Who’s The Father?

Investigating Mendelian Genetics with Wisconsin Fast Plants™
One Gene (Monohybrid)

Grade Level: 5—12
Catalog Number:

The Mother
Non-Purple Stem

The Offspring
Purple Stem

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Introduction

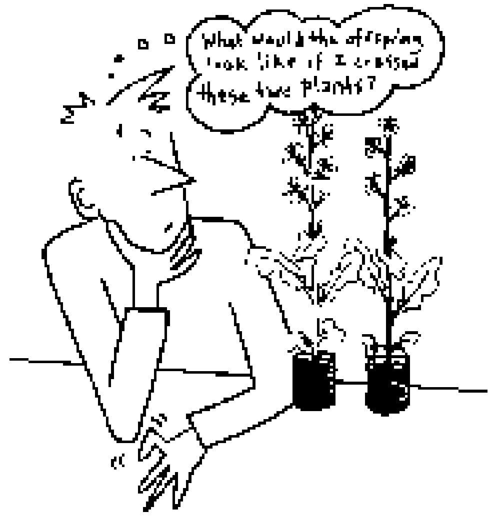
The Investigation: Who's the Father?

Who's the Father? *was designed in collaboration with the Wisconsin Fast Plants Program at the University of Wisconsin - Madison. Special thanks to: Dan Lauffer, Paul H. Williams, and Coe Williams (Wisconsin Fast Plants Program); Lisa Darmo and Kathy Douglas (Carolina Biological Supply Company).*

Written by Sarah Lauffer and illustrated by Amy Kelley. For more information about Wisconsin Fast Plants™, go to www.fastplants.org or www.carolina.com/fastplants. See back page for ordering information.

Who's The Father?

How are traits passed from one generation to the next?



Since the dawn of agriculture, humans have been trying to improve and increase their food supply. Historically, this was done by selecting the best plants and animals, then breeding them to get the tastiest, hardiest, most nutritious, or most appealing offspring. But no one really understood how these traits were inherited. Many people believed that traits "blended" in the offspring, or that only one parent passed a trait on to its offspring.

In the mid-1800's, a monk named Gregor Mendel gathered evidence that began explaining how inheritance works. Mendel studied discrete and contrasting traits. For example, the traits that he explored in pea plants included tall vs. short plants and purple vs. white flowers. His careful, repetitious work yielded two principles of genetics: the **Law of Segregation** and the **Law of Independent Assortment**.

In this investigation, students will gather their own evidence to explain how inheritance works. As they observe three generations of Wisconsin Fast Plants™, students will unravel a mystery of paternity: What is the father's phenotype? Is it the same as the mother's phenotype or the offspring's phenotype? Or is it something entirely different? As the generations of plants grow, students will make observations that will serve as evidence to support or refute their explanations about the inheritance of a trait.

The Investigation

This investigation spans the entire life cycle of the first-generation plants (F_1); an additional nine days allow students to observe the second-generation offspring (F_2) and the father generation (P_2). *Who's the Father?* is designed to provide students with the opportunity to investigate the inheritance of a single gene in Wisconsin Fast Plants™. The anthocyaninless gene (*anl*), determines whether the stem color of each plant will be purple or non-purple.

To ensure success of the plants — and to optimize conditions for expression of the genetic traits used in this investigation — it is important that you carefully follow the enclosed *Wisconsin Fast Plants™ Growing Instructions* booklet.

Objectives

At the end of this activity, students will be able to:

- Explain the inheritance of two genes
- Observe Mendel's Law of Segregation
- Identify and quantify the phenotypes that are conditioned by a single gene
- Use scientific skills effectively

Life Science Standards

Met by the Objectives of Who's the Father?

- Reproduction and heredity

Materials

The following materials are included with the *Who's the Father?* Kit.

Each kit contains enough materials for 8 groups of 2–4 students.

