Human Traits vs. Crucial Experiments

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IN SCIENCE TODAY, as well as in the teaching of science, much is said about the scientific method. Perhaps one of the most widely read recent papers on the subject is John R. Platt's "Strong Inference" (Platt 1964). In this paper Platt discusses at length the so-called "method of multiple working hypotheses" expounded some 70 years earlier by T. C. Chamberlin (1965 ed.). Chamberlin and Platt have much to say about the merits of the impartiality of the investigator and the value of devising "crucial experiments" to test alternate hypotheses. They feel much is to be gained by impartially and cautiously performing these crucial experiments, to select the correct hypothesis from among those proposed and, in so doing, to move surely and steadily closer to the ultimate truth.

This view has many followers. We science teachers, too, stress impartiality and objectivity on the part of our students as they conduct and interpret laboratory experiments.

The purpose of this paper is twofold. First, the credibility of this widely held view concerning the role of impartiality and crucial experiments in science will be questioned. The 18th-century controversy between the Italian physiologist Lazarro Spallanzani and the English naturalist John T. Needham will be analyzed as an historical example. Second, the implications for science-teaching will be discussed.

Where Does Life Come From?

The controversy between Spallanzani and Needham centered on the question of whether animals could come to life spontaneously from inert matter or whether they could arise only from prior life. From ancient times until the Middle Ages everyone believed in the existence of spontaneous generation. Aristotle said that all dry things that become moist and all moist things that become dry engendered animals (Conant 1953:16).

This view, however, was being challenged in the 16th and 17th centuries. One of the first and most influential of the early challengers was the Italian physician Francesco Redi. With a series of very simple but convincing experiments he demonstrated that putrefying meat alone could not produce flies, as was believed; rather, adult flies must first deposit eggs on the meat if young flies are to emerge. These experiments, together with those of the physicist and naturalist René Réaumur, led many people away from the notion of spontaneous generation for a brief time. But at this time early work with the microscope was adding support to the Aristotelian position and further confusing the situation. Many of the newly discovered creatures seem to just appear in infusions prepared from animal and vegetable matter (Conant 1953:17).

Into this climate of controversy came Spallanzani and Needham. Spallanzani was born in 1729 in Scandiano, in northern Italy. He was educated at the Jesuit college at Reggio di Modena, where he pursued an intense interest in science. At 26 he was made professor of Greek logic and mathematics at Reggio (Bulloch 1938:398).

While at Reggio, Spallanzani become involved in the question of spontaneous generation and the origin of microscopic animals—infusoria, as they were called. Spallanzani was familiar with most of the work and ideas of the earlier investigators. Perhaps he was influenced most by Redi's work, for his subsequent experiments show him to be clearly against the idea of spontaneous generation.

The other side of the question was as ardently supported by Needham. He was born in London in 1713 into a well-to-do family. Needham's early studies were taken under the secular clergy at the English college at Douai. In 1738 he was ordained at Cambrai, where he immediately began teaching rhetoric (Cooper 1917). Needham had always interested himself in natural science, and his most important work, including that which concerns us here, involved microscopic examinations.

Infusoria in Sundry Bottles

The controversy between these two men began when Needham, who was determined to show that spontaneous generation was possible, devised what he (and others) considered to be the crucial experiment. This experiment—described in the Royal Society's *Philosophical Transactions* in 1748—was as follows:

Needham put some mutton gravy into a vial, which he plugged with a cork, so that no tiny ani-

