this kit to extract DNA from Arabidopsis https://www.thermofisher.com/us/en/home/life-science/dna-rna-purification-analysis/dna-extraction/genomic-dna-extraction/plant-dna-extraction.html.

    Or obtain what is needed from the UF lockers- to perform DNA extraction. If you are going to use lockers from UF, go through this list on the website for what you will need or contact CPET directly for assistance https://www.cpet.ufl.edu/teachers/sets/equipment-and-visit-requests/equipment-lockers/

    Also, you can use this kit to run the gel and show students the actual bands Modes of Inheritance kit: Carolina predigested DNA for use in agarose gels. Other lockers required: pipetting stations, E-Gels.

41. **(10 min)** Have students watch the video clip on SNPs, then pair-up for this activity: DNA sequencing and aligning with known reference genome (not the actual Arabidopsis genome of 137bp). Each pair will align their sequence and locate the SNPs after all teams have aligned their sequence. **How do they know there is a SNP?**

42. **(15 min)** Allow students to explore these websites and answer the questions on Handout

43. (**5 min**) Share out. Can change in single nucleotide cause a change in an organism?

ASSESSMENT SUGGESTIONS:

Handout: *Biotechnological Advances*

EXTENSIONS:

- Send DNA to be sequenced: Dr. Kirst volunteered to do it for my students. I will send the students' DNA after the whole lesson (data will be used the following year).
  Use Blast to align their results: http://blast.ncbi.nlm.nih.gov/Blast.cgi
- Use PCR to amplify the SNP.
- Using the information you have learned from reading this article about SNPs. Create a poster showing the significance of this discovery to developing new drugs to combat resistance. http://learn.genetics.utah.edu/content/pharma/snips/
- After learning about the four DNA testing available from the pbs.org (http://www.pbs.org/wgbh/nova/body/genetic-testing.html). Students will summarize the information using their words, and generate a five question survey per summary to gather data and create a graph of their results and write a concluding paragraph taking a stance and justifying it.
- Suggest Independent study with their developed Question from Lesson One.

RESOURCES/REFERENCES:

- Epigenetics: https://www.youtube.com/watch?v=xG8nt9OlODo
- DNA Extraction: https://www.youtube.com/watch?v=PgwWuTDaPd4
- SNPs: https://www.youtube.com/watch?v=tJjXpiWKMyA

Reference DNA

AGACGGTA CCTCCGGT GGGTGCTT GTCTGTAT CCTTCTCA GTATCCCT CTTTACACA

Students' sequences

TCTGCCAT GGAGGCCA CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCT CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAT CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATA GGAAGAGT CATAGGGT GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATG GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATG GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATG GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAA GGAGGCCA CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCC CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCC CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCC CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

Handout 1: Biotechnological Advances

Websites

http://learn.genetics.utah.edu/content/pharma/snips/

http://www.pbs.org/wgbh/nova/body/genetic-testing.html

Directions: After reading the information from these two websites. Answer the questions below

1. How can scientists use what they know about SNPs to develop better drugs?

2. The Nova website provided information on four DNA test. Summarize the contents of each test.

    a. Prenatal

    b. Gene Sequencing

    c. SNP

    d. Genome Sequencing

3. Which one would you choose to have done and why? If you choose not to do one, Why not?

4. What impact do these different tests have on society?

Reference DNA

AGACGGTA CCTCCGGT GGGTGCTT GTCTGTAT CCTTCTCA GTATCCCT CTTTACACA

Students' sequences

TCTGCCAT GGAGGCCA CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCT CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAT CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATA GGAAGAGT CATAGGGT GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATT GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATT GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATT GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

