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Pollination Ecology in the Classroom

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It is a warm sunny day in the middle of May and red clover is in bloom in the meadows. A bumblebee moves from flower to flower, reaching deep into each with her proboscis and tongue to suck up the nectar. As she does this, the stamens (male organs of the flower) which are attached below move up and hit her on the abdomen, dusting her with pollen. On she flies to another clover plant and this time her abdomen touches the stigma (the top of the female organ) which scrapes off some of her pollen. The bee has unwittingly achieved the plant's aim—cross-pollination, and has filled her own honey-stomach with nectar. She begins to clean her body of pollen grains, working them from the front to the hind legs where they are finally compacted into a hairy container called a pollen basket. Now she flies back to the nest to empty her loads of nectar and pollen.

Bumblebees and red clover—two organisms that are interdependent. The plant which would become extinct without its pollinator, has developed several features that almost guarantee pollination; attractive petals, sufficient nectar, stamens that release pollen on the underside of the bee and a stigma that precisely picks up pollen that the bee carries from other red clover flowers. Although each red clover flower contains both male and female sex organs it is self-sterile and depends wholly on pollen from other plants in order to set seeds. The bumblebee, on the other hand, gets all its food from the flowers; the nectar provides carbohydrates and the pollen supplies both protein and fats. A bee will die of starvation in an hour if deprived of these floral foods (Heinrich, 1979).

Everyone has probably heard the story that the power of the British Empire rests (or rested) on its bumblebees British sailors eat beef, the beef cattle eat clover and the clover is pollinated by bumblebees. That this story was not so far-fetched became obvious last century in New Zealand. Settlers from England had brought over red clover to plant as a forage crop but it never set seeds. Finally it was realized that there were no native bumblebees in New Zealand to pollinate the clover and in 1880, one hundred English bees were imported. Seed set was no problem afterwards (Meeuse, 1961).

Bringing in hives of honeybees (instead of bumblebees) to New Zealand would not have solved the problem of the red clover, however. Honeybees have a tongue that is only about 6 mm long, not long enough to reach the nectar deep inside the red clover, available only to bumblebees with a longer tongue. On the other hand, honeybees are more efficient pollinators of white clover which has a much shorter flower.

Flowering plants (angiosperms) and their pollinators have become adapted to one another over the ages for maximum mutual benefit. This is called CO-EVOLUTION and has been taking place ever since angiosperms

first appeared in the fossil record of the Cretaceous period, about 90 million years ago (Percival, 1965). Hymenoptera (bees and wasps) had already made their appearance in the Jurassic period, 144 million years ago and the Lepidoptera (butterflies and moths) began to evolve in the Tertiary of the Cenozoic era, starting about 60 million years ago.

It is difficult to see the details of the co-evolution of flowering plants and their pollinators from the spotty fossil record but a lot can be inferred from studies of living organisms.

Plants are of course stationary and can reproduce only if their pollen is carried by wind, water or various animals from one flower to another. There is great competition among the angiosperms to secure visits by pollinators. Many plants have developed flowers with attractive colors and scents. There may or may not be food rewards offered. One orchid, *Ophrys* , mimics a female bee so perfectly that male bees try to mate with it. Unknowingly, they get pollen caught on their bodies (Baker, 1963).

Usually flowers do offer food in the form of nectar and/or pollen in order to attract pollinators. The amounts offered are usually quite tiny so that the pollinators are forced to visit as many flowers as possible.

Insects compete intensely with one another for this available nectar and pollen. Heinrich (1979) reports observing a bumblebee that visited 800 jewelweed flowers in two hours. Often bumblebees work from dawn to dusk, visiting 20 to 40 flowers per minute.

The most efficient pollinators are those that are adapted to certain flowers (such as bumblebees to red clover). If one knows enough about a pollinating animal; whether it has color vision, is nocturnal or diurnal, the length of its tongue, the ability to hover, one can make a very educated guess as to which flowers it might pollinate.

Conversely it is often possible for a biologist to look at a flower and decide from its appearance how it is pollinated; whether by bees, butterflies, moths, birds, bats, flies, wind or by a combination. Last century, a new orchid, *Angraecum sespuipedale* , with a corolla tube of 30 cm was found in Madagascar. Its pollinator was unknown but Alfred Wallace (of evolution fame) correctly predicted that it would turn out to be a hawkmoth with a proboscis that could reach all the way down to the nectar (Percival, 1965).