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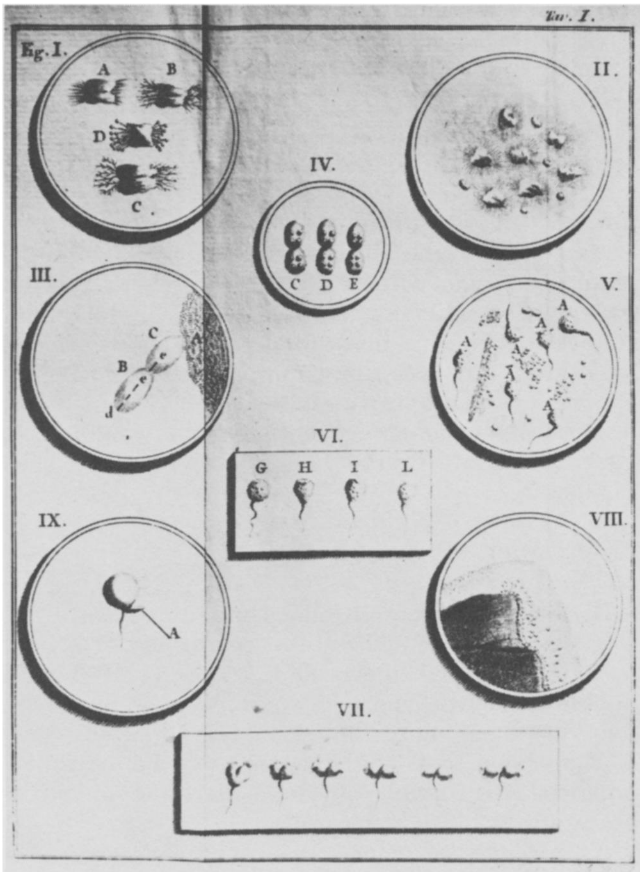

Microorganisms through an 18th-century microscope: a plate from *Opuscoli di fisica animale e vegetable dell' abate Spallanzi* (Modena, 1776), courtesy of the DeGolyer History of Science Collection, University of Oklahoma Libraries.

mals or their eggs could enter from the air. Next, he heated the vial in hot ashes. He felt this would surely kill any living things or eggs that might remain in the vial. He put the vial away for a few days. When he came to examine the gravy, under the microscope, he found it teeming with animalcules (Needham 1748).

This procedure provided hard experimental fact. Needham had demonstrated with his crucial experiment that life can spontaneously arise from dead matter.

In 1750 Needham's major work, *An Account of Some New Microscopical Discoveries,* was translated into French. This brought him into close contact with Count Buffon, an enormously influential encyclopedist of scientific knowledge. Many of the ideas of Needham are found in Buffon's work (which was completed by an assistant after his death). Buffon and Needham made numerous conjectures about the cause or method of spontaneous generation. Eventually (see below) they postulated that a "vegetative force" acted upon inert filaments in the infused organic material to bring to life the animalcules (Buffon 1828).

Needham's influential paper in *Philosophical Transactions* was read by Spallanzani, who, because of his opposition to the idea of spontaneous generation, looked for a flaw in Needham's experiment. He went to work to experimentally prove Needham and Buffon wrong. The results of his efforts were published in 1765 at Modena. This work was translated into French (Spallanzani 1769), perhaps at the request of Needham (Bulloch 1938: 80).

To refute Needham's work, Spallanzani began with the assumption that microbes grew in Needham's vials because the caps of the vials were not tight enough or because the vials had not been heated long enough. So Spallanzani carefully cleaned several flasks, put seeds of various kinds, as well as peas and almonds, into them, and added distilled water. To close the flasks he melted the necks in a flame. Then he boiled the contents—some for only a few minutes and some for as long as an hour. To establish controls he repeated the procedure with another set of flasks, except that he plugged the tops with corks.

Days later, he observed under his microscope what had happened. In the flasks that had been boiled a short time he found infusoria; however, in those boiled for an hour and sealed hermetically he found none. The flasks that had been corked, as Needham had done, were full of infusoria—even the ones boiled for an hour (Spallanzani 1769: 123–138).

Once again a crucial experiment had been performed. This, indeed, seemed conclusive proof that the idea of spontaneous generation was wrong. But now a curious thing happened. Instead of admitting that they were wrong, Needham and Buffon answered Spallanzani in a way that, to many, was quite convincing. Needham reasoned that seeds contained a force that creates life—a "vegetable force." Needham asserted that the fierce heat applied to Spallanzani's flasks had weakened and damaged the "vegetable force" so that it could no longer create the infusoria (Needham, in Spallanzani 1769: 211–217).