Written Materials

- *Who's the Father?* Book, which includes: a detailed life cycle description (pages 8–9), a Teacher's Schedule of observation days and plant care (page 10), and Student Notebook Pages (pages 11-13).
- *Wisconsin Fast Plants™ Growing Instructions*

Wisconsin Fast Plants™ Materials

- Wisconsin Fast Plants™ seeds
  Seeds of three generations are included:
    - Non-Purple Stem (P_1)
    - Purple Stem (P_2)
    - F_1 Non-Purple Stem
- 8 growing systems
  Each growing system includes:
    - 1 Circular watermat
    - 1 Long watermat wick
    - 1 Small container
    - 1 Large container (reservoir)
    - 4 Pots
    - 4 Small blue watermat wicks
- Potting mix
- Fertilizer
- Stakes and ties
- Labels

Materials that you may need to supply or order separately

- Plant Light House or Plant Light Bank (Purchase through Carolina Biological Supply Company, Catalog Numbers 15-8997 and 15-8998) or make your own (see **www.fastplants.org** for instructions)

Time Requirements

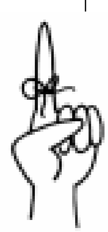
- **It is recommended (but not necessary) that you begin this activity on a Monday.**

- **Total days to complete the activity: About 53**
  The F_1 generation will complete the full Wisconsin Fast Plants™ life cycle, which is approximately 40–45 days. An additional nine days allows students to observe the second-generation offspring (F_2) and the father generation (P_2). The actual time of this exploration may vary, depending on the environmental conditions in each classroom.

- **See detailed Teacher's Schedule on page 10.**

  Observation days—Students tend the plants, make observations, and record their observations on the Student Notebook Pages. On these days, plan 10-30 minutes.

  Twice a week—Verify that there is enough nutrient solution in the plant reservoirs (especially before a weekend), and that the plant tops are 10 cm below the lights.



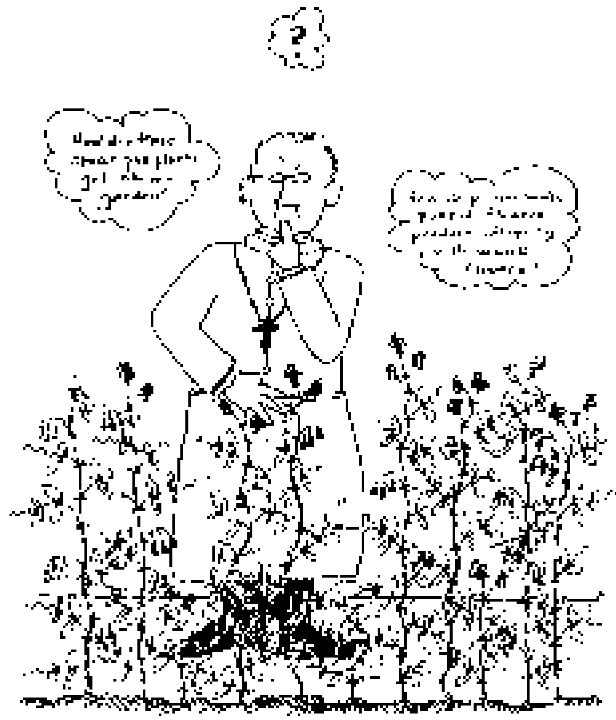
Successful Wisconsin Fast Plants™ require continuous water, fertilizer, and fluorescent light, 24 hours a day. The optimal temperature is 65—78 °F (18—26 °C).

Background: Inheritance and Mendel

Every cell in plants and animals contains DNA that is made up of thousands of genes. And every cell (except the gametes) has two copies of each gene—one from each parent—and the two sets of genes are different from each other. Cells with both sets of genes are referred to as **diploid**.

During meiosis, each gene pair is split apart randomly — and independenly of the other genes — so that the resulting gametes (eggs or sperm/ pollen) have a single set of reassorted genes. Cells that have only one set of genes are referred to as **haploid**.

During mating, two parents each contribute a single gamete. When the two gametes fuse, the two sets of genes are then united in the diploid offspring. The new assortment of genes contains all the information for a whole new organism.