It should be emphasized that though many flowers and pollinators are specifically adapted to each other, there are also many flowers that are visited by numerous different insects.

The next part of this paper will cover specific adaptations of pollinators and plants to one another. See Appendix for drawings and descriptions.

Honeybees , Bumblebees and Bee Flowers

Most bee-pollinated flowers are yellow, blue or white. This corresponds exactly to the color vision of bees as tested by Karl von Frisch (1950). High school students would be fascinated by his simple elegant experiments and it would be interesting to replicate some of them in class.

To find if bees could detect the color blue, he laid out 15 small squares of varying gray shades and one square of blue paper, arranged into a large square. All of the pieces of paper contained a watchglass but all were empty except the one on the blue paper which contained sugar. Naturally the bees were attracted to this square. He changed the position of the blue square often and the bees always found the sugar water. Now he removed the sugar water. Although there was nothing attracting the bees they still always landed on the blue

square, no matter where von Frisch placed it. In other words they were trained to blue.

Von Frisch successfully repeated this experiment using yellow, but when he tried training the bees to a red square it proved to be impossible. Evidently, bees see red as another shade of gray and are “red-blind” unlike humans.

Further experiments by other scientists have shown that bees are actually sensitive to two other colors, blue-green and ultraviolet. They can be trained to cards that reflect UV, which of course we humans cannot see. Many flowers actually look very different to bees than they do to us. For instance, bee flowers often have nectar guides on their petals. These are spots or lines that point the bee to the interior of the flower where the nectar is located. Thirty percent of bee-pollinated flowers have patterns that are clearly visible to the human eye but another 26 percent have UV patterns that are visible only to the eye of a bee (Proctor and Yeo,1973). It is intriguing for high school students to realize that lowly insects can see something that they can’t.

White flowers all look approximately the same color to the human eye, but not to bees. Many white flowers absorb ultraviolet and therefore appear as blue-green to the bees’ eyes. (blue-green and UV are complementary colors and when one is removed by absorption from white light, the other becomes visible).

Bees have always been attracted to the European poppy, a bright red flower, and are among its main pollinators. This seems strange in the light of von Frisch’s experiments showing that bees can’t see red, but the mystery was cleared up when it was discovered that poppies strongly reflect ultraviolet light. The bee is not seeing the poppy as “red” but rather as the color “ultraviolet” which is invisible to us.

The scent of a flower is important too in bee pollination. When a worker bee returns to the hive, the scent of the flowers visited clings to her body. The other workers detect this scent by means of their antennae and then, guided by the dance of the returning bee (von Frisch,1950) they fly out to seek the same flowers. Because of this scent message, bees are very specific pollinators. Once they have started working one kind of flower they will continue until these nectar and pollen supplies are exhausted. This ensures efficient cross-pollination; bee flowers usually have a high percent of fertilized seeds (Grant,1951).

There is one interesting exception to efficient pollination by bees, however (Webster,1979). The production of apples depends on bees; growers usually place a colony of honeybees in every three acres of orchard in order to ensure pollination of flowers and subsequent development of fruit.

However, it has been obvious for years that yields of Delicious apples have always been much lower than that of other varieties. A graduate student at Cornell felt that the problem might be one of pollination and over the next two years he observed thousands of honeybees in action in orchards. He discovered that in the flowers of Delicious apples the bees could push through the gaps in the stamens and steal nectar without ever touching the stigmas. Thus little pollination occurred. This meant that over 20 million bushels of Delicious apples did not develop each year. One solution may be to put two colonies of bees in each acre of orchard.

The main types of bees in the United States are honeybees and bumblebees. Our bomblebees are native insects but honeybees are descendants of bees brought over by early settlers. The Indians used to call them “white man’s flies”.

These two bees are similar in many respects and they compete fiercely for many of the same flowers, both wild flowers and crop plants. We are dependent on bees for the following fruits and vegetables; apples, pears, squash, cantaloupe, avocado,pumpkin, raspberry, watermelon, peach,plum and blueberries (Rahn, 1975.

In the summer of 1970 in Maine there was a dramatic demonstration of the relationship of bees and blueberries (Heinrich, 1979). There had been serious infestations of spruce budworms for years. DDT was effective but it was taking its toll of fish and birds, so that summer a new poison called Fenitrothion was sprayed on millions of acres of forests. This spray, unlike DDT, is lethal to bees. Most of them died and as a result there was no blueberry crop that summer.