This idea of the vegetative force illustrates an interesting point. Spallanzani's crucial experiment had been robbed of its force by the skillful reasoning of Needham. By inventing an alternate explanation, he swayed the mind of many an 18th-century scientist and kept the controversy as hot as ever.

Spallanzani was, no doubt, dismayed by Needham's latest claim. But he saw a possible flaw. Once again, the Italian got out his equipment. This time he set up a whole series of flasks containing seeds, which he heated for various lengths of time. Some were boiled only a few minutes, some for one-half hour, some for an hour, some for two hours; and some were baked until they were charred. After this, Spallanzani sealed the flasks with corks. If Needham were correct, no microbes would be found in the flasks containing charred seeds. Days later, Spallanzani examined the flasks and found that all of them were alive with animalcules (Spallanzani 1776: 14–24).

Surely Needham would not be able to refute this crucial experiment. But refute it he did—with the

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ingenious claim that, while Spallanzani was heating his flasks, he was destroying the elasticity of the air. Elastic air was necessary for the "vegetative force" to work (Needham, in Spallanzani 1769: 217–218).

Spallanzani doggedly set out to disprove this idea. All the flasks he had used previously had wide necks, so heating to seal them required a relatively long time. This, he reasoned, heated and consequently drove out a large quantity of air. The flasks had been sealed when the air inside them was still hot. Days later, the air inside had cooled and contracted, and, when the flasks were opened, air rushed in. This had given rise to Needham's claim of "less elastic" air. Spallanzani, this time, took the same kinds of flasks and partly filled them with seeds and water. Then, by heating, he diminished the necks of the vessels until the opening was almost capillary. After letting the internal air and the external air come to the same temperature, he put the opening to his blowpipe to seal it instantaneously, so that the internal air underwent no alteration. This done, he heated the flasks in boiling water for an hour. Upon opening the flasks nearly a month later, Spallanzani found that a candle-flame was deflected away from the neck. This showed the internal air to be more elastic—not less, as Needham had argued (Spallanzani 1776: 25–44).

Again, a crucial experiment! Needham and his supporters surely would have nothing with which to refute this. Spallanzani had shown tremendous skill in deducing the consequences of his beliefs and putting them to the test.

Indeed, much of the opposition to Spallanzani quieted; but it should be noted that the idea of spontaneous generation was by no means dead. Such distinguished men as O. F. Müller, Treviranus, Lamarck, Cabanis, Burdach, Kützing, and Dujardin still held fast to prior beliefs (Bulloch 1938: 80).

The question of spontaneous generation persisted well into the 19th century. Louis Pasteur's classic attempt to settle the matter is well known. He set up flasks containing nutrient liquid, as others had done before. However, instead of sealing the flasks, he drew the necks out under a flame, so that a number of curves were produced, and some sections of the necks pointed downward, so that air alone might enter the flasks. He boiled the liquid for several minutes. Several days later he opened the flasks and found that no organized bodies had developed in the liquid. "The great interest of this method," Pasteur wrote, "is that it proves without doubt that the origin of life, in infusions that have been boiled, arises uniquely from the solid particles that are suspended in the air" (Pasteur 1862). This, to Pasteur and many others, seemed just as crucial as Spallanzani's experiments. But even Pasteur's logic, clarity, and simplicity of experimentation was not completely accepted.

In view of the failure of these crucial experiments to dispel all doubts, it is interesting to briefly note what two eminent scientists have written on the subject. Charles Darwin, in a particularly perceptive passage at the end of *The Origin of Species,* wrote: "Although I am fully convinced of the truth of the views given in this volume . . ., I by no means expect to convince experienced naturalists whose minds are stocked with a multitude of facts all viewed, during a long course of years, from a point of view directly opposite to mine. . . . [B]ut I look with confidence to the future—to young and rising naturalists, who will be able to view both sides of the question with impartiality" (Darwin 1963 ed.). And Max Planck, in his autobiography, said: "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it" (Planck 1949).

