NAME: ______________________________________ DATE: _______________ HOUR: _____

Biology

INTRODUCTION TO MENDELIAN GENETICS

*Read the following article describing Gregor Mendel's contributions to the science known as genetics. Answer the questions along with the reading and follow the instructions in **bold type** to complete the coloring.*

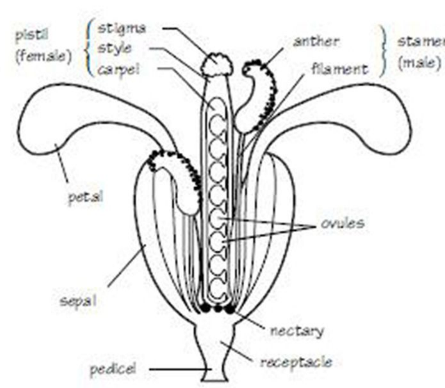
Genetics is the branch of biology that studies how hereditary traits are passed from one generation to the next. Even in ancient times it was already well known that in plants as well as in animals, the offspring of a pair of parents tends to show a highly variable mixture or blending of the traits of the parents, frequently a great deal more from one parent than from the other.

By the middle of the nineteenth century the process of plant hybridization (crossbreeding) was in common use, and a number of scientists had carried out large numbers of experiments that also pointed to a variable blending that seemed to follow no rules. But in 1865 the first reliable laws of heredity were announced by Gregor Mendel, a monk in an Augustinian monastery in Austria. Although Mendel reported his findings at a meeting of scientists and published those findings the following year in a scientific journal with an extensive international circulation, it was not until 1900, after Mendel had been dead for a number of years, that other biologists recognized the validity of his results.

1. **True or False.** Until Gregor Mendel, no one realized that offspring show a mixture of traits from their parents. ____________________

2. **True or False.** Mendel's work was not recognized by other scientists because he did not publish his experimental results for other scientists to see. ____________________

In beginning the study of genetics, it is well worth taking a close look at Mendel's actual experiments. They have such an elegant simplicity that they provide one of the easiest ways to be introduced to genetics as well as a superb opportunity for a look at how scientific investigation should be designed. At the time of his experiments, Mendel was a teacher in an agricultural and technical college and he did his experiments in his spare time with pea plants. Let us look first at the general approach to all kinds of plant hybridization before examining Mendel's experiments in the paragraphs that follow.



Most people are familiar with petals, which give flowers much of their color; hay fever sufferers are certainly familiar with pollen, which is the immediate cause of their discomfort. **Pollen** contains the male reproductive cells and is produced in a structure called the anther, located on the end of a long filament. The filament and anther are known collectively as a stamen. In the center of the flower is the pistil, the expanded base of which is called the ovary. The ovary contains one or more ovules, each of which produces an **egg** cell. If the egg cell is fertilized by pollen, it grows into an **embryo** plant within a seed. The extension of the ovary is called the style, and its tip is called the stigma. For reproduction to occur, pollen must land on the stigma. In some plants, it is enough for it to land on the stigma of the same flower; other plants are self-sterile, and the pollen must be carried to the stigma by wind, insects, or other animals from a different plant of the same species.

When the pollen grain contacts the stigma, it germinates to form a pollen tube, which then grows longer and longer and migrates down through the tissues of the stigma and style and enters the ovary. One of the three cells in the pollen tube then unites with the egg cell in the ovule to form the **zygote**, or fertilized egg, which then grows and divides to form the embryo plant of the next generation.

To form a hybrid between two plants with different traits, all that is necessary is to remove the stamens from the flowers of one plant before the pollen is mature and later transfer mature pollen from another plant to the stigma of the stamenless flower. Every effort must be made, of course, to prevent wind or insects from transferring unwanted pollen to the experimental flowers. The resulting seeds can be planted, and the **hybrid** offspring from this “cross” can be observed in the following growing season.

3. In plants, the male gamete is called ____________________.
4. In plants, the female gamete is called a(n) ____________________.
5. Another name for a plant embryo would be a(n) ____________________.
    a. pollen
    b. egg
    c. seed
    d. fruit
6. What two things need to combine in plants to form a zygote? ______________________________.
7. Define the term **hybrid** in your own words.

It is clear that Mendel’s success where others had failed was not just the result of good luck. The introduction to his published report shows that he was familiar with the work of other scientists and recognized what mistakes they made:

> “Whoever surveys the work in this field will come to the conviction that among the numerous experiments not one has been carried out to an extent or in a manner that would make it possible to determine the number of different forms in which hybrid offspring appear, permit classification of these forms in each generation with certainty, and ascertain their numerical relationships.”