Gene Aliases: Alleles

Genes can have different forms, called **alleles**. Each allele codes for a slightly different form of a gene. Different alleles of the same gene are represented with the same letters, which are differentiated by capitalization. Example: Mendel described a gene for flower color with the following alleles: "P" for purple and "p" for white. Another way to describe the alleles is with three-letter names. Example: The two alleles for anthocyaninless gene in Wisconsin Fast Plants™ can be represented as "*ANL*" (purple) or "*anl*" (non-purple). Together, the two alleles describe the **genotype** of a specific **trait.**

The interaction of the paired alleles, along with the environment, determines the **phenotype** of the offspring. The interaction can be simple (one allele is dominant over a recessive allele), or the interaction can be more complex (the two alleles both contribute to the apparent phenotype). In the case of Mendel's flower color, the dominant P allele masks expression of the recessive p allele; if the dominant P allele is present, the flowers appear purple. So if the genotype is either PP or Pp, then the phenotype is a purple flower; if the genotype is pp, then the phenotype is a white flower.

Mendelian Genetics

- **Law of Segregation**: Paired alleles separate during the formation of gametes.
- **Law of Independent Assortment**: Each allele segregates independently of the other allele in gamete formation.
- **Alleles** retain their identity during gamete production and pollination/ mating.
- Two alleles (one from each parent) are paired in the offspring; this constitues the **genotype** of a trait.
- The offspring's **phenotype** is based on the expression of both alleles; one allele may "mask" the expression of another in a dominant/recessive relationship, or both alleles may contribute to the apparent phenotype.

The Trait: Anthocyaninless (Non-Purple)

Anthocyanin is a purple pigment found in many plants. Anthocyanin is best observed when the plants are 4–7 days old. Look on the stems and hypocotyls, under the cotyledons, and at the leaf tips.

The anthocyaninless gene (*anl*) in Wisconsin Fast Plants™ regulates whether or not anthocyanin will be expressed. In the homozygous recessive form *(anl/anl)*, anthocyanin expression is completely suppressed, and the plants appear a bright green color (which is the "non-purple stem " phenotype). If the genotype is heterozygous *(anl/ANL)* or homozygous dominant *(ANL/ANL)*, then anthocyanin is expressed at varying levels (which is the "purple stem" phenotype).

The P_1 and P_2 plants used for this investigation are true-breeding for their phenotypes. The F_1 plants are the hybrid offspring that result from crossing the two parents.

Mother Generation (P_1)

Seed Packet Name: Non-Purple Stem
Phenotype: non-purple stem
Genotype: ***anl/anl***

The P_1 plants are homozygous with the recessive alleles for anthocyanin expresion (*anl*). Anthocyanin expression is suppressed, and the stems appear bright green.

Father Generation (P_2)

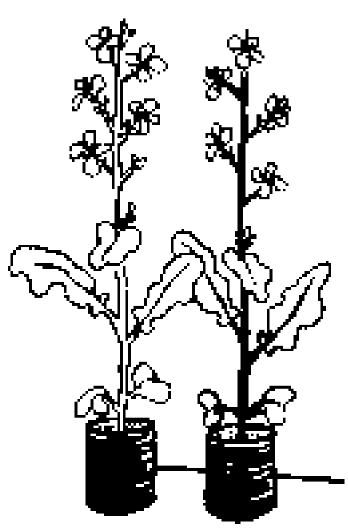
Seed Packet Name: Purple Stem
Phenotype: purple stem
Genotype: ***ANL/ANL***

The P_2 plants are homozygous with the dominant allele for anthocyanin expression (*ANL*). Anthocyanin is expressed, so the stems show some purple color.

First-Generation Offspring (F_1)

Seed Packet Name: F_1 Non-Purple Stem
Phenotype: purple stem
Genotype: ***anl/ANL***

The F_1 plants are the result of crossing the P_1 and P_2 plants. They are heterozygous with both a dominant and a recessive allele for anthocyanin expression. Anthocyanin is expressed, so the stems show some purple color.



Second-Generation Offspring (F_2)

There is no seed packet for this generation.
See page 16 for a list of genotypes.

