HISTORY OF SCIENCE CASES FOR HIGH SCHOOLS

Case 1

THE SEXUALITY OF PLANTS

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This experimental edition of the HISTORY OF SCIENCE CASES FOR HIGH SCHOOLS is published in co-operation with the Department of School Services and Publications, Wesleyan University, Middletown, Connecticut.

Acknowledgement is hereby made for the generosity of the publisher in supporting this project.

INTRODUCTION

In this HISTORY OF SCIENCE CASE, we shall make a critical study of a part of the development of a major scientific idea. Although we want to learn something about this idea, our chief interest in this CASE will be to find out as much as we can about:

- the methods used by scientists
- the means by which science advances and the conditions under which it flourishes
- the role of scientists as people and the personal characteristics of scientists
- the interplay of social, economic, technological, and psychological factors with the progress of science
- the importance of accurate and accessible records, constantly-improved instruments, and free communication

Proper study of this CASE consists of more than simply reading this little booklet. In the narrative outline, which follows this introduction, you will find numerous comments and questions in the margins. These marginal notes are intended to stimulate your thinking and to guide discussion on the points illustrated by the CASE. Space is provided on the left-hand pages for you to write answers to the questions which appear in the marginal notes . . . A most important part of the study of this CASE are the experiments and exercises which are suggested in this booklet, following the narrative outline. You should try to complete as many of these exercises as possible, so that you may get a real "feel" for the situations faced by scientists in creating science. Your teacher may suggest additional exercises and experiments that you can work on in connection with this CASE. On the last page of this booklet, you will find some reading suggestions of books and articles relating to the story of this particular CASE.

Some students will think that this CASE is out of date, because the story is set in the scientific past. Nothing could be further from the truth. The points about science and scientists which are featured in this CASE hold just as cogently in the present as they did in the past. The methods of scientific investigation are much the same today as they have been for several hundred years; similar non-scientific factors now interact with the progress of science as they did then; the character and personalities of scientists are always paramount factors when we think about science; adequate recording, free communication, and improved instrumentation continue as vital needs. These aspects of science held true yesterday, hold true today, and will hold true tomorrow.

As you study this CASE and work through the exercises, you will learn a great deal about scientists and about what goes on in science.

L.E.K.

The principal people you will meet in this CASE are:

Nehemiah Grew	English botanist. Born 1641 at Warwickshire. Died 25 March 1712 at London.
Cotton Mather	American clergyman, scholar, and author. Born 12 February 1663 at Boston. Died 13 February 1728 at Boston.
Rudolph Jacob Camerarius	German botanist. Born 12 February 1665 at Tübingen. Died 11 September 1721 at Tübingen.
Carolus Linnaeus	Swedish botanist. Born 23 May 1707 at Råshult, Småland. Died 10 January 1778 at Uppsala.
Joseph Gottlieb Kölreuter	German botanist. Born 27 April 1733 at Sulz am Neckar. Died 18 November 1806 at Karlsruhe.
Christian Konrad Sprengel	German clergyman, schoolmaster, and botanist. Born 22 September 1750 at Spandau. Died 7 April 1816 at Berlin.

[Use these left-hand pages to take notes and to write out your answers to the questions asked in the margins of the story.]

Here is a first note that you should keep in mind--

All the plants that will be mentioned in this Case are angiosperms. This doesn't mean that the idea of sexuality of plants applies only to the angiosperms. It just happened that this idea was first worked out with angiosperms, and we are going to look at the early history of the idea in this Case. Later work has given botanists a deeper understanding of sexuality throughout the plant kingdom ... In science, new ideas usually arise from investigations in one specific area. Later, these ideas may be developed into broader concepts that apply to a much larger field.

Incidentally, do you know what we mean by "seed plants"? -- What other groups of seed plants are there besides angiosperms?

How could the Babylonians use this food crop? -- Today, in this country, we use dates chiefly as a dessert sweet or in candies. Yet, since this fruit was a staple crop in ancient Babylonia, there must be other uses for it. What might be some of these uses?

THE SEXUALITY OF PLANTS

Just about all the plant foods that we eat come from seed plants. From the beginnings of civilization, seed plants have been cultivated for food. Thus, the farmer is greatly interested in how the seed plants grow and reproduce, because he wants to know of the best ways to manage his crops. The scientist is also interested in seed plant reproduction, but for a different reason. His understanding of this process would provide him with one more link in his efforts to comprehend the wonderful world of nature.

It is not difficult to see that sexuality is connected with reproduction in the higher animals. By analogy, we might suppose that sexuality is also connected with reproduction in the higher plants, the seed plants. But, the sexual parts of plants are much more difficult to observe than those of animals. Moreover, while most animals are clearly either male or female, the male and female parts of most seed plants are not obvious and are usually contained in the same individual. Thus, we cannot be sure that our analogy is correct. In fact, our first observations would suggest that the idea of sexuality in plants is simply a romantic illusion. How could scientists decide whether or not this idea is correct? . . . The story of how the sexuality of seed plants became established as a scientific idea is one of the most fascinating in the history of science. We shall follow some of the highlights of that story in this Case.