There are some flowers that are pollinated only by bumblebees, and not by honeybees. These are flowers that require greater strength to open or else have deeply hidden nectaries. Some of these “bumblebee flowers” are; snapdragon, butter and eggs, red clover, monkshood, jewelweed and Solomon,s seal.

Butterflies and Butterfly Flowers

Butterflies are different from bees in many of their pollinating characteristics. They have a much longer proboscis, made of two halves that fit together to form a long hollow tube. This tube is kept coiled up under the head like a watchspring when not in use. Their only food is nectar, unlike honeybees who gather pollen both for themselves and their larvae. Butterfly larvae (caterpillars) subsist wholly on plant foliage.

Butterfly-pollinated flowers often have nectar hidden at the ends of long spurs (columbine) or deep at the base of fused petals (trumpet vine). The flowers are often red or orange, for unlike bees, butterflies are sensitive to these colors. Bee-flowers are usually scented but butterfly-flowers are not, since smell does not seem to be a well-developed sense, in butterflies. Interestingly enough, butterflies have taste organs on their feet; touching a source of sweetness with their feet causes the proboscis to unroll into a feeding position.

Some common butterfly-pollinated flowers are; lilies, purpleloosestrife, goldenrod, phlox, milkweed, trumpet vine, columbine and various composites like dandelion.

Moths and Moth Flowers

Moths and butterflies are closely related but there are also many differences which are reflected in the flowers that they pollinate. Since moths are mainly nocturnal, their flowers are usually white or light-colored and open at night. The flowers of evening primrose open at about 6 PM and close again 24 hours later.

Moths are extremely sensitive to odors and mothpollinated flowers emit strong cloying odors which attract them in the darkness. Some common moth flowers are: honeysuckle, tobacco, Easter lily, gardenia, night-blooming cacti, bindweed, morning glory and yucca.

Yucca and its pollinator, the female *Pronuba* moth, provide an example of a very specific relationship. There are some thirty species of yucca plants in North America, mostly in the West, and each one is pollinated by a Pronuba moth. The moth remains in the flower in the daytime and becomes active at night. She gathers pollen masses in her mouthparts and flies with them to the stigma of a different flower where she deposits them. Then she bores holes in the ovary of the yucca flower and lays her eggs. The larvae feed on the developing seeds when they hatch, although there are always plenty of seeds left over for the propagation of the plant.

In New Haven, there are lots of yucca plants which have become naturalized on the rocky slopes of East Rock. However, there are no Pronuba moths in this area so a developing ovary with seeds is a rarity.

Hummingbirds and Bird Flowers

Hummingbirds are fascinating. There are 319 species found only in the New World but in eastern North

America there is only one, the Ruby Throated Hummingbird. These birds can hover, fly vertically and also backwards while their wings are beating at 75 times a second.

Flowers supply them with two foods; copious watery nectar and also protein in the form of tiny insects that live inside the flowers. The nectar is usually found at the bottom of deep corollas. The hummingbird hovers in front of the flower and thrusts its beak far into the interior.

Hummingbirds seem particularly attracted to red and orange flowers (although they will also explore other colors). The Old World which has no hummingbirds has fewer red flowers than the Americas.

Some typical hummingbird flowers are; fuchsia, hibiscus, salvia, red columbine, cardinal flower, impatience, trumpet vine and horse chestnut.

Flies and Fly Flowers

Short-tongued flies which normally feed on carrion and excrement are attracted to flowers that smell rotten such as skunk cabbage and wild ginger. The world's largest flower, *Rafflesia* , which is found in Malaysia is also fly-pollinated. This saprophyte may have a flower that is up to a yard in diameter. It has been claimed that it is pollinated by elephants whose eyebrows dislodge the pollen when it probes for nectar with its trunk: Such an odd flower deserves its legends.

There are many curious fly flowers that actually trap flies (for instance, Jack-in-the-pulpit and Dutchman's pipe) and release them days later , covered with pollen and no worse for the experience since they will fly to another trap plant and repeat the experience. Often fly flowers offer no nectar as a food reward,; instead they attract their pollinators by means of odors, glistening spots and dull colors and then trap them. Bee-pollinated flowers certainly behave more generously towards their visitors:

Wind-pollinated Flowers

Flowers that depend on the wind for pollination are usually very small and plain with single-sex flowers. Because they do not depend on animal pollinators, they do not need to produce nectar or strikingly colored petals. Much of the plant's energy goes into making pollen to compensate for the fact that so few pollen grains actually reach the female flowers. The amount of pollen produced is staggering a single corn plant may have from 20 to 50 million grains (Rahn,1975). (Insect-pollinated flowers produce far fewer pollen grains since pollination is a much more certain thing).