The F_2 plants are a result of intermating the F_1 plants. They represent all the genotypes in the P_1, P_1, and F_1 generations. The phenotypic ratio is **approximately*** 3:1 as follows:

3 purple stem
1 non-purple stem

** Ratio is approximate, due to the random nature of independent assortment and segregation of gametes.*

Getting Started

In this activity, students will have the opportunity to investigate how two genes are inherited in Wisconsin Fast Plants™. The students are responsible for:

1. *Tending the plants.*
2. *Articulating hypotheses about the inheritance of genes.*
3. *Gathering evidence (by recording their observations on Student Notebook Pages).*
4. *Determining whether or not their evidence supports their hypotheses.*
5. *Explaining inheritance of a single trait in Wisconsin Fast Plants™, based on their evidence.*
6. *Determining the father's (P_2) stem color, based on their explanation of inheritance.*

Students will observe and record the stem color of both generations, but they will tend only the first-generation (F_1) plants through the entire life cycle. During the investigation, students will tend the plants, pollinate the flowers, harvest the seeds of the second-generation offspring (F_2), and plant the seeds. A few days after planting the second generation seeds, students will observe the stem and leaf colors of the F_2 seedlings, then plant seeds of the father generation (P_2). Finally, they will observe the stem and leaf color of the P_2 plants. (See page 10 for a detailed teacher's schedule.)

The week prior to starting, assemble a 24-hour fluorescent light source (the Plant Light House or Plant Light Bank). Read the *Wisconsin Fast Plants™ Growing Instructions* (included with this kit.)

On day 0, assemble the growing systems and plant seeds of the mother generation (P_1) and the first-generation offspring (F_1).

Data Analysis and Discussion

Throughout the activity, students can record their observations, predictions, hypotheses, and results by using the Student Notebook Pages (pages 11–13). After they have recorded the stem color of the F_2 plants, students can do a χ^2 test with data from the entire class (pages 14–15). The χ^2 results will provide additional strength to help them determine whether or not their evidence supports their hypotheses.

By explaining how their observations agree or disagree with their hypotheses and sharing their analyses with fellow students, they will unravel the mystery of paternity and come to understand the inheritance of a single trait in Wisconsin Fast Plants™, and the Law of Segregation.

The Life Cycle of Wisconsin Fast Plants™

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Week 1 (0-6 days old)

Each seed contains a tiny, new plant, called an embryo. The outside of the seed is called the seed coat. A seed can remain quiescent (sleeping) for years, as long as it stays dry and cool.

A day or two after planting and watering, the tiny seeds germinate. During germination, the seed takes up water and swells until its seed coat cracks. The radicle (embryonic root) comes out first, followed by the hypocotyl (stem) and two cotyledons (seed leaves). A few days later, the hypocotyl pushes through the soil, pulling the seed leaves along with it.