How could the Babylonians use this food crop?

The date was actively cultivated as a food crop in Babylonia as early as 2000 B.C. From bas-relief pictures on monuments found in the Near East, we know that the ancient Babylonians believed that date palms could be either male or female. In their domesticated animals, they saw that the offsprings were always borne by the female. By a-

What is the difference between science and technology? [Be sure that you understand this difference, because the point will come up several times later in this Case. -- What has been the relationship between science and technology at various times?]

What do we mean when we say that the ancient Greeks were the first scientists? -- What did they contribute to the science of today?

In what important way are date palms different from most seed plants?

nalogy, they called the fruit-bearing date palms female, and the "sterile", or non-fruit bearing trees, were called male. The ancient cultivators knew that they had to bring the flowers of the male trees together with the flowers of the female trees in order to get any fruit. They conscientiously carried out this procedure, often with ceremonial rites, but they made no attempt to understand the reason for doing it.

What is the difference between science and technology?

The method of getting date palms to produce fruit was passed on through the Babylonian generations and was observed in that country by Herodotus, the great Greek historian of the 5th century B.C. Some one hundred years later, the Greek botanist, Theophrastus, described the methods used in date culture in his book on the History of Plants. Here are his words:

The ancient Greeks are considered to be the first scientists. What do we mean when we say this?

> With dates it is helpful to bring the male to the female; for it is the male which causes the fruit to persist and ripen. . . .The process is thus performed: when the male palm is in flower, they at once cut off the spathe [or sheath] on which the flower is, just as it is, and shake the bloom with the flower and the dust over the fruit of the female, and, if this is done, it retains the fruit and does not shed it. . . .It appears that the "male" renders aid to the "female," -- for the fruit-bearing tree is called "female" --.

In what important way are date palms different from most seed plants?

Now, although Theophrastus was considered the greatest ancient authority on botany and his books on the subject were regarded highly for many centuries, his observations on the palm trees were forgotten. Thus, a possible clue to the understanding of reproduction in seed plants was lost. Dates continued to be cultivated according to the ancient methods, but the means by which flowering plants reproduce remained largely a mystery for nearly two thousand years longer.

(And that's a long time to wait!)

The first scientist of the modern period to voice the belief that seed plants reproduce sexually was Nehemiah Grew. Grew, who lived from 1641 to 1712, was an English investigator, who, together with his Italian contemporary, Marcello Malpighi, founded the science of plant anato-

What is meant by "plant anatomy"?

What kind of organization is the Royal Society of London? -- Who belongs to organizations like the Royal Society? What do these organizations do for the benefit of science?

Where are the stamens and pollen located in the flower? -- [A look at a diagram of a representative flower will help you answer this question.]

Is Grew's idea obtained by scientific methods? Give some reasons for your answer.

What are some essential parts of a scientific method?

Why was Latin used in scientific publications at the time of Camerarius? -- Is the Latin language generally used in scientific publications today? If not, what have we gained by writing in other languages? What have we lost?

my. In a now famous address before the Royal Society of London on 9 November 1676, Grew gave his opinion that the stamens are the male organs of the seed plant and that the pollen acts as a kind of vegetable sperm. If you keep in mind that Grew called the stamens and their attached parts the "attire," you can easily understand this key quotation from his speech:

What is meant by "plant anatomy"?

What kind of organization is this? What does it do?

Where are the stamens and pollen located in the flower?

> But the PRIMARY AND CHIEF USE of the attire [or stamens] is such, as hath respect to the plant itself; and so appears to be very great and necessary. Because, even those plants which have no flower or foliature [or leafage], are yet some way or other attired; either with [semen-containing or flowery] attire. So that it seems to perform its service to the seed, as the foliature to the fruit. In discussion hereof with our learned Sedlian Professor, Sir Thomas Millington, he told me he 'conceived the attire does serve as male, for the generation of the seed.'

Is this idea obtained by scientific methods?

In this quotation, we can see that Grew's idea of the sexuality of seed plants was based on speculations. Grew and Millington also had in mind the possible analogy between seed plants and male and female animals. Although Grew did much important experimental work in his lifetime, he did not attempt any experiments that might confirm or deny the idea of plant sexuality.

What are some essential parts of a scientific method?

The next step was taken a few years later by Rudolph Jacob Camerarius, a professor of medicine at Tübingen, Germany. Camerarius reported his experiments in a book De sexu plantarum epistola, (Letter on the Sex of Plants), dated 25 August 1694.

Why was Latin used in scientific publications at this time?

