Teacher Preparation Notes for
Dragon Genetics -- Independent Assortment and Genetic Linkage

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This activity is designed for students who already understand mitosis, meiosis, fertilization, and basic genetics. Useful activities for introducing these topics are "Mitosis, Meiosis and Fertilization" and "Genetics", both available on this web site.

We recommend that you allot two 50-minute periods for this activity, the first for the law of independent assortment (pages 1-6 of the student handout) and the second for genetic linkage and discussion (pages 7-10). Alternatively, you may want to cover pages 1-5 in the first period and pages 6-10 in the second period (when you could finish the law of independent assortment, cover genetic linkage, and have a brief discussion).

Teaching Points

- The inheritance of multiple genes can be predicted by understanding the behavior of chromosomes during meiosis and fertilization.
- The Law of Independent Assortment states that, if two genes are on different chromosomes, then the alleles for these genes separate independently of each other during the formation of eggs or sperm. Therefore, the traits determined by these two genes are inherited independently.
- Genetic linkage occurs because genes that are located near each other on the same chromosome move together during meiosis and fertilization.
- Inheritance in real animals and plants is much more complex than the examples in this hands-on activity.

Preparation of Popsicle Stick Chromosomes

Each popsicle stick represents a pair of homologous chromosomes, with the alleles of one of the homologous chromosomes on one side of the popsicle stick and the alleles of the other homologous chromosome on the other side of the popsicle stick. The appropriate alleles can be written directly on each side of the popsicle stick.

For the Law of Independent Assortment activity, each student will need two popsicle sticks, representing the two pairs of homologous chromosomes for the mother. One popsicle stick will have a **W** on one side of the popsicle stick and a **w** on the other side, representing the heterozygous wing genes. The other popsicle stick will have a **H** on one side of the popsicle stick and an **h** on the other side of the popsicle stick, representing the heterozygous horn genes. You may want to use different color popsicle sticks for the **Ww** vs. **Hh** chromosomes.

For the Genetic Linkage activity (especially 3 on page 8 of the student handout), students may find it useful to have a set of four popsicle sticks, two representing the two pairs of homologous chromosomes in the heterozygous father and two representing the two pairs of homologous chromosomes in the homozygous mother. For the father, the first popsicle stick will have **W F N** on one side and **w f n** on the other side (see page 7 of the student handout). The second popsicle stick will be the same as for the previous activity, with **H** on one side and **h** on the other. For the mother, the first popsicle stick will have **w f n** on both sides, and the second popsicle stick will have **h** on both sides.

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[1] These teacher preparation notes, the related student handout, and multiple additional activities are available at http://serendipstudio.org/sci_edu/waldron, with additional activities available at http://serendipstudio.org/exchange/bioactivities.

Discussion

The Law of Independent Assortment activities help students to understand that genes located on two separate chromosomes are inherited independently. First, the basis for understanding the Law of Independent Assortment is developed by analyzing expected outcomes of meiosis and fertilization. Then, a simulation of the Law of Independent Assortment is provided by a hands-on activity which uses popsicle sticks to simulate the behavior of two pairs of homologous chromosomes during meiosis 1, with modified Punnett squares to tabulate the genotypes and phenotypes of the resultant fertilizations. The questions on page 5 guide the students to interpret the results of the simulation in terms of the expected outcomes of meiosis and fertilization. Sometimes (particularly if you have a small class), the results of the simulation differ substantially from the prediction (question 3 on page 5); this provides a good opportunity to discuss random variation in small samples (see discussion in our Genetics activity on this website). The last part of this first activity (question 4 on page 6 of the student handout) illustrates one application of the Law of Independent Assortment to human genetics, namely, that both sexes are equally likely to inherit an autosomal genetic condition such as sickle cell anemia.

The second activity illustrates genetic linkage (without crossing over) and contrasts patterns of inheritance for closely linked genes (e.g. no new combinations of alleles) vs. independent assortment.

In both activities, one of the parents is homozygous recessive so that the genotypes of the gametes of the other parent have a clear effect on phenotypic characteristics (similar to the use of a homozygous recessive individual in making a test cross). Thus, these activities can be used to reinforce the test cross concept.

If you would like more background information, we recommend that you read a good basic introduction to genetics such as pages 251-8 and pages 274-9 in Biology, seventh edition, by Campbell and Reece.

Sources to help students understand the discussion question topics at the end of the student handout include:

- extension worksheet shown on the next page to understand inheritance of genes located far apart on the same chromosome
- our activity, Using Blood Tests to Identify Babies and Criminals, to learn about co-dominance and incomplete dominance
- multiple genetics activities available at http://serendipstudio.org/exchange/bioactivities

Possible Extension

Due to time limitations, this activity helps students to understand Independent assortment and genetic linkage for two genes located very close together on the same chromosome, but it does not investigate genetic recombination due to crossing over between two genes located further apart on the same chromosome. The **worksheet shown on the next page** helps students to understand genetic recombination and asks students to compare and contrast the different outcomes for inheritance of two genes, depending on their locations on the same or different chromosomes.

Inheritance of Genes Which Are Further Apart on the Same Chromosome
When genes are very close together on the same chromosome, inheritance of these genes displays genetic linkage, since closely linked alleles will move together during meiosis and fertilization. The further apart two genes are on the same chromosome, the more likely it is that crossing over will occur between these genes during meiosis. Crossing over can result in genetic recombination for the alleles of these genes.

To illustrate the effects of crossing over, we will consider the inheritance of two genes which are relatively far apart on human chromosome 11. The table below summarizes the proteins produced from two common alleles for each gene.

Allele		**Protein**		**Allele**		**Protein**
S	→	normal hemoglobin		**A**	→	normal enzyme for melanin production
s	→	sickle cell hemoglobin		**a**	→	defective enzyme for melanin production

Fill in the phenotypes in the following table.

Who	Chromosome 11	Phenotype
Mother	(**s** | **a** |) (**s** | **a** |)	
Father	(**S** | **A** |) (**s** | **a** |)	
Baby	(**S** | **a** |) (**s** | **a** |)	

For the baby's chromosomes, indicate which parent contributed each chromosome.
Explain how the first chromosome was produced.

Complete the following table to summarize your understanding of the inheritance of two genes, depending on their locations on the same or different chromosomes.

Location of two genes	Indicate which of the following influences inheritance of each pair of genes: crossing over genetic linkage independent assortment	Are alleles for these two genes inherited independently of each other?
Very close together on the same chromosome		
Far apart on the same chromosome		If the genes are sufficiently far apart, their alleles will be inherited independently.
On different chromosomes		