"Science 100," 1963—64

Original papers are used as textbooks in a university course for nonscience students.

H. H. J. Nesbitt and John Hart

It is generally agreed, at least among scientists, that it does nonscience university students no harm to absorb some science during their early undergraduate years. But the way to help them do this is not agreed upon at all. We suggest that two kinds of general science courses usually available, which may be roughly classified as "history and philosophy" on the one hand and "the nature of the world" on the other, do very little to impart what science really is, and what scientists really do. There is quite a strong body of opinion opposed to the general science approach; the opponents favor a scheme in which all students take a few specialist courses primarily designed for science students. In our opinion even the most imaginative and well-planned specialist course program conveys little of the true nature of scientists to the science student; that feeling comes later, often in graduate school. The arts student may be completely out of place in the specialist course and is unlikely to derive any lasting benefit from it.

The Intention

We were faced with the problem of imparting to arts students, in 26 weeks, a smidgen of what science is all about. The course had to convey a sense of the scientist's participation in the progress of science, a feeling not necessarily engendered by even the most imaginative "Elementary Laboratory, 3 hours per week." We wished to establish the idea that progress in science is irregular and at times haphazard, that scientific papers are not always masterpieces of great clarity, and that scientists may on occasion err. We wanted to show that technology has through the ages been a constant and inseparable companion of research. Finally, we thought that, at the end of the course, there should be plenty of unanswered questions, science being essentially an open-ended business. In retrospect, we believe that the course has progressed some way toward these goals and that it might do science students, as well as arts students, a great deal of good to be subjected to this discipline. (An experiment along those lines will be tried this year at Brock University.)

The authors are, respectively, dean of science at Carleton University, Ottawa, and director of science studies, Brock University, St. Catharines, Ontario, Canada.

The Course

We thought that our objectives might be met if we could find as a course topic for "Science 100" a subject rather narrow in itself but with wide implications and general public interest. The prerequisites in mathematics and other technical subjects were to be minimal. We wanted a field with an active current literature and yet a clearly defined history. Our idea was to trace the history of the subject chronologically through a judicious selection of papers from the original literature, including papers in closely allied fields, treating each paper as though it were fresh off the press with no interpretation or textbook digest available, and considering at each stage the technology available at the time of publication for the pursuit of further experimental work. The accent throughout was on contemporaneity. The question to be asked all through the course was, "What would *you* do next?"

Genetics, and in particular the biochemistry of genetics, is a suitable topic. We listed papers in this field and in peripheral fields of mathematics, chemistry, physics, and technology. We decided that experiments should be performed only as demonstrations, since we are not entirely convinced that the elementary laboratory teaches nonscience students very much. We were, of course, ready to use films and other audiovisual aids.

It turned out that the mathematics, physics, and chemistry papers were readily available in the original (or in literal translations thereof); the genetics papers that we had chosen (by something approaching serendipity) were available in the paperback *Classic Papers in Genetics*, edited by James A. Peters (*1*). We decided to use articles from *Scientific American*, provided they were more or less contemporary with the paper being discussed. This plan was criticized by some students, who preferred to stick to the original papers.

It is hardly necessary to give an outline of the course. The genetics started with Darwin and finished with Crick, Watson, Benzer, and even more recent work. Early in the course there was a discussion of the influence of iron and coal technology on science, and papers in chemistry from Paracelsus to Prout were studied. Here the inevitable discussion of the difference between "How?" and "Why?" developed naturally from the literature, and the change in scientific thought in the mid-17th century, as personified by Boyle, was covered. Subsequently, such topics as elementary statistics, polarimetry, chromatography, and chemical bonding were discussed, always with reference to contemporary papers.

Things the students learned that they might not have got out of a more conventional course make a long list. They discovered quite early that original papers are difficult to read, and there was, not unexpectedly, an early crop of dropouts. The students who persisted learned, particularly from the work of Boyle and Lavoisier, how painstaking the early scientists were, and how they were held up for want of good instruments, particularly balances. As the course progressed, some of the students were vociferous in comparing the "wooliness" of the writing of more recent scientists with the beautiful, detailed accounts of Lavoisier. The more intelligent students, even those who had previously taken little chemistry or physics, were able to follow the chemistry papers and to arrive at an idea of what equivalent weights and chemical bonds represented.