> Let me begin with a description of the plants, by looking at the flowers. These are the precursors [or forerunners] of the seeds and show two separate parts: petals and stamens. When the latter are fully developed, they have different colors and are a kind of vessel or capsule, each of which is set upon its thread or peduncle, and they open along furrows. They are at that time filled with a fine homogeneous [or uniform] powder, which is spread about. It is this powder which dyes the nose yellow, when one smells a rose or a lily. If you rub it on the hand, it is fine and mealy, and under the microscope it appears in the form of numerous globules, of specific form in each plant, and in some the surface is set with spines.
> (See Exercise 1, page 22.)

(Especially if you have a long nose!)

Special equipment is needed in scientific work.

What name is now used for "the primitive forms of the fruits in the flowers"?

Is the tassel of Indian corn staminate or pistillate?

Do you know of any other plants that have stamens and seeds on different individuals?

Would you like the world to be less complex than it is? -- [There would certainly be some advantages if we lived in a less complex world. For one thing, in a simpler world, there might not be so many differences in plants, and biology students wouldn't have to struggle so hard to learn about these differences. On the other hand, there might also be some disadvantages to living in a less complex world.] -- How do you feel about this? Give some reasons for your opinion.

The stamens surround the pistil, which is a prolongation of the seed-case. In many flowers you find the stamens and the pistil, so long as they are still closed, like sticking one to the other; yet with the swelling of the bud, they separate and grow distinct when the bud unfolds. This pistil or pistils -- according to the species -- is always close to the stamens, in such a way that its cloven [or split] end must be powdered by the pollen of the stamens early and amply.

Are Camerarius's observations correct? -See exercise 2, page 22.

The unfolding of the petals and of the stamens is soon followed by their death. Then, the lower, remaining part of the pistil swells, while its upper part wilts away. Based upon this observation, I opened a flower of the pea family before it had unfolded, in order to study the early state of the pod, which swells after they have done flowering. Against the light or under the microscope, small green vesicles [or bladders] could be recognized in linear arrangement through the membrane, along the dividing line of the tender pod. By continued observation on various flowers, it became obvious that these vesicles are nothing else than the shells of the future seeds. We thus find the primitive forms of the fruits in the flowers. . . .

Observations and ideas go hand-in-hand.

Camerarius next considers the unusual relations of the stamens to the pistils in certain species of flowering plants. As you know, in most flowers the stamens and pistils are located quite close together, but

What name is now used for these "primitive forms"?

In some plants the stamens are so far distant from the pistils that they form a special organ which withers without forming a fruit, while at some distance the pistil and the beginnings of the seeds take origin. This is the case, for example, in the maize [or Indian corn]. In this cereal, the tassel at the end of the stalk is too well known to need a detailed description. After the wilting and drying of this tassel without seed formation, farther down those thick cylindrical spadices [or spikes] are taking shape. These spadices and their grains are covered by some leaves. Protruding from each grain is a long thread, which spreads like a tail and which receives the pollen. . . .(See exercise 3, page 22.)

Is the tassel staminate or pistillate?

In certain plants we find another relation of the stamens to the seeds. In the marigold and in the hop, part of the plants bear flowers, the other seeds. And when we put the mature seeds into the soil, we see that two kinds of plants are produced by them. These are similar and bear the same name, until they prepare for propagation. Then one notices that some bear only staminate flowers and remain without fruit or seed, while others bear fruits but are definitely wanting in petals and stamens. (See exercise 4, page 23.)

Do you know of any other plants that have this characteristic?

Now, the fact that there exist plants with flowers that are not perfect is certainly a nuisance to the biology student, who would like the world to be less complex than it is. However, the existence of such

Would you like the world to be less complex than it is?

Why would experiments with perfect flowers have been impossible for Camerarius to do in his time? --[We'll be sporting and give you the answer to this question, but in return we'd like you to answer the more interesting question which follows right after our answer.]

Experiments with perfect flowers may not have been impossible for Camerarius to do in his time, but it would have been very difficult. For one thing, in the 17th century, he could not easily obtain the tools that he would need for such experiments. He would have to dissect flowers and to remove parts from them. For this, his minimum needs would have been a good lens and a small, sharp cutting instrument, such as a razor blade.

If he were lucky, Camerarius might have had a sufficiently good lens, but they were expensive and hard to come by in the 1600s. There was no mass production of lenses then, as there is today. Each lens had to be laboriously ground by a skilled craftsman. As to razor blades, these were certainly not being manufactured in the 17th century. (Shaving must have been quite a problem in those days.) Thus, one important reason why Camerarius didn't work with perfect flowers probably is that the tools he would need for that kind of experiment were not readily available in his time.

Is it generally true that scientists cannot do certain experiments unless they have the necessary tools available? If so, does progress in science at a given time depend on how far the industries of a country have developed? To what extent?

Do you think Camerarius would have begun such experiments if he did not already have the idea of plant sexuality in his mind? -- Which comes first: the experiment, or the idea?