Implications for Science-Teaching

Historical perspective makes one thing clear. Once a crucial experiment has been performed, it always faces the risk of being rendered "uncrucial" by the nimble and surprisingly fertile mind of an opponent. The very meaning of the term "crucial experiment" is challenged, and the existence of the objective, impartial investigator, of whom Platt and Chamberlin wrote, is brought into question.

As teachers of science we must recognize that performing investigations and conducting experiments are not entirely devoid of human bias and emotion. If science is to have its full impact in the schools, the creative, imaginative, and even the emotional aspects of the discipline need to be emphasized. Getzels (1964) suggests that teachers seldom stress creativity in their classes because creative thinking, as well as innovative problem-solving, entails, to a certain extent, a regression to fantasy and childlike modes of thought. Needham's notion of a "vegetative force" could well fall into this category, in the minds of many teachers. Getzels goes on to point out that premature censorship of ideas has inhibiting consequences for creative thinking and problem-solving. And I, like many other teachers, believe that only when students are free to voice their opinions and ideas in an atmosphere in which ideas are openly and freely discussed, debated, and tested is the classroom accurately reflecting the scientific enterprise. Furthermore, it is becoming increasingly clear that only in this way are students led to progress from concrete to the abstract, or hypotheticodeductive, modes of thinking that are characteristic of formal operational thought.

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(Concluded on p. 348)

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taxonomy. The second part of the lesson uses the BSCS Inquiry Film *The Prairie Chicken.*

Day 8. The students visit a field that is partly mowed and partly unmowed. Which abiotic factors are most important in causing the differing vegetation? The students make sketches of the field. They are told about the different kinds of plants.

Day 9. We are back in the field, collecting data. Students work in groups to obtain a part of the data. Both abiotic and biotic data are collected.

Day 10. The field data are accumulated, and the students discuss possible explanations of the differences in vegetation. They are asked to suggest how the use of pesticides might affect this field.

Day 11. The content of the PAK is pulled together, from the framework established on the first day, and a quiz is given.

Students' Responses to the Program

How successful has been the inclusion of social issues in the biology curriculum? Last year we conducted two surveys of our students. One was an end-of-the-year general survey of attitudes; the other (conducted by Melba James and Ed Schmidt for presentation to the Missouri Science Academy) compared social-issues biology with traditional biology.

The general attitude survey of the students showed the following:

1. 97% thought the inclusion of social issues was great, and more than 50% wanted more of the social-issues lessons.

2. When students were asked to pick what they considered to be the three most important social issues and the three least important issues, the student's responses gave varying ratios of best–least importance; for example, drugs and mutations had 33 "best" for each "least" response, and overpopulation had 9 "best" for each "least." Only one of the 16 social issues was overwhelmingly rejected: the lesson on monocropping. (This lesson was altered this year to include the issue of strip mining as another example of land use and its effect on succession.)

3. In the section in which the students could express their opinions about the course, the bulk of the comments centered on the materials of the course and the usefulness of the course.

The second study was set up so as to be computer-scored and statistically analyzed. It surveyed the 10th-, 11th-, and 12th-graders who had taken biology or were taking biology. In all three grades, similar biologic concepts had been taught; in many cases even the same basic learning materials had been used. The major difference was the use of social issues as a unifying theme for the biologic concepts. An analysis-of-variance test showed four significant differences ($P < 0.01$) between those who took social-issues biology and those who did not: the social-issues biology students indicated that the course (i) was not frustrating, (ii) was easy, (iii) was such that they learned more in it than in any other academic course they had taken, and (iv) was such that they learned more than they had expected.

There have been other indications of success. The number of sections of advanced biology increased from one section to four sections. In addition, last year's students have been "public-relations personnel": when we returned to school last fall, preenrollment in biology had jumped by 100!

These findings have encouraged us to continue on this path of making biology a useful subject to help students to develop a greater understanding of social issues and to acquire skills for dealing with them.

Acknowledgment.—Our colleagues Elizabeth Rosenbaum and Victor Phillips, who teach biology, were participants in the development of the course; indeed, they might well have been listed as coauthors.

Human Traits . . . from p. 336

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