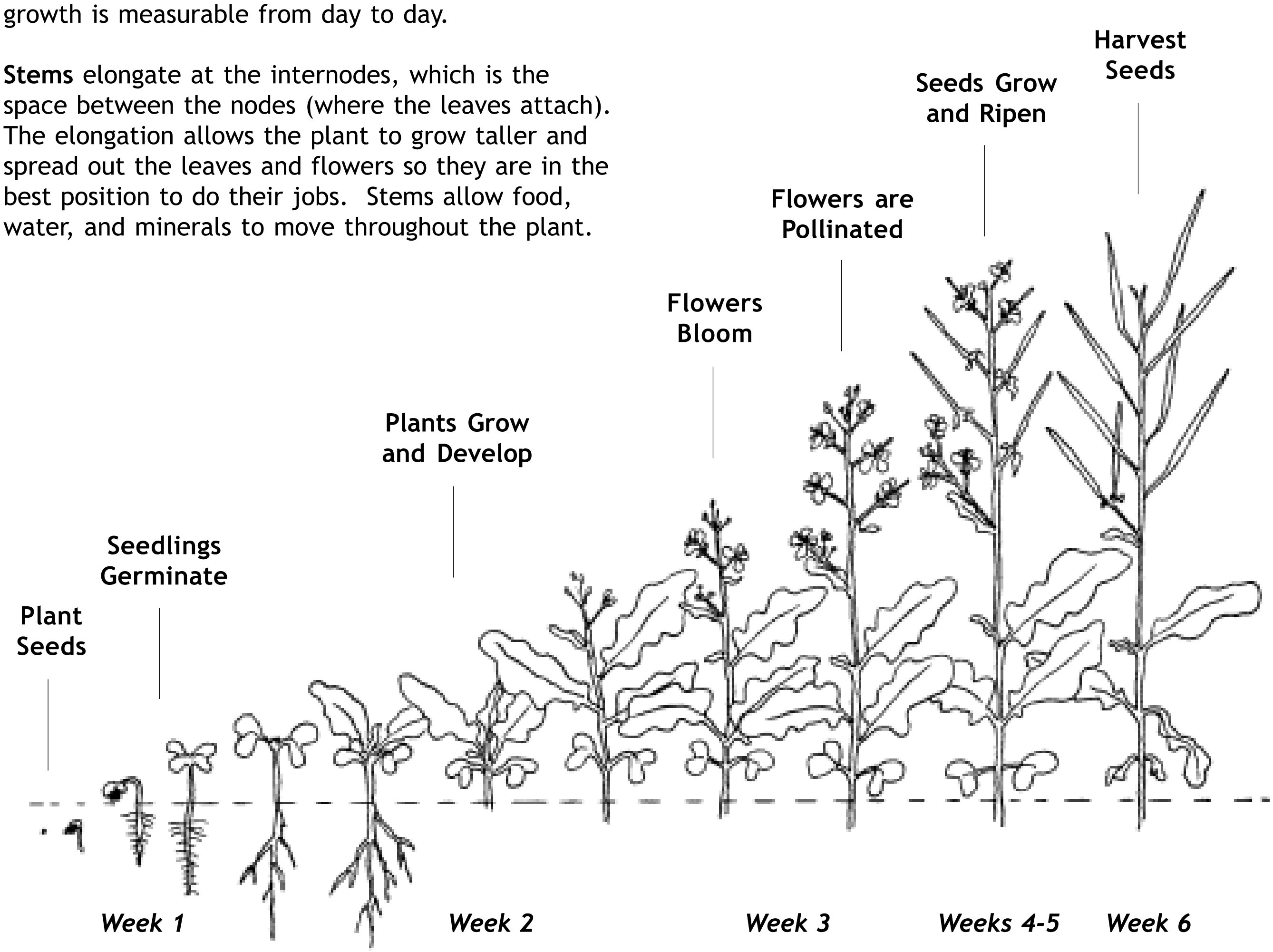
Week 2 (7-14 days old)

Above ground, the true leaves, stems, and flowers originate at a point at the very top of the plant, called the shoot meristem (growth tip). Each part emerges gradually, then grows larger — and the growth is measurable from day to day.

Stems elongate at the internodes, which is the space between the nodes (where the leaves attach). The elongation allows the plant to grow taller and spread out the leaves and flowers so they are in the best position to do their jobs. Stems allow food, water, and minerals to move throughout the plant.

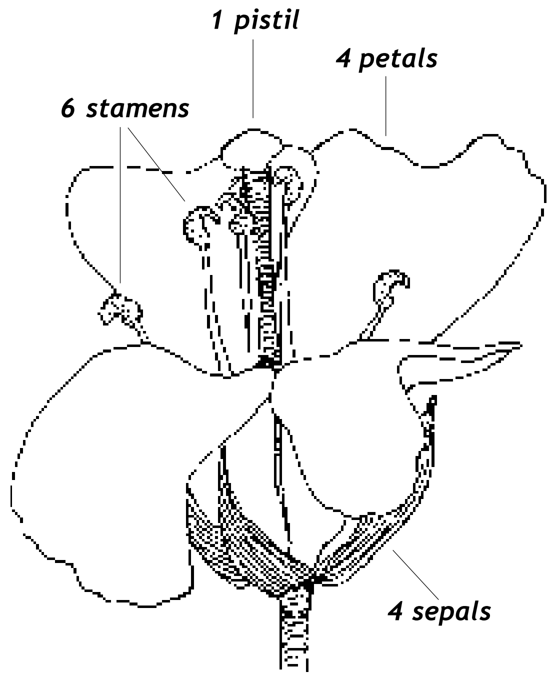
Leaves contain many pores (called stomata) on their surfaces that allow the plant to "breathe" by uptaking carbon dioxide (CO_2) from the air, and then expelling oxygen (O_2). A green pigment, called chlorophyll, causes the leaves to appear green and captures energy from light. When CO_2 and water are combined in the presence of light, the plant makes its own food, called carbohydrates (or sugar). This amazing process is called photosynthesis.