Would you call this statement Camerarius's hypothesis? [What is an hypothesis in science?] -- If the statement is an hypothesis, is it correct, according to Camerarius's experimental observations?

plants was a boon to Camerarius. He was able to use them in experiments that probably would have been impossible for him to do with perfect flowers. In his first series of experiments, Camerarius worked with plants that had separate staminate and pistillate flowers on the same individual.

Why would experiments with perfect flowers have been impossible for Camerarius to do in his time?

> I have learned in two cases how detrimental to the plants is the loss of the stamens. In the castor oil plant, when I took away the round flowerbuds, [the staminate flowers], before the unfolding of the stamens and prevented carefully the appearance of new ones, I never obtained complete seeds from the remaining intact seed buds, [the pistillate flowers]. The empty seed-coats remained suspended, wilting and drying. Similar was the case with the maize. When the unfolding tassel was cut early, two ears appeared which contained not a single seed. They contained only a great number of empty seed-capsules.

Do you think Camerarius would have begun such experiments if he did not already have the idea of plant sexuality in his mind?

In his next experiments, Camerarius isolated plants of species that bear staminate and pistillate flowers on different individuals.

> The mulberry tree and the dog's-mercury exemplify the group of plants where fruits and [staminate] flowers occur on separate plants. A mulberry tree, which had no others in its neighborhood with flowers, yielded berries. However, they did not contain a single seed. Similarly, the dog's-mercury bearing the seed-part [pistils] was isolated from other flowering plants. It yielded many seeds, but no germinating seeds whatever.

> It seems thus justified to ascribe to the stamens the function of the male organs, and then the seed capsule, with its stigma and pistil, would correspond to the female organ.

Would you call this Camerarius's hypothesis?

To Camerarius, the sexuality of the plants which bear staminate and pistillate flowers on different individuals was not simply an analogy to the sexuality of animals. He declared:

> They behave indeed to each other as male and female, and are otherwise not different from one another. Thus, [these plants] are distinguished with respect to sex, and this is not to be understood as it is ordinarily done, as a sort of comparison, analogy, or figure of speech. It is to be taken actually and literally as such.

However, Camerarius was not satisfied with merely announcing his ideas. He raised questions and doubts about them, and he continued his experiments. He reported three experiments with maize plants and with

Is it wise for a scientist to report his failures? [It may give people the impression that he isn't very competent, you know.] -- Are reports of experiments that did not turn out as expected of any value in science?

What is a theory in science? -- How is it different from an hypothesis? How is it different from a scientific law?

What was the theory of sexuality? -- [This is a tough question. Up to this point, we haven't given you a clear statement of the theory, and now we're asking you to formulate one. Keeping in mind what a theory is in science, try to give as exact a statement as you can of the theory of sexuality. Your statement of the theory will best be made in the form of several short sentences.]

What reasoning by the gardeners would lead to this deduction? Are there any assumptions involved in this reasoning?

Do amateur scientists make many contributions to science today? If not, why not?

Can you explain why there was a greater effect on the leeward side of the field?

Why were the new squashes bitter?

hemp which did not turn out as he expected. This led him to exclaim:

> And what shall I do now, since that deceitful experiment has left me in the lurch?

But, Camerarius need not have despaired! Many naturalists read about his experiments, became interested in his ideas, and carried them forward to later generations.

Is it wise for a scientist to report his failures?

Scientists are human and have human emotions.

Every scientist builds on the work and ideas of his predecessors.

Among those who became interested in the theory of sexuality were persons who could apply it to practical experiments in gardening. They reasoned that, if the theory of sexuality is correct, it should be possible to obtain new varieties of plants in those species where the male and female flowers are separated. This deduction from the theory was soon put to the test by gardeners both in Europe and in the American colonies.

What is a theory in science?
What was the theory of sexuality?
What reasoning would lead to this deduction?

The first report of such a production of new varieties of plants came from America in a letter written by Cotton Mather, the Puritan minister who is better known as a witch-hunter than as a scientist. Nevertheless, Mather was a Fellow of the Royal Society of London. On 24 September 1716, Mather wrote:

Mather was a minister and an amateur scientist. -- Do amateur scientists make many contributions to science today?

> In a Field not far from the City of Boston, there were lately made these TWO Experiments.
>
> First: my Friend planted a Row of Indian Corn that was Coloured Red and Blue; the rest of the Field being planted with corn of the yellow, which is the most usual colour. To the Windward side, this Red and Blue Row so infected Three or Four whole Rows as to communicate the same Colour unto them; and part of ye Fifth, and some of ye Sixth. But to the Lee-ward Side, no less than Seven or Eight Rows had ye same Colour communicated unto them; and some small Impressions were made on those that were yet further off.
>
> Secondly: The same Friend had his garden ever now and then Robbed of the Squashes, which were growing there. To inflict a pretty little punishment on the Thieves, among the Squashes, he planted some Gourds, [which look very much like the Squashes but have a bitter taste] . . .By this method, the Thieves were deceived & discovered & ridiculed. But yet the honest man saved himself no squashes by ye Trick; for they were so infected and Embittered by the Gourds, that there was no eating of them.