Wind-pollinated flowers have long feathery stigmas that catch the pollen that comes flying through the air and the stamens dangle loosely at the ends of long threads. Often the male flowers are arranged into catkins which move in the wind, freely releasing pollen into the air.

Tree flowers that are wind-pollinated often bloom early in the spring before leaves emerge, giving the pollen a better chance to reach the female flowers on other branches or trees.

Many trees of colder climates are wind-pollinated such as oak, poplar, birch, elm, walnut, alder, hazel and conifers. Other common plants include grasses, ragweed, dock and plantain.

Certain times of year when wind-pollinated trees or grasses are blooming may be a time of tribulation for hayfever sufferers. The abundant pollen from these plants often contains a protein which acts as an allergen when it lands on our mucous membranes. Although it is harmful to us this protein serves an important

function for the plant. Wind-pollinated plants are usually self-incompatible and pollen grains will not germinate if they land on a stigma of the same plant. It is this allergen protein which acts as the inhibitor to self-fertilization (Lewis,1979).

Classroom Activities

To the teacher:

Flowers are normally studied in high school biology classes as part of a unit on reproduction. One or two flowers are dissected, the parts are learned and then there is usually a brief discussion of pollination, whether by wind or insects.

My unit on pollination ecology goes into the subject in more depth, and is an attempt to approach it equally from both the viewpoint of the pollinators and the plants. How are various insects adapted to pollinate specific flowers? How have plants adapted to derive maximum benefit from their pollinators?

Therefore as well as labs on floral structure there will also be labs on pollinating insects. Then there will be a final lab to see whether students can look at the structures of flowers and guess which insects pollinated them. As well as encouraging their powers of observation this exercise should also develop their powers of reasoning for they will have to explain their answers.

Floral pollination is best taught in early May, when New Haven gardens and trees are in full bloom. (Any earlier and the the teacher may need to purchase flowers at the florist.) Students should also be encouraged to bring in flowers for the labs.

Insects may be purchased from Biological Supply companies or simply caught and mounted.

There are several issues of National Geographic magazine with spectacular photos of pollinating animals (see Bibliography). These should be cut out and displayed on the board during the unit.

Lesson I: The Parts of a Flower

Objectives:
To understand that the flower contains the sexual organs of the plant and to learn the parts.

Materials:
Drawing of a trumpet vine flower-colored pencils

(figure available in print form)

Procedure:
Label floral parts, then color. Write down function of each (with teacher's help)

Answers:
1. petals fused into a corolla, 2. pistil (2a. stigma, 2b.style, 2c. ovary with seeds) 3. nectar guides , 4. stamen (4a. anther, 4b. filament), 5. sepals, 6. nectary

Lesson 2: Wind and Insect Pollinated Flowers

Objectives:
Now that students have learned the main parts of a flower they should be able to contrast an insect-pollinated and a windpollinated flower

Materials:
handlenses(3x-6x), microscopes, slides, cover slips,

Insect-pollinated flower: daffodil, gladiolus, rhododendron, forsythia,snapdragon Wind-pollinated flower: oak, walnut, birch, poplar, plantain, grasses

Information for Students:
As you saw in the last lab, flowers contain both male and female sex organs. However, a plant normally can't fertilize itself and the male pollen must get from the stamen of one plant to the stigma of another. Since plants are anchored in the ground by their roots they obviously can't move around. Therefore they either depend on insects or wind to carry the pollen.

Insects visit flowers that have large attractive petals, an enticing odor, nectar (sugar water) and nutritious pollen. As they move from flower to flower the tiny pollen grains stick on them and then rub off on the next stigma.

Other flowers are not attractive and are not visited by insects. Their pollen is carried from flower to flower by wind. These flowers have no nectar, petals or scent.

Procedure:
Fill in the chart below using the two flowers your teacher will give you.