TCTGCCAT GGAGGCCA CCCACGAA CAGACATA GGAAGAGT CATAGGGA GAAATGTGA

RESOURCES

- Picture a: https://missingbrains.com/2013/10/24/how-it-works-mendelian-inheritance/
- Picture b. https://abrcoutreach.osu.edu/trained-educational-kits
- Picture c. https://en.wikipedia.org/wiki/Dominance_(genetics)#Co-dominance
- Picture d. http://evolution.about.com/od/Evolution-Glossary/g/Incomplete-Dominance.htm
- Picture e. http://www.thrombocyte.com/most-common-blood-type/
- Picture f. https://www2.estrellamountain.edu/faculty/farabee/biobk/BioBookhumgen.html
- Picture g. http://www.math.armstrong.edu/statsonline/3/ex3.b.3.html
- Genotype/Phenotype: https://www.youtube.com/watch?v=lal1aaf14PQ
- Mutations-Power of mutations: https://www.youtube.com/watch?v=GieZ3pk9YVo
- Genetics vs. Environment https://www.youtube.com/watch?v=y6rGht8s9E8
- ReadingWorks Vriation on Traits: http://www.readworks.org/passages/variation-traits
- Meiosis: https://www.youtube.com/watch?v=D1_-mQS_FZ0
- Meiosis and independent assortment: https://www.youtube.com/watch?v=-Zzp3mLIycM
- Crossing over and recombination: https://www.youtube.com/watch?v=pdJUvagZjYA
- Handout 1, 2,3: http://learn.genetics.utah.edu/content/pigeons/geneticlinkage/
- RILs: https://www.youtube.com/watch?v=SNvG_CqFvVY
- Two Types of Traits: *eebweb.arizona.edu/courses/ecol223/ECOL223%203-20.pdf*
- Epigenetics: https://www.youtube.com/watch?v=xG8nt9OlODo
- DNA Extraction: https://www.youtube.com/watch?v=PgwWuTDaPd4
- SNPs: https://www.youtube.com/watch?v=tJjXpiWKMyA
- CPET Lockers: https://www.cpet.ufl.edu/teachers/sets/equipment-and-visit-requests/equipment-lockers/

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McGuire, T. (2008) Introduction to the gene inheritance and transmission topic room. *Nature Education* 1(1):189

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Wyatt, S., & Ballard, H. E. (2007). Arabidopsis ecotypes: a model for course projects in organismal plant biology & evolution. *The American Biology Teacher*, *69*(8), 477-481.

STUDENT PAGES: CONTENT ASSESSMENT

Student name: ____________________________________ Date: ___________________

Part I. True/False: Write T or F in the blank next to each statement.

1. ___________Scientists have discovered that Mendel's law of independent assortment was completely wrong.
2. ___________Linked genes are in the same chromosomes
3. ___________Monozygotic twins or clones have the same genotype and phenotype
4. ___________Discrete traits can help scientist understand the varying degrees of the environmental effects on genes
5. _____________An organism's genome is made up of a few genes.

Part II. Short answer. Write your answer in the provided space.

6. Why is Arabidopsis a good model organism for genomic study? Give three reasons.

7. Can the environment change an organism's traits? Justify your answer.

8. Explain how gene linkage does not support Mendel's law of independent assortment. You can also draw a picture to show it.

9. In your lab on Quantify trichomes, why did you have a second or a third person count them?

10. Differentiate between discrete and continuous traits. You can draw a Venn diagram to show your answer.

11. Explain how to locate a SNP in a DNA sequence.

TEACHER ANSWER KEY: CONTENT ASSESSMENT

Student name: ______________________________________ Date: ____________________

Part I. True/False: Write T or F in the blank next to each statement.

1. __F________Scientists have discovered that Mendel's law of independent assortment was completely wrong.
2. _____T______Linked genes are in the same chromosomes
3. _____F______Monozygotic twins or clones have the same genotype and phenotype
4. _____F______Discrete traits can help scientist understand the varying degrees of the environmental effects on genes
5. _____F________An organism's genome is made up of a few genes.

Part II. Short answer. Write your answer in the provided space.