Can you explain why there was a greater effect on the leeward side of the field?

Why were the new squashes bitter?

Who are the "philosophers" that Mather mentions? -- Are scientists also philosophers?

Did these attempts provide any evidence for the theory of sexuality? -- Who did this work? For what purpose?

How does a scientist find out about the work and ideas of other scientists? -- [Scientists communicate with one another both in formal and in informal ways. Your answer should include at least two examples of both kinds of ways.]

> Several Useful Hints relating to Vegetation and Agriculture may be taken from these Experiments; which I wholly leave to your Sagacity and that of ye Philosophers, to whom you may see cause to mention them.

Who are the "philosophers" that Mather mentions?

In addition to Mather's experiments, numerous other attempts to produce new plant varieties, based on the idea of the sexuality of plants, were begun in the first half of the 18th century. Thus, this theory was almost immediately put to practical use.

Did these attempts provide any evidence for the theory?

At the same time, the idea of the sexuality of plants made an important contribution to systematic botany, for it was taken up by Carl Linnaeus, the great Swedish classifier of plants and animals. Linnaeus learned about the theory of sexuality from the teachings and writings of Sebastian Vaillant, a French naturalist who was the demonstrator in the Royal Gardens of Paris. Vaillant enthusiastically accepted the theory of sexuality set forth by Grew and Camerarius, and taught it as early as 1702. One of his hearers about this time was Professor Rothman, who was later a teacher of Linnaeus. Vaillant's best-known work on the subject, however, was his opening lecture at the Royal Gardens in 1717. This lecture contained an eloquent argument for the theory of sexuality in plants. It was published the following year in book form, both in French and in Latin, under the titles Discours sur la Structure des Fleurs and Sermo de structura florum (Lecture on the Structure of Flowers). Probably inspired by Vaillant's book and teachings, Linnaeus decided to base his system of botanic classification on the sexual parts of plants.

Men from many nations contribute to the progress of science. - See exercise 5, page 23.

How does a scientist find out about the work and ideas of other scientists?

Now, in the hundred years or so before the work of Linnaeus, the classification of plants was in pretty much of a mess. Many new species had been discovered, notably in the new lands of American and other outposts. European botanists were at a loss to put the large

("Land Ho!" -- "New Plants Ho!")

Why do scientists need to classify their materials? -- Is classification the most important kind of work that scientists do? If not, what is?

Why is it important to be able to quickly identify the genus of a given plant specimen?

To what extent is Linnaeus's system of plant classification still used today?

Did Linnaeus's system provide any new proof for the theory of sexuality? -- [To answer this question satisfactorily, you should first be sure of what we mean by "proof" in science.]

What is the importance of instruments in scientific work? -- How can the development of a new instrument assist scientific investigation? Can you give any examples of this happening?

What is meant by "pollination"?

collections into some useful order. A system was needed to arrange the ever-growing mass of material, and many systems were suggested. By the end of the 17th century, so many systems were in use that it seems that there were almost as many systems as there were people doing the classifying. Yet, few of the systems were particularly satisfactory for all the known plants. (See exercise 6, page 23.)

Why do scientists need to classify their materials?

Linnaeus, then, performed quite an important service to science when he worked out and, in 1735, published what he called the "Sexual System of Classification". The Sexual System was the first workable and convenient arrangement that included all the then-known plants. One of its chief benefits was that it led to a rather quick identification of the genus of a given plant specimen. (See exercise 7, page 24.) Linnaeus' system, which also included a consistent binomial nomenclature and capsule plant descriptions, was a great boon to systematic botany and was widely adopted in the 18th century.

Why is this important?

To what extent is Linnaeus's system still used today?

By basing his system on the sexual parts of the flowers, Linnaeus did much to spread the notion of the sexuality of plants. However, many scientists were still not convinced that this theory was appropriate for plants and would not accept it. What needed to be done to gain acceptance for this idea?

Did Linnaeus's system provide any new proof for the theory of sexuality?

Part of the answer to the problem was provided by Joseph Gottlieb Kölreuter, a most careful German investigator who became Professor of Natural History in the University of Karlsruhe. Using a microscope, Kölreuter examined the details of pollination in numerous typical flowers. This study led him to a long series of experiments in which he used the pollen of one plant species to pollinate the flowers of another species. Kölreuter called this process "hybridization", and

What is the importance of instruments in scientific work?

What is meant by "pollination"?

Why do scientists publish books and papers about their work? -- [This is a double-barrelled question: from the point of view of the advance of science, the reasons are quite clear, BUT, scientists also have personal reasons for publishing books and papers. Your answer should include both kinds of reasons.]