Under the soil, the **roots** grow downward. Roots anchor the plants into the soil so they don't blow or wash away. Root hairs absorb water and nutrients from the surrounding soil and bring them to the rest of the plant. Most of the absorbed water is used to cool the plant as water evaporates from the leaves; some of the water is used for cellular processes such as photosynthesis.



Week 3 (14-20 days old)

The **flowers** bloom. At the growth tip, new flower buds begin to appear. Each bud is protected by four green sepals. Once a flower opens, the sepals are hidden beneath four bright yellow petals. The flower's center boasts a single pistil, which is the female part of the flower. The pistil is surrounded by six yellow stamens, which are the male parts of the flower. Each stamen is covered with lots of powdery, yellow pollen.



The bright yellow petals may catch your eye — and the eye of insects. The petals form a beacon that lets insects know that there is food available. Hidden deep inside the flower are nectaries, which produce nectar. Nectar is a sweet, sugar-rich substance that insects love to eat. That's why bees and butterflies are attracted to flowers — they're hungry!

In exchange for food, insects pollinate flowers. When an insect moves from flower to flower looking for nectar, pollen from each flower gets caught in the insect's body hairs and is transferred to other flowers. After pollen has landed on the tip of another flower's pistil, it grows a tube down into the pistil, where the eggs are housed. Sperm (from inside the pollen) are then able move down the tube until they reach the eggs and fertilize them. The fertilized eggs then become the embryos of new seeds.

Weeks 4, 5, and 6 (21-40 days old)

As the seeds mature and ripen, the outside of the pistil swells to become the **seed pod** (or **fruit**) that encases several seeds. The leaves and flowers slowly wilt and fall off, one by one.

After the seeds have dried out completely, they are ready to be planted or stored. Inside each seed is a tiny **embryo**, waiting for water and warmth so it can germinate into a new plant, and another life cycle can begin.

About Wisconsin Fast Plants™

Wisconsin Fast Plants ™ (*Brassica rapa*) are rapid-cycling brassicas. They are members of the crucifer family of plants, closely related to cabbage and turnips that have been bred over 30 years at the University of WIsconsin - Madison.

These petite plants (~20 cm tall at maturity) whiz through an ultra-short life cycle in about 40 days. In just over a month, students can plant seeds, tend plants, pollinate flowers, and harvest new seeds. The seeds can be immediately planted or stored for up to 10 years. Easily grown in the classroom, Wisconsin Fast Plants™ require little more attention than continuous fluorescent light, water, and fertilizer.

For details about growing Wisconsin Fast Plants™, refer to the *Wisconsin Fast Plants™ Growing Instructions*. For classroom activities and investigation ideas, go to **www.fastplants.org**.

Teacher's Schedule

The objective of this investigation is to understand how a single trait is inherited. Students will make observations about stem color that will serve as evidence to explain how the that trait is inherited. From their evidence and explanations, they will predict the phenotype of the father (P_2) generation.

Day Activity

0 **Students work in groups of 2–4.** Each student should record observations, notes, hypotheses, and explanations on the Student Notebook Pages (pages 11–13).

All student groups (except one) **plant** the seeds of the first-generation offspring (F_1). One student group plants seeds from the same population as the mother plants (P_1). Refer to the *Wisconsin Fast Plants™ Growing Instructions* for details.

4–7 **Observe** the stem color of the young P_1 and F_1 plants. Students decide how they will quantify the stem color phenotypes. (Example: Counting the number of purple stems vs. non-purple stems, or quantifying how purple the stems are.)
Record your observations.
Discard the P_1 plants, but continue to **maintain** the F_1 plants according to the *Growing Instructions*.
Thin the F_1 plants to 2 per pot.
Explain how you think stem color is inherited in Wisconsin Fast Plants™.
State a testable hypothesis, then **predict** the father's (P_2) stem color, based on your hypothesis.