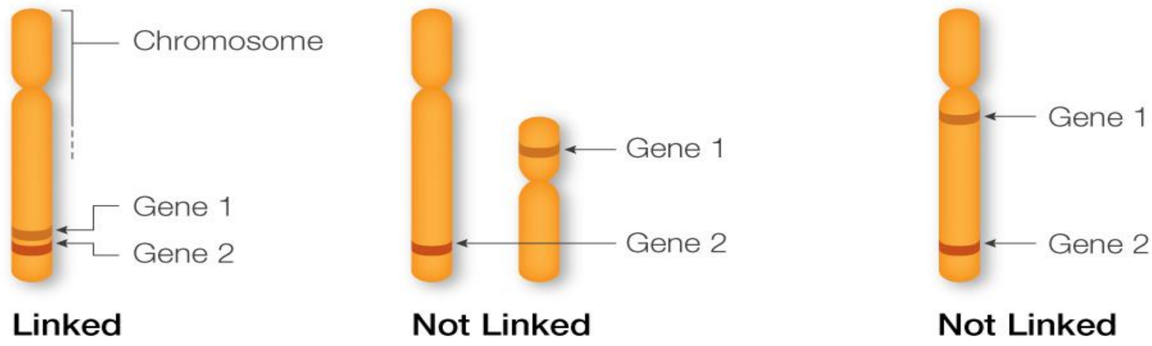
6. Why is Arabidopsis a good model organism for genomic study? Give three reasons.

Any three covered here

Approximately 115 Mb of the 125 Mb genome has been sequenced and annotated (Nature, 408:796-815; 2000).
Extensive genetic and physical maps of all 5 chromosomes are available.
The life cycle is short--about 6 weeks from germination to seed maturation.
Seed production is prolific and the plant is easily cultivated in restricted space.
Transformation is efficient utilizing Agrobacterium tumefaciens.
A large number of mutant lines and genomic resources is available.
A. thaliana is studied by a multinational research community in academia, government and industry.

7. Can the environment change an organism's traits? Justify your answer.
   Yes (Justifications may vary)
   Poor diet
   Fat contents
   Blood pressure etc.

8. Explain how gene linkage does not support Mendel's law of independent assortment. You can also draw a picture to show it.
If genes are linked, then the alleles are not assorted independently. These genes are inherited together.



9. In your lab on Quantify trichomes, why did you have a second and third person count them? It is standard practice to avoid errors-

10. Differentiate between discrete and continuous traits. You can draw a Venn diagram to show your answer.

-Discrete, or discontinuous, traits are controlled by a small number of genes, often only one.

-Generally have two alleles

-It is controlled, in part by the organism's collection of genes

-Continuous traits are controlled by multiple genes.

- Can also be influenced by environmental factors
-Show wide range of possibilities in characteristics

11. Explain how to locate a SNP in a DNA sequence. (answer may vary)-Blast
First a Known DNA genomic sequence is used as a reference
Then the sequenced DNA is aligned with that known sequence
If the single base nucleotide does not match the reference in the same location within aligned sequence, then a SNP is present.

CONTENT AREA EXPERT EVALUATION

Thank you for reviewing *The Beyond Seven* curriculum. Please review the entire curriculum and then complete the questions below. You are welcome to insert comments directly in the manual as well as in the section provided below. Comments and suggestions are greatly appreciated!

Reviewer name: ____

Date reviewed: ______________________ Email: ____________________________

Employer: ____________________ Department/Division: ______________________

Job title: ____

Part I: For each item below, please indicate your response to each question as it relates to the curriculum **overall** by circling Yes (Y), No (N), or Undecided (U).

Is the science content in the curriculum accurate?	Y	N	U
Is the science content in the curriculum current?	Y	N	U
Is the science content in the curriculum important for science literacy?	Y	N	U
Is the content in the curriculum related to major biological concepts? (e.g., molecular genetics)	Y	N	U
Is the content coverage in the curriculum thorough and complete?	Y	N	U
Are potential misconceptions adequately addressed?	Y	N	U
Is the content in the curriculum properly sequenced for a novice?	Y	N	U
Are there additional concepts that should be included? (If yes, please elaborate below.)	Y	N	U

Part II: Please include below any comments or suggestions about the curriculum.