What is a controlled experiment? How might Kölreuter have set up controls in his hybridization experiments? -- Is it always necessary to use controls in biological experiments? Why or why not?

Why is the demonstration that plants of different species can produce fruitful hybrids evidence for the theory of sexuality? -- What chain of reasoning connects this demonstration with the theory? What assumptions are involved in this reasoning?

Was science Sprengel's principal interest? Would you call Sprengel an amateur scientist?

What view of nature is Sprengel expressing in this paragraph? -- Do today's scientists share this view?

the offsprings were called "hybrids". In 1761, Kölreuter published an account of his first results under the title Vorläufige Nachricht von einigen das Geschlecht der Pflanzen betreffenden Versuchen und Beobachtungen, (Preliminary Report on some Experiments and Observations Concerning Sex in Plants). This report was followed in 1763, 1764, and 1766 by three supplementary papers, which recorded the results of 136 distinct hybridization experiments involving 54 different species.

Why do scientists publish books and papers about their work?

We have already noted (page 13 above) that new plant varieties were obtained by gardeners during the first half of the 18th century. Kölreuter, however, carried out the first extensive, controlled experiments to produce hybrids in an effort to provide scientific evidence for the sexuality of plants. He demonstrated that plants of different species can unite sexually and produce fruitful hybrids. In addition, Kölreuter's varied observations gave the first hint on how the pollination of plants occurs in nature:

What is a controlled experiment?

Why is this evidence for the theory of sexuality?

> Everywhere, insects are always involved, in the case of plants in which pollination does not ordinarily occur through direct contact; . . . [The insects furnish, if not to all plants, at least to a very great part of them, this uncommonly great service: for almost all flowers . . . carry something with them that is agreeable to insects, and one will not easily find a flower where insects are not also found in great numbers.

This process of pollination by insects was first fully described some twenty years later by Christian Konrad Sprengel, at the time, a rector in Spandau, Prussia. Sprengel wrote:

Was science Sprengel's principal interest?

> In the summer of 1787, when I examined carefully the flowers of a geranium, I found that the lower part of the petals was provided with fine, soft hairs on the inside and on both edges. Convinced that the Wise Farmer of nature has not produced even one small hair without a definite purpose, I wondered what the purpose of these hairs might be. And it soon occured to me that, on the supposition that the [nectar of the flower is] intended for the food of certain insects, it is not unlikely that there is some provision for protecting the nectar from being spoiled by rain. The hairs might have been placed where they are for this purpose.

What viewpoint of nature is Sprengel expressing in this paragraph? -- Do today's scientists share this view?

How are the insects attracted to the flowers? What characteristics of a flower might serve to attract insects?

What does Sprengel mean by "fertilization"?

Are all flowers pollinated by insects? If not, in what other ways may flowers be pollinated?

How does the "newly-revealed secret" help to establish the theory of sexuality? -- What is the chain of reasoning that connects Sprengel's observations with the theory? Are there any assumptions involved in this reasoning? If so, what assumptions?

Since the flower is upright and fairly big, drops of rain must fall into it when it rains. But no rain-drops can reach the nectar-drops and mix with them, because it is stopped by the hairs above the nectar, just as a drop of sweat running over a man's forehead is stopped by the eyebrows and eyelashes before it reaches the eyes. Yet an insect is not prevented by these hairs from reaching the nectar.

I examined other flowers and found that some of them had certain peculiarities in their structure which seemed to serve the same purpose. The longer I continued these studies, the more I discovered that those flowers which contain nectar are so arranged that the insects can easily reach it, but that rain cannot spoil it.

From these and further observations, Sprengel learned that certain parts of many flowers are specialized for the attraction and feeding of insects. In the following summer, Sprengel carefully studied some species of iris.

How are the insects attracted?

I soon discovered that their flowers can only be fertilized by insects. I looked for other flowers which might be built in such a way that they could be fertilized by insects only. I found that many, and perhaps all, flowers which contain nectar are fertilized by the insects that feed on them. Thus, this feeding is an end for the insects, but for the flowers the one and only means of their fertilization.

What does Sprengel mean by "fertilized"?

The whole structure of such flowers may be understood when the following points are kept in mind:

1. These flowers must be fertilized by one or another species of insects, or by several of them.
2. The flowers must be so arranged that the insects, in their search for the nectar, alight on the flowers, creep into them, and, in doing so, brush off the pollen from the stamens and bring it to the stigma. To receive the pollen, the stigma is covered either with fine hairs or by a sticky liquid.

Are all flowers pollinated by insects?

In 1793, Sprengel published an account of his discoveries in a book with the impressive title, Das neu endeckte Geheimniss der Nature im Bau und in der Befruchtung der Blumen, (The Newly-Revealed Secret of Nature in the Structure and Fertilization of Flowers). In this work, he clearly set forth how the pollen is carried by insects from the stamens of one plant to the pistils of another. Through the activities of insects, reproduction is made possible in the majority of flowering plants.