As the investigation progresses, students may re-evaluate how they measure phenotypes in order to get data that is more meaningful for testing their hypotheses.

If you prefer a more structured investigation, tell the students that the two phenotypes are:
(1) purple stem
(2) non-purple stem

15–17 **Intermate** the entire population of F_1 plants over a 3–day period. (*Intermate* means to pollinate plants from the same generation.) Be sure that all flowers receive pollen from several different plants. See *Growing Instructions* for information about making beesticks and pollinating flowers.

18 **Terminate** (cut off) any new flower buds that were not pollinated on days 15–17.

37 **Stop watering** the plants. Let them dry out for a full week, until they are brown and crispy.

44 **Harvest** the seeds from the pods of the F_1 plants, according to the *Growing Instructions*. These are the seeds of the second (F_2) generation.
Predict the stem color of the F_2 plants, based on your hypothesis.

45 **Plant** the F_2 seeds.

49 **Observe** the stem color of the young F_2 plants.
Record your observations.
Perform a χ^2 test to analyze your evidence. Do you accept or reject your hypothesis?
Predict the stem color of the P_2 plants, based on your (revised) hypothesis.

50 **Plant** the P_2 seeds.

53 **Observe** the stem color of the young P_2 plants.
Record your observations. Does the evidence support your (revised) hypothesis?

Who's the Father?

Student Notebook Pages

Your Challenge

The goal of this investigation is to determine... ***Who's the Father?*** **You and your classmates will gather evidence to explain how stem color in Wisconsin Fast Plants™ is inherited. From your evidence and explanations, you will predict the phenotype of the father (P_2) generation.**

Day Activity

0 **Work in groups of 2–4.** All student groups (except one) **plant** the seeds of the first-generation offspring (F_1). One student group plants seeds from the same population as the mother plants (P_1).

Refer to the ***Wisconsin Fast Plants™ Growing Instructions*** **for details.**

4–7 **Observe** the stem color of the young P_1 and F_1 plants. **Record** your observations in the table below.

NUMBER OF PLANTS WITH EACH TRAIT IN THE P_1 AND F_1 GENERATIONS

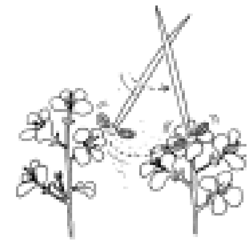
List Each Phenotype:					
P_1 Generation					
F_1 Generation					

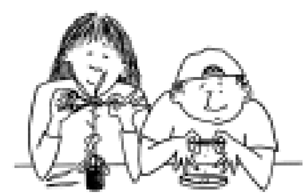
Discard the P_1 plants, but continue to **maintain** the F_1 plants according to the *Growing Instructions* by thinning the F_1 plants to 2 plants per pot.

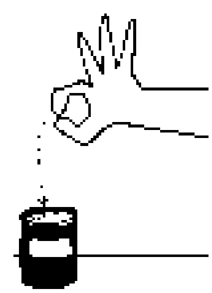
Explain how you think stem color is inherited in Wisconsin Fast Plants™.

State a testable hypothesis, then **predict** the father's (P_2) stem color, based on your hypothesis.

Day	Activity
15–17	**Intermate** the entire population of F_1 plants over a 3–day period. (*Intermate* means to pollinate plants from the same generation.) Be sure that all flowers receive pollen from several different plants. See *Growing Instructions* for information about making beesticks and pollinating flowers. Based on your hypothesis (from day 4-7), **predict** the stem color of the second-generation offspring (F_2) that will result from the pollination you did today.
18	**Terminate** (cut off) any new flower buds that were not pollinated on days 15–17.
37	**Stop watering** the plants. Let them dry out for a full week, until they are brown and crispy.
44	**Harvest** the seeds from the pods of the F_1 plants, according to the *Growing Instructions*. These are the seeds of the second (F_2) generation. **Notes and Observations:**
45	**Plant** the F_2 seeds.
49	**Observe** the stem color of the young F_2 plants. **Record** your observations in the table below. (See more Day 49 information on the next page.)