1. GENERAL COMMENTS ABOUT THE OVERALL CURRICULUM ________________

____

____

____

____

____

____

____

2. COMMENTS REGARDING INDIVIDUAL LESSONS

Lesson 1: I THINK THEREFORE I AM.	
Lesson 2: ON SHOULDERS OF GIANTS: LINK WHAT?	
Lesson 3: WILD THING: WHAT’S YOUR DIGITS?	
Lesson 4: LET’S SNP IT REAL GOOD!	

TEACHER FEEDBACK FORM

Thank you for reviewing *The Beyond Seven* curriculum. Please review the entire curriculum and then complete the questions below. You are welcome to insert comments directly in the manual as well as in the section provided below. Comments and suggestions are greatly appreciated!

Teacher name: ____

Subjects taught: ______________________________ Grade levels taught: ____________

School: ______________________________ Email: ______________________________

Part I: Evaluation of the entire curriculum

Section A: For each item below, please indicate your response to each question as it relates to the curriculum **overall** by marking Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D), or Strongly Disagree (SD).

	SA	A	U	D	SD
1. Are the experimental procedures appropriate for your students?					
2. Are the topics addressed important for your course objectives?					
3. Are the topics addressed relevant to your students' lives?					
4. Are the topics addressed interesting to your students?					
5. Is the depth of coverage of topics appropriate?					
6. Is the overall quality of the curriculum satisfactory?					
7. Is the content in the curriculum properly sequenced?					
8. Is the content in the curriculum adaptable for a range of student ability levels?					

Section B: Please provide additional comments pertaining to the laboratory manual **overall**.

1. Are there any topics/sections that should be added to/deleted from the curriculum? If so, please explain. _____

____

____

____

2. Additional comments ____

____

____

____

Part II: Evaluation of individual lessons - Section A: For each question below, please indicate your response for each **specific lesson** by marking High, Moderate, Low, or Not Applicable (NA).

	Lesson 1: I Think Therefore I Am.				**Lesson 2: On Shoulders of: Link what?**				**Lesson 3: Wild Thing: What's Your Digits?**				**Lesson 4: Let's SNP It Real Good!**			
	High	Mod-erate	Low	NA	High	Mod-erate	Low	NA	High	Mod-erate	Low	NA	High	Mod-erate	Low	NA
1. Is the amount of teacher background information sufficient?																
2. Do the time estimates seem reasonable?																
3. Is the amount of advance preparation reasonable?																
4. Is the procedure clearly stated?																
5. Is the suggested assessment sufficient?																

Section B: Please provide additional comments pertaining to each specific lesson.

Lesson	**Are there any topics, sections, or resources that should be added or deleted? If so, please explain.**	**Additional comments**
Lesson 1: I Think Therefore I Am.		
Lesson 2: On Shoulders of Giants: Link What?		
Lesson 3: Wild Thing: What's Your Digits?		

Lesson 4: Let's SNP It Real Good!		

STUDENT FEEDBACK FORM

Student name: ______________________________ Date: ________________ Student grade level: _________________ Circle one: Male Female

School name: _______________________________ Teacher's name: ____________________________ Subject: ______________________

Section A: Evaluation of individual lessons- For each question below, please indicate your response for each **specific lesson** by marking High, Moderate, Low, or Not Applicable (NA).

	Lesson 1: I Think Therefore I Am.				**Lesson 2: On Shoulders of Giants: Link What?**				**Lesson 3: Wild Thing: What's Your Digits?**				**Lesson 4: Let's SNP It Real Good!**			
	High	Mod-erate	Low	NA	High	Mod-erate	Low	NA	High	Mod-erate	Low	NA	High	Mod-erate	Low	NA
1. Is the amount of background information sufficient?																
2. Do you feel you were provided adequate advance instruction?																
3. Were you provided enough time to complete the lesson?																
4. Is the procedure clearly written?																

Section B: Please provide additional comments pertaining to each specific lesson.

Lesson	Are there any topics, sections, or resources that should be added or deleted? If so, please explain.	Additional comments
Lesson 1: I Think Therefore I Am.		
Lesson 2: On Shoulders of Giants: Link What?		
Lesson 3: Wild Thing: What's Your Digits?		
Lesson 4: Let's SNP It Real Good!		