Mendel's paper brought the students their first contact with statistics, and playing-card experiments were used with great effect. We compared the playing-card results with those of Mendel and were puzzled because Mendel's seemed to be a little better than they should have been! At this stage we made no mention of genes or chromosomes, but we did introduce such nomenclature as "zygotes." We established the "$A + 2Aa + a$" ratio, and persuaded the students to form a Punnett square. Bateson and Punnett's papers on the physiology of heredity were studied in detail. What was revealing here was the original misinterpretation of the data, and the subsequent correction. Hardy's paper on a mixed population was also discussed in some detail, and led to further criticism of Mendel by the students. Unfortunately, many of them are, we are sure, still not clear as to the difference in the populations chosen by Mendel and by Hardy.

Sturtevant's paper on sex-linked factors in *Drosophila* really made our students think, the more so since Sturtevant appears to have made a small and not very specific adjustment in some of his numerical results. Students found that they had to read back through Morgan's paper to get the background. The significance of the sex-linked characteristics in determining crossover points had to be explained in extreme detail, from models. The students wondered why long distances gave fewer crossovers than might be expected from the elementary statistics.

Wright's paper on color inheritance provided a suitable place for pausing to discuss the situation in organic chemistry at the end of World War I. It also provided an excellent introduction to the action of enzymes.

The next paper studied was that of Muller, in which he describes the artificial transmutations of genes; Peters (*1*) thinks that this paper "represents the beginning of a new epoch in genetic history." We agree, and therefore at that stage in the course we tried to deal with some modern physics and chemistry. Here we found that we were no longer able to use original articles; instead, we went to articles in *Scientific American* on the relevant topics: the role of amino acid residues, the α-helix, binding between chains, and so on. We studied the hydrogen bond in some detail, and discussed the structure of DNA and RNA. Finally, we referred to Crick's paper "On the genetic code" (*2*) (not in Peters' book) and showed where knowledge of the genetic code stands today.

The questions on the final and half-term examinations were roughly divided into five categories: (i) the influence of technology on science; (ii) "What is science, really?"; (iii) some facts of genetics; (iv) some facts of physical science; and (v) "What experiment would *you* do next?"

Student Performance

Many of the immature entering students apparently thought the course might be a "snap." They were speedily disillusioned. They had to work hard, interpreting papers in a field well outside their previous experience. Some of the early complaints were revealing. The students complained that they had to search the library for books to help them interpret the papers; they complained that the course itself was as "woolly" as some of the papers; and many of them, without even trying, dismissed the whole thing as being far too esoteric for them. On the other hand, the more intelligent and more mature students, particularly those who had already had a year of arts courses, were highly interested and read widely. A few wanted more time to read the "real" science books that they had theretofore avoided. As might be expected, the final results reflected very strongly the degree of initiative and self-reliance of the student.

Future of the Course

We think we are on the right track. We have shown that good students can learn a great deal from original papers in a field new to them—far more, we believe, than they can learn from a conventional textbook on modern science. By deliberately restricting the field we ensure that the course has depth, and by making necessary excursions into relevant peripheral fields we have introduced breadth, too. After all, this is exactly how a scientist operates. He has to plough his way through previous work; he acquires the skills and knowledge that are relevant to his specialty; and he has to devise experiments in which modern technology is used to the utmost. There is no doubt that many of the criticisms of the course are justified. It has been a bit disorganized, simply because this is the first time such a venture has been attempted, and the necessary papers have not always been available to the students, nor has enough background material been available in the bookstore and library. Still it appears that the students, whether they participated actively in the course or were merely passengers, have been shown something of the real nature of science—the glamour, the frustration, the waiting, the complexity. Whatever their occupation after leaving the university, they will, we hope, remember the experience rather than the facts and understand a little more of the true nature of science and scientists than if they had taken a conventional general science course as their science elective.

References

1. J. A. Peters, Ed., *Classic Papers in Genetics* (Prentice-Hall, Englewood Cliffs, N.J., 1959).
2. F. H. C. Crick, *Science* **139**, 461 (1963).