NUMBER OF PLANTS WITH EACH PHENOTYPE IN THE F_2 GENERATION

List Each Phenotype:					
F_2 Generation					

Day Activity

49 **Share** your results with your classmates.
(cont) **Perform** a χ^2 test to analyze your evidence, using results from the entire class.
Describe your χ^2 results:

Do you accept or reject your hypothesis, based on your evidence? If your hypothesis was accepted, are you convinced that it is correct, or do you need more evidence? If your hypothesis was rejected, what is your new hypothesis? Explain.

Predict the stem color of the P_2 plants, based on your (revised) hypothesis.

50 **So...Who's the Father?**
Plant the P_2 seeds.

53 **Observe** the stem color of the young P_2 plants.
Record your observations in the table below.

NUMBER OF PLANTS WITH EACH PHENOTYPE IN THE P_2 GENERATION

List Each Phenotype:					
P_2 Generation					

Does the evidence support your (revised) hypothesis?
Justify your answer with evidence.

Put Your Results to the Test!

Probability and the χ^2 Test for *Who's The Father?*

Put your claims to the test! Was the ratio of the phenotypes in the F_2 generation what you predicted it would be? Was it even close? A χ^2 test will compare your observations with your hypothesis.

The χ^2 test calculates (1) the deviation between your observed numbers and your expected numbers and (2) the probability that the deviation is due to **chance** or that the deviation is **significant**. If the deviation is merely due to chance, then your results support your hypothesis, and you can **accept** your hypothesis. If the deviation is significant, then your results do not support your hypothesis, and you **reject** your hypothesis.

STEP 1 **Determine the ratio of phenotypes you expected in the F_2 generation, based on your hypothesis.**

Phenotype	**Expected Ratio**	**Expected Number of Plants (*e*)**
1. ________________	______	__________
2. ________________	______	__________
3. ________________	______	__________
4. ________________	______	__________

STEP 2 **Record the ratio of phenotypes you observed in the F_2 generation.**

Phenotype	**Observed Number of Plants (*o*)**
1. ________________	__________
2. ________________	__________
3. ________________	__________
4. ________________	__________

STEP 3 Calculate the χ^2 value. Fill out the following table, using numbers from the entire class. For *o* and *e* values, use the actual numbers of plants, not percentages or ratios.

List Each Phenotype:	**1**	**2**	**3**	**4**
Observed Value (*o*)				
Expected Value (*e*)				
Deviation (*d*) = *o-e*				
Deviation Squared (d^2)				
d^2/e				

STEP 3 *Calculate the χ^2 value, continued.*

Add all of the d^2/e values together to get the **χ^2 value**:

STEP 4 Calculate the degrees of freedom.

To calculate the degrees of freedom, subtract one from the number of phenotypes possible.

Number of phenotypes possible — 1 = *Degrees of freedom*

STEP 5 Determine whether to accept or reject your hypothesis.

Find the probability that the deviation of the observed values from the expected values was a chance occurrence. Look up your degrees of freedom in the table below. Find where your χ^2 value falls in that row.

Degrees of Freedom	Probability of Chance Occurrence								
	90%	80%	70%	50%	30%	20%	10%	5%	1%
1	0.016	0.064	0.148	0.455	1.074	1.642	2.706	3.841	6.635
2	0.211	0.446	0.713	1.386	2.408	3.219	4.605	5.991	9.210
3	0.584	1.005	1.424	2.366	3.665	4.642	6.251	7.815	11.341
4	1.064	1.649	2.195	3.357	4.878	5.989	7.779	9.488	13.277

Probability value:

If the probability is 5% or greater, then you can **accept** your hypothesis.
If the probability is less than 5%, then **reject** your hypothesis.

Do you accept or reject your hypothesis?

WHO'S THE FATHER?

INVESTIGATING MENDELIAN GENETICS WITH WISCONSIN FAST PLANTS™