How does the "newly-revealed secret" help to establish the theory of sexuality?

Now that you are coming to the end of this Case (which is by no means the end of the story of the sexuality of plants), you should be able to summarize how the foundations for the scientific acceptance of the sexuality of seed plants were established. -- What did each of the persons or groups listed below contribute to the establishment of this idea? For each contribution, tell if it was chiefly important as scientific evidence, or as a practical application, or as a means of spreading the idea.

Babylonian date growers -

Theophrastus -

Nehemiah Grew -

Rudolph Jacob Camerarius -

Gardeners of the early 18th century -

Carolus Linnaeus -

Joseph Gottlieb Kölreuter -

Christian Konrad Sprengel -

The major purpose of this Case has been to illustrate what is often involved in the establishment of a scientific theory. -- Is it simply a cold-blooded matter of piling up experimental evidence, or do the personal beliefs of the scientists who work on the problem also play a part?

In one or two paragraphs, write as complete an answer as you can to the question:

What are some of the factors involved in the establishment of a scientific theory?

Thus, we see that, by the end of the 18th century, the foundations for the scientific acceptance of the sexuality of seed plants had been established. But much remained to be done. The details of pollination and fertilization had to be explored and the importance of the sexual process had to be better understood. Many scientists today believe that the idea of sexuality in seed plants was overemphasized by the earlier investigators. In the century and a half since the work of Sprengel, it has been found, from studies of many plant phyla, that all but the simplest plants go through a complex life cycle, which is partly sexual and partly asexual. In the seed plants, the sexual part of the cycle takes up only a relatively brief time in the life of the plant. Nevertheless, the idea of the SEXUALITY OF PLANTS, though greatly modified, remains as a valuable scientific concept.

Experiments and Exercises

1. Examination of Pollen Grains. ::: Collect pollen grains from several different plants. Mount the grains on a microscope slide in a drop of water or in melted glycerine jelly. Examine the mounted grains under the low power of the microscope. YOUR Observations
How do the pollen grains differ? Sketch some of the different shapes that you see. ... Estimate the relative size of the pollen grains, that is, how large are the pollen grains compared with the total size of the plant from which they come? ... Do you think it might be difficult to imagine how a huge tree could start from the minute grains of pollen? Might this be a factor in making the idea of sexuality of flowering plants "hard to take?"

2. Camerarius's Observations on Complete and Perfect Flowers. ::: In the quotations on pages 5 and 7 of the Case, Camerarius described his examination of complete and perfect flowers. Do you know what these adjectives mean when applied to flowers? ... You can easily check on the correctness of Camerarius's observations by carefully examining some representative flowers. Some representative flowers that you might wish to obtain are a rose, a lily, a tulip, a daffodil, an apple blossom, a cherry blossom, or a pea blossom.
   Obtain three or more different flowers to examine and disect. First, identify the basic parts of all the flowers: the sepals, petals, stamens, and pistil. What differences are shown in the sepals of your flowers? How many sepals are there in each type of flower? ... What differences are there in the petals? How many petals are there in each type? ... What are the differences in the shapes and numbers of the stamens? ... Is there only one pistil or are there more than one in each type of flower? How are the pistils alike? How are they different?
   Remove one of the largest of the stamens and draw a sketch of it. In your sketch, label the filament and the anther. Can you locate the pollen grains in the stamen you have removed? What color and shape are they?
   Remove one of the largest of the pistils for dissection. Cut the pistil in half lengthwise. Make a sketch of the section and identify the stigma, style, and ovary. What else can you observe when the dissected pistil is placed under the microscope?
   Do you think Camerarius's observations are correct? Why or why not?

3. Examination of Indian Corn. ::: Indian corn is an example of a plant which bears separate staminate and pistillate flowers on the same individual. Obtain a young corn stalk and locate the tassels and the young ears. Are the flowers of Indian corn complete? ... Are they perfect? ... Explain your answers.
   With a hand lens or under the low power of a microscope, examine one of the tassels to find the stamens. Can you also find the pollen grains? ... Now, turn to the young ears and identify the pistil. What is the shape of the style? Of the ovary? ... In this plant, how do the pollen grains get from the stamens to the pistils? ... If a young ear on a growing corn plant were covered with a small plastic bag, what would be the result? (If you are not sure and can get into a corn field, try it.)

4. Examination of Date Palms. ::: The ancient Babylonians were already aware of the fact that date palms bear different flowers on different individuals. You can check on this observation by examining the flowers of "male" and "female" date palms. Since date palms may be rather hard to come by, you can observe similar structures in flowers from trees which are more common in various parts of this country, such as willows, ash, box elder, or ginkgo. You will have to go to at least two trees of the same species to obtain the flowers that you need. Why?