In this paragraph we see Mendel performing what many great scientists have emphasized is the most important step in a scientific investigation: making a clear statement of the experimental questions. He didn’t phrase it as a question, with a question mark at the end, but he did state exactly what answers his experiment should provide.

Mendel correctly recognized that the experiment needed to answer two essential questions: (1) how many different kinds of offspring result and (2) how many are produced of each kind? He also recognized that the choice of the plant group for the experiments was an important one. He wrote:

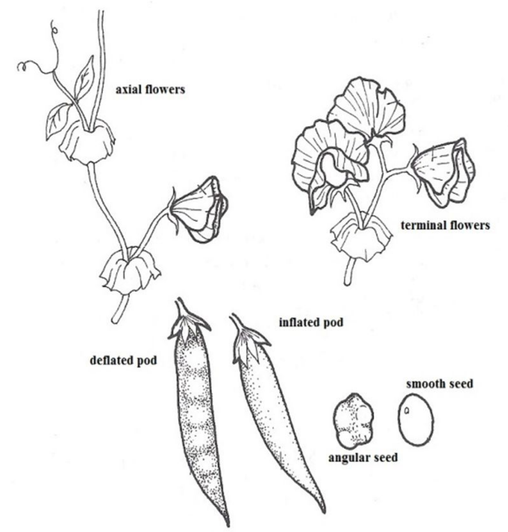
1. [The experimental plants must necessarily] possess constant differing traits.
2. The hybrids must be protected from the influence of all foreign pollen during the flowering period or easily lend themselves to such protection.
3. There should be no marked disturbance in the fertility of the hybrids and their offspring in successive generations.

Since Mendel grew up on a farm, he was very familiar with peas. He began with a number of different varieties, but in keeping with his requirement of “classification with certainty,” he rejected many characteristics that differed from one another only on a “more or less” basis and settled on seven pairs of traits that always showed up as either one thing or the other.

8. **True or False**. Scientists before Mendel had investigated the inheritance of traits. _____________
9. **True of False**. Mendel used the mistakes made by other scientists to improve his own experiments. _____________________
10. **True or False**. A successful genetic experiment with plants must include a way to control the source of pollen used in fertilization. ____________________

Mendel knew that peas had a flower structure that prevented **cross-pollination**. The reproductive parts of the pea flower are completely enclosed by the petals. Before the flower even opens, the anthers burst and dust pollen all over the stigma. Thus unless an insect (or a scientist) interferes, **self-pollination** is virtually certain.

Pea flowers are always either purple or white; there is no blending of those traits, which are clearly hereditary. A given plant produces only purple flowers or only white flowers. Mendel chose the other traits for his experiments to have the same sharp differences. On any given plant, all the flowers are axial (growing out of the axil, the junction where a leaf grows out of a stem) or terminal (growing out of the end of a stem). In height, pea plants are always either tall (over 2 meters) or dwarf (less than 1 meter). Medium-tall or semi dwarf pea plants never occur. Seeds are either green or yellow and either smooth or angular (wrinkled). The pods in which the seeds grow are either green or yellow and either inflated or deflated (constricted or wrinkled). Each of these traits is distinct from its opposite, and there is never an in-between state.



11. Describe the difference between cross-pollination and self-pollination.

12. **True or False.** One key to Mendel's success was his choice of traits with only two distinct versions, such as tall or dwarf. ____________________
13. Listed below are the seven traits Mendel chose to investigate in his pea plants. List the two possible versions for each of these traits on the lines below.

    Flower color: ____

    Flower position: ____

    Plant height: ____

    Seed color: ____

    Seed shape/texture: ____

    Pod color: ____

    Pod shape/texture: ____

Another key to Mendel's success was his decision to begin his experiments with plants that were **pure-breeding**, that is, would produce nothing but the same trait generation after generation. Other investigators had merely cross-pollinated thousands of plants without paying attention to this. Mendel clearly recognized in advance what his experiments ultimately proved, that some hereditary traits that do not show at all in one generation of plants might be carried in invisible form and passed on to show up in the next generation.

To be sure that all his batches of seeds were really pure-breeding, Mendel planted them in different parts of the garden and allowed them to self-pollinate for two successive years. (Sure enough, some did not breed true and had to be discarded.) Once he was sure he had only pure-breeding strains, he cross-pollinated each strain with its opposite – tall with dwarf, white flower with purple, and so on.