	Flower I	Flower II
1. odor		
2. sepals; number and color		
3. petals; number color and nectar guides		
4. stamens number		
5. pollen grains; (draw at 50x)		
6. stigma; sticky or feathery		
7. ovary; number of ovules		

Questions on Lesson II:

1. You have just studied two different flowers. Which of the flowers has petals? What color are they?

2. Does either flower have an odor? What does it smell like?

3. When you shake the two flowers, which one releases pollen?

4. How does the pollen of the two flowers look different under the microscope?

5. Which flower is adapted to attract insects? Give all the reasons why.

6. Which flower is adapted for wind-pollination and why?

Lesson 3: A Look at Pollinating Insects

Objectives:
To examine four different insects to see how they are adapted to the pollination of flowers.

Materials:
Dried honeybees, bumblebees, butterflies, moths handlenses, dissecting microscope, slides of insects

Procedure:
A. Observe as much as possible (using a handlens) about the following features. Then draw and label.

> HONEYBEE: antennae, mouthparts, compound eyes, furry body, pollen baskets,stinger
> BUMBLEBEE: same as honeybee but observe longer mouthparts and more powerful body
> BUTTERFLY: antennae with knobs, long tubular mouthparts, compound eyes
> MOTH: feathery antennae, long tubular mouth-parts, compound eyes.

B. Examine the microscopic slides of insect parts. Draw what you see and label

Lesson 4: Identifying the Pollinators by Looking at Flowers

Objectives:
To look at a wide variety of flowers and to decide from their structure how they might be pollinated.

Materials:
There should be plenty of flowers available from vacant lots, trees and gardens by the middle to the end of May. Some of the possibilities are:

Wind-pollinated: grasses, plantain, dock, trees mentioned in text.
Bee-pollinated: fruit tree blossoms, lilacs, rhododendron, lily-of-the-valley, white clover
Bumblebee-pollinated: snapdragon, violets, red clover, butter-and-eggs
Butterfly-pollinated: columbine, lilies, phlox
Moth-pollinated: bindweed, honeysuckle flowering tobacco, yucca

Instructions to Students:
Examine each flower carefully. Write down the name, how you think it is pollinated and all the reasons for your choice.

There will be a general class discussion after the lab.

Instructions to the Teacher:
The post-lab discussion should emphasize each student's observations and his reasoning abilities. After a consensus has been reached on the pollinator for each flower, the teacher would ask how these plants and animals have become so well adapted to one another.

Hopefully there will be a discussion of the co-evolution of these organisms.

Teacher Bibliography

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Bibliography from the National Geographic

These issues of the National Geographic contain spectacular photos of pollinating animals, both birds and insects, at work. Since there is almost no audiovisual material on the subject, it would be desirable to cut out these pictures with their captions and display them in the classroom during the unit

I found these issues in various thrift shops in New Haven.

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Appendix

Flowers and Their Adaptations to Various Pollinators

A Wind-pollinated flowers

grass flower x5

(figure available in print form)

plantain flowers x1

(figure available in print form)

male oak flowers x 1

(figure available in print form)
Characteristics of Wind-pollinated Flowers: Reduced or absent petals or sepals, no nectar or scent, stamens move freely in wind releasing dry powdery pollen grains, stigma is exposed and often feathery, male and female sex organs may be in separate flowers.

B. *Butterfly-pollinated flowers*

Characteristics of Butterfly-pollinated flowers:

Bright colors, including red and orange, often deep corollas of spurs containing nectar, weak scent, contain a landing platform, open in the daytime.

(Bumblebees, with their long proboscis may often pollinate these flowers.)

petunia x2

(figure available in print form)
C. Moth-pollinated flowers

Characteristics of moth-pollinated flowers: Pale, open at night heavy sweet ordor, no landing platform

honeysuckle x3

(figure available in print form)
D. *Bee-pollinated flowers:* (either honeybee or bumblebee)

Characteristics of bee-pollinated flowers: Colors are usually blue, white or yellow. There are often nectar guides on the petals . Flowers have an open form and are often sweetly scented.

mountain laurel x3

(figure available in print form)
buttercup x3
(figure available in print form)

E. Bumblebee-pollinated flowers :

butter and eggs x 5

(figure available in print form)
snapdragon x1
(figure available in print form)
Characteristics of bumblebee-pollinated flowers: It often requires strength to enter these flowers. Only a bumblebee is powerful enough to separate the upper and lower lips in order to reach the nectar of a snapdragon. The nectar may also be at the end of a long spur.

F. *Bird-pollinated flowers*

Characteristics of Hummingbird-pollinated Flowers: These flowers are usually red or orange, although hummingbirds are attracted to other colors as well. There is usually abundant nectar which is often deeply hidden.

fuchsia x1.5

(figure available in print form)