Examine each of the flowers that you have obtained. Are they complete flowers? Why or why not? Are they perfect? Why or why not? ... Are all flowers which are incomplete also imperfect? Are all flowers which are imperfect also incomplete? Explain your answers. ... Remove a pistil from one of the pistillate flowers and dissect it. Locate the stigma, style, and ovary. How does this pistil compare with that from a perfect flower? (Refer back to Exercise 2.)

5. Science is an international activity. We can best recognize this when we see that many men from different countries often contribute to the development of a single field of investigation. Listed below are the names and nations of men who made some contribution to the growth of the idea of the sexuality of seed plants during the 17th and 18th centuries. Some of these men contributed to the scientific understanding of the idea, some opposed it, and some made practical applications of it. -- Who were these men? What did they contribute to the growth of the theory of sexuality? What other contributions did they make to science and to society? -- The answers to these questions will provide material for some good reports to your class. A visit to the library will help you.

American Colonies	- Cotton Mather, Paul Dudley, John Bartram, William Douglass, James Logan
England	- Nehemiah Grew, John Ray, Thomas Fairchild, Richard Bradley, Philip Miller, Benjamin Cooke, Samuel Moreland, Thomas Andrew Knight
France	- Sebastian Vaillant, Joseph Pitton de Tournefort, Jean Marchant, Edme Giles Guyot, Claude-Joseph Geoffroy
Germany	- Rudolph Jacob Camerarius, Johann Gottlieb Gleditsch, Joseph Gärtner, Joseph Gottlieb Kölreuter, Christian Konrad Sprengel,
Italy	- Marcello Malpighi, Jules Pontedera
Sweden	- Carolus Linnaeus, Pehr Kalm, Johannes Wahlbom, Johannes Haartman
Switzerland	- Johannes Gessner

Incidentally, isn't there something peculiar about the above list? Although there are representatives from seven modern countries on the list, there were certainly more countries than that in the 17th and 18th centuries. Yet, there are no representatives from these many other countries on the list. Why not? Can you give some reasons why one country may produce a considerable number of scientists at a given time while another country does not? What does this mean to us today?

6. Classification. ::: Collect a large number of different kinds of flowering plants. Try to get at least 30 different kinds; 60 is better. ... Now, classify your collection. What basis will you use for classification: color? size? odor? number of petals? shape? - See if you can work out a useful system that will include all the plants in your collection. What do we mean by "useful"? ... Do you see why the systematic botanists of the 17th century may have had difficulties in arranging their collections?

7. Linnaean System. ::: You can arrange your plant collection of Exercise 7 according to the Linnaean System (in simplified form). In this system, the Class and Order of a given plant specimen may be found quite quickly by counting the number of stamens and pistils. The number of stamens determines the Class. Linnaeus used Latin names, but we can simply call them: "Class 1-Stamen,""Class 2-Stamen," etc. The number of styles fixes the plant's Order in each Class. So, under Class 5-Stamen, we might have: "Class 5-Stamen, Order 1-Style," "Class 5-Stamen, Order 2-Style," etc. Once the Order of the plant specimen is found, we can find its Genus in the Linnaean System by considering the form and grouping of the sexual parts, (but don't go that far). ... Can you classify all the plants in your collection by this system? Is this as satisfactory a system as the one you used in Exercise 7? ... Can you suggest any reason why the Linnean System as a whole is no longer used by systematic botanists today?

Sources of Quotations

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pages 5, 7, and 9 — F. S. Bodenheimer, The History of Biology, (London: William Dawson and Sons, 1958). Pages 284-286. -- Translation from the German book, R.J. Camerarius, Ueber das Geschlecht der Pflanzen; De sexu plantarum epistola, 1694, translated from the Latin by M. Möbius, Ostwald's Klassiker der exakten Wissenschaften No. 105, (Leipzig, 1899). (Adapted.)

page 9 (bottom) — H. F. Roberts, Plant Hybridization before Mendel, (Princeton, N. J.: Princeton Univ. Press, 1929). Page 14. -- Translation from Camerarius, op. cit.

pages 11 and 13 — Conway Zirkle, The Beginnings of Plant Hybridization, (Philadelphia: Univ. of Pennsylvania Press, 1935). Pages 104-105. -- From a manuscript letter.

page 17 — H. F. Roberts, op. cit. Page 41. -- Translated from the German, Joseph Gottlieb Kölreuter, Vorläufige Nachricht von einigen das Geschlecht der Pflanzen betreffenden Versuchen und Beobachtungen, nebst Fortsetzungen 1, 2, und 3, 1761-66, Ostwald's Klassiker No. 41, (Leipzig, 1893).

pages 17 and 19 — F. S. Bodenheimer, op. cit. Pages 338-340. -- Translated from the German, Christian Konrad Sprengel, Das neu endeckte Geheimniss der Nature im Bau und in der Befruchtung der Blumen, Ostwald's Klassiker No. 48, (Leipzig, 1894).

Reading Suggestions

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