On the "Flower Color Hybrids Image" color the heading P Generation and titles A, B, and C and their representations at the top of the page. Use purple, blue, or another dark color for "A" and leave the items labeled "B" white. Choose a different color for "C".

The image on the next page shows one of Mendel's experiments in which he cross-pollinated purple flowered plants with white-flowered plants. To determine if pollen, or ovule were more important in transmitting heredity, all his crosses were made by pollinating in both directions: plants with purple flowers were pollinated with pollen from plants with white flowers, and plants with white flowers were pollinated with pollen from plants with purple flowers. He found that no matter which parent contributed the pollen, the results were the same. (The symbol P in the plate is commonly used today to indicate the parental generation and F_1 the first generation of offspring – called the first filial generation, from the Latin word for "son" or "daughter").

On the "Flower Color Hybrids Image" color the heading F_1 Generation and the associated illustration. Use the same colors as those you used in the P Generation.

A peculiar thing happened in the first generation of offspring. Among the offspring, only one trait of each pair showed up. The opposite trait just vanished. Although plants with purple flowers had been crossed with plants with white flowers, all the F_1 plants had only purple flowers. Even this, however, was nothing new. Other investigators had done similar experiments, including some with pea plants, and had obtained similar results. But Mendel had the genius to select a species of plant that produced fertile hybrids, so he was able to allow the F_1 plants to self-pollinate and produce an F_2 (second filial) generation, which he could also observe.

On the "Flower Color Hybrids Image" color the heading F_2 Generation, title D, and the associated illustration. Use the same colors as those you used in the P Generation and F_1 Generation. You will need a new color for title D.

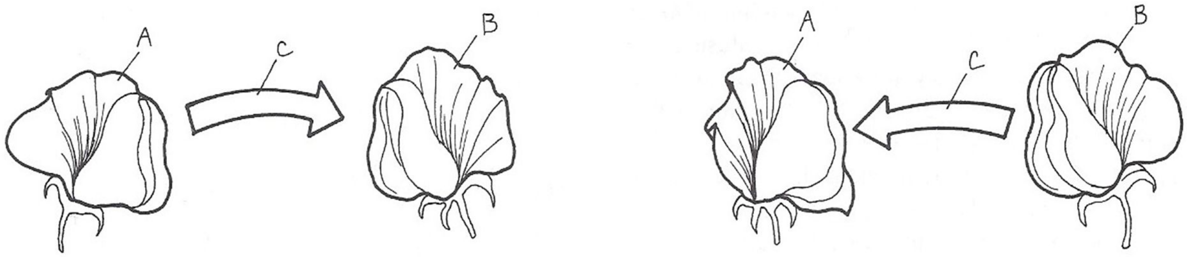
14. Define the term **pure-breeding** in your own words.

15. How did Mendel produce his P generation?

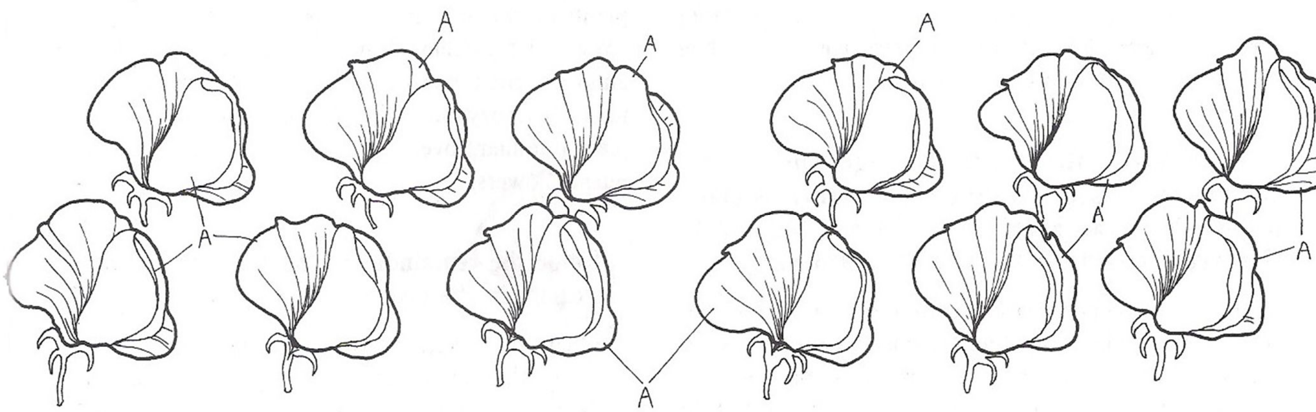
16. How did Mendel produce his F_1 generation?

FLOWER COLOR HYBRIDS.

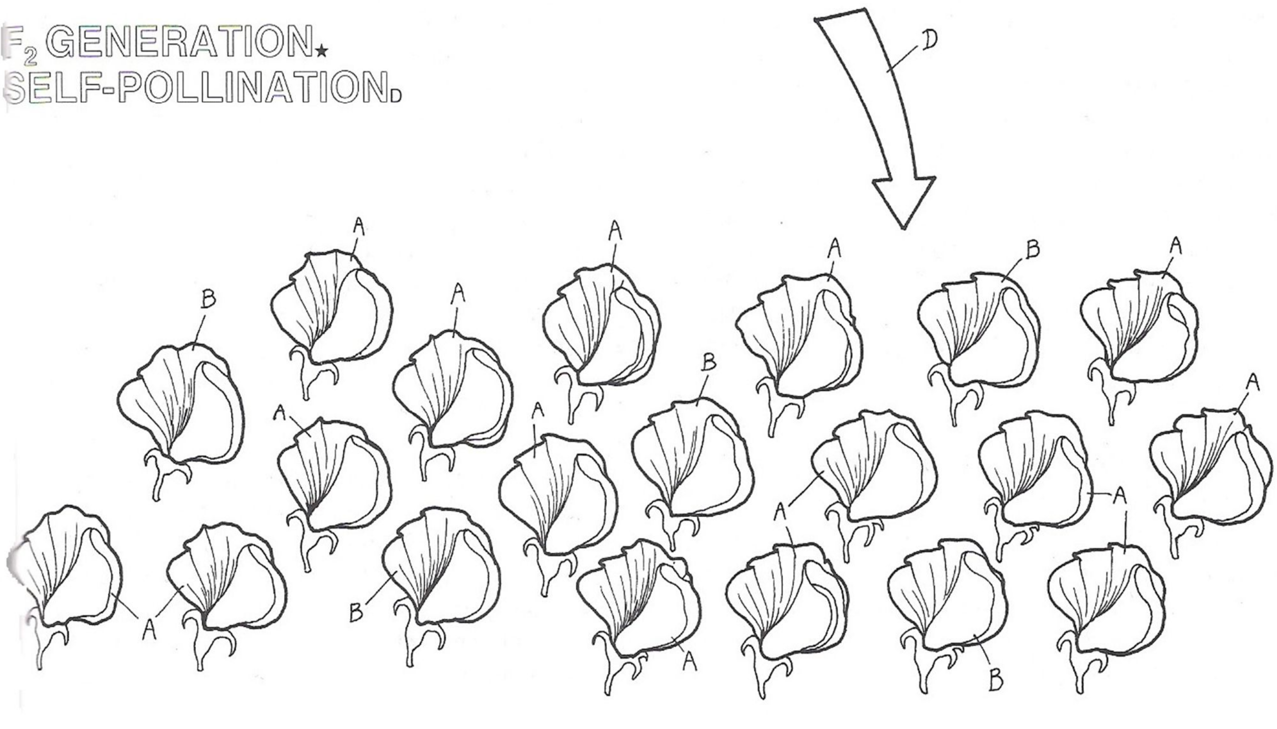
P_1 GENERATION★
PURPLE FLOWER A
WHITE FLOWER B
CROSS-POLLINATION C



F_1 GENERATION★



F_2 GENERATION★
SELF-POLLINATION D



When the hybrid plants of the F_1 generation were allowed to self-pollinate, they produced an F_2 generation with the proportion of flower colors shown here. Of 929 plants, 705 had purple flowers and 224 had white flowers. Because of his mathematical approach, Mendel recognized what no one else had recognized in similar cases, that this was a ratio of almost exactly 3 to 1. His results with the other pairs of traits he studied were almost identical, as shown in this table:

P Cross	**F_1 Generation**	**F_2 Generation**
Purple flowers x white	All purple	705 purple, 224 white
Axial flowers x terminal	All axial	651 axial, 207 terminal
Tall x dwarf	All tall	787 tall, 277 dwarf
Yellow seed x green	All yellow	6022 yellow, 2001 green
Round seed x angular	All round	5474 round, 1850 angular
Green pod x yellow	All green	428 green, 152 yellow
Inflated pod x deflated	All inflated	882 inflated, 229 deflated

This table shows that actual numbers of plants and seeds that Mendel counted. (You can see he was a thorough fellow.) In each case, one trait vanished in the F_1 generation and then reappeared in the F_2, though in much smaller numbers. Mendel applied the term "**dominant**" to the trait that was visible in the F_1 and the term "**recessive**" to the trait that disappeared from sight in the F_1 but reappeared in the F_2. For each pair of traits, Mendel calculated the ratio of dominants to recessives in the F_2 generation and found all of them to be very close to 3:1.

17. How did Mendel produce his F_2 generation?

18. Define the term **dominant** in your own words.

19. Define the term **recessive** in your own words.

To explain the results of his experiments, Mendel proposed certain hypotheses. First, hereditary traits must be passed from one generation to the next as separate units, rather than by some variable sort of blending. (Today these elements are known as genes.) Second, each individual plant must have a pair of these genes for each characteristic, one of them received from each parent. Third, when an individual has two conflicting genes, one dominates the other. (There are exceptions to this, but not among the traits Mendel studied.)

To illustrate how the experimental results could be produced, Mendel symbolized dominant genes with capital letters, such as "P," and recessive genes with small letters, such as "p."

The term "**phenotype**" is used to designate the observable or detectable traits of an organism being studied, as opposed to its "**genotype**," which is the set of genes that produced that phenotype. In the previous image, one plant had the phenotype of purple flowers while the other one had the phenotype of white flowers. (Be aware, however, that phenotype is really the result of both the genotype and the environment. Flower color is not easily influenced by the environment, but many traits are.) Since Mendel made certain that the plants he started with were pure-breeding for their respective traits, each of the P plants must have had two genes of the same kind. Today we would say they are "**homozygous**" (Greek: *homo*, "same"; *zygos*, "yoked" or "joined"). One is **homozygous dominant** (PP), while the other is **homozygous recessive** (pp).

20. **True or False.** An example of a phenotype would be brown hair. ____________________

21. **True or False.** The term homozygous recessive describes an organism's phenotype. __________

22. List the letters or alleles that would represent each of the following genotypes. Use the letter B.

    homozygous dominant: __________

    homozygous recessive: __________

    heterozygous: __________

This section illustrates the fourth hypothesis Mendel made to explain his results: in the formation of pollen and ovules (today known collectively as gametes), the genes of each pair "segregate" into different gametes so that any gamete has only one gene of each pair. This fourth hypothesis is known as "**Mendel's first law**" or the "**law of segregation**." We see that because segregation, each gamete of the homozygous purple-flowered plant has only one gene for flower color (purple), and each gamete or the homozygous white-flowered plant has only one gene for flower color (white).

When two gametes fuse to form a new individual, the genes will be in pairs once again and will remain so as cell division occurs again and again to produce the mature plant. Here we see that cross-pollination of these particular plants results in F_1 individuals that all have one gene for purple flowers and one gene for white flowers. Such individuals are said to be "**heterozygous**" (Greek: *hetero*, "other"). Since purple is dominant over white, all of them will produce only purple flowers.

When the heterozygous F_1 individuals produce gametes, the paired genes once again segregate so that each gamete contains only one gene of the pair. Half of the gametes will contain a gene for the dominant trait (P), and half will contain a gene for the recessive trait (p). When the F_1 plants are allowed to self-pollinate, four combinations are possible. The most error-free way of keeping track of these combinations is by means of a "Punnett square," named after its inventor, Reginald Punnett, an eminent British geneticist of the early 1900s. The gametes of one parent are listed along the top margin and the gametes of the other along the side margin. Then each possible combination of one gamete from each parent is written in the square where the appropriate column and row intersect. These combinations of genes are the genotypes of the F_2 generation. Since there are two different ways of getting one gene of each kind, half of the F_2 plants are heterozygous. One-fourth (1/4) of them are homozygous dominant, and one-fourth are homozygous recessive. If you toss two coins 100 times and keep track of the resulting combinations of heads and tails, you will get approximately the same 1:2:1 ratio. With peas, however, purple is dominant over white, so the phenotypic ratio is three purple to one white.

23. True or false. Mendel's law of segregation describes the events that occur during anaphase I of mitosis. ____________________

	P	p
P	PP	Pp
p	Pp	pp

24. What do the letters to the left and on top of the Punnett square represent?

25. What do the letters inside the boxes of the Punnett square represent?