THE NEED FOR PHILOSOPHY OF SCIENCE IN SCIENCE EDUCATION

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It has been said that one can not really know a thing until he knows how he knows it. This remark might be further enlarged to say also that one can not really know a thing until he knows what he knows. I shall take the position in this paper that there are some aspects of scientific knowledge which we normally relegate to philosophy of science but which more logically should be carefully integrated into the science curriculum. The aspects of scientific knowledge which I shall consider are:

(a) the methods used in the search for scientific knowledge,
(b) the logical nature of scientific knowledge, and
(c) the relation of scientific knowledge to reality.

I shall attempt to show in what follows that some consideration of these matters can make a substantial contribution to the education of both the science major and the general student.

Let me emphasize at the outset that what I advocate is *not* the addition of a required course in philosophy of science. Rather I propose that the courses we have be taught from a changed point of view. Let us first see how such a change would modify our concern for methodology.

METHODOLOGY. In most elementary texts, whether they are slanted toward general education or toward introduction to a specific discipline, there is a paragraph, a section, or a chapter devoted to what the author calls *the* scientific method. I want to emphasize the word *the* in this phrase. Usually, the content of these textual passages on the scientific method can be summarized or suggesed by a sequence of infinitives—to observe, to infer or hypothesize, to deduce, to test or confirm. This, I say, is done in the elementary text. In the more advanced work it is usually simply assumed that the student knows what scientific method is and the *piece de resistance* of the course is pursued.

Now while this view of scientific method may be defensible enough, I believe that it is superficial and avoids coming to grips with the *ways* in which man establishes scientific knowledge. In a recent publication J. J. Schwab[8] has maintained that there are *four* methods by which men create scientific knowledge. Schwab is tentatively of the opinion that there are only four methods. These methods for creating and establishing knowledge result in four kinds of products—that is, in four kinds of knowledge.

The first method is that of classification. Geology with its categories of rocks is an example of a science some of whose content results from classification. Other such sciences are zoology, botany, medical syndrome, and chemistry.

The second method is that of establishing equations to describe the functional relationships between measurable variables. In physics the laws of falling bodies are algebraic equations relating the measurable variables of distance and time and are exemplary of knowledge produced by this method. Chemistry and some of the newer phases of biology also employ this method in the search for knowledge.

A third method for producing scientific knowledge is that of model building or analogue construction. This may also be called metaphorical or *as-if* science. Astronomy through the work of Hipparchus, Ptolomy, Copernicus, and Kepler employed this method. The observed motions of the sun, the moon, and the planets are describable *as if* they occur in this or that model of the solar system. Genetics builds models containing genes which are used by the geneticist to systematize the observed characteristics of a hereditary line. The "model" character in atomic theory is so prominent that one sometimes speaks of the Thomson, Rutherford, or Bohr models of the atom.

The fourth method is somewhat troublesome and I have placed it last in this list for that reason. It is the determination of cause. Cause-and-effect apparently means many things to many people. In some cases the boundary lines separating cause-and-effect science from classification science, equation science, and model science become very vague. Witness the fact that we sometimes speak of grossly theoretical entities such as genes and electrons as causes; yet these theoretical entities were created in our models and analogues to *be* causes. This is quite a different sort of notion from that of too much aspirin causing palpitation of the heart. However, according to Schwab, despite the semantic difficulties with cause, physiology and sociology produce a kind of cause and effect knowledge which cannot in any sense be confused with classification science, equation science, and model science.

So much for the kinds of scientific method. Now we customarily study only the products resulting from the application of these methods to our observational data. What advantages are achieved by the inclusion of some study or at least some awareness of scientific methods themselves? I shall list four reasons why some explicit study of methods should be undertaken.

To begin with, at the general educational level, I believe that a kind of scientific study of science itself has important value. It may indeed be worthwhile for the general student to be exposed to our formalized or systematized knowledge, to the laws of falling bodies, to present day conceptions of genetics, or to the notions of the distinctions between inorganic and organic compounds. But it is of at least comparable importance for this general student to have some conception of the problems involved in the search for knowledge. Last year the federal contribution of tax-payers' money to research and development was about 1.1 billion dollars; a very sizable portion of this money went into research in pure science. In a democracy it is the general citizen, our erstwhile general student, who as voter, congressman, or commission member must understand that tax money supporting research buys the application of scientific methods, not well-established laws and theories.

Furthermore, the explicit study of scientific methodology will bring out all its facets. The student will be aware of the essential differences in the activity of the zoologist concerned primarily with classification and that of the chemist attemping to determine the structural model of a complex organic molecule. Or he will appreciate the different concerns of a geologist seeking the cause of a particular formation and a physicist attempting to establish an equaticn relating some statistical parameters of the nucleus.

Moreover, a study of scientific methodology would acquaint the student with the hierarchy of appropriateness of the four methods. F. S. C. Northrop[2], among others, has pointed out that none of the other methods is appropriate prior to some application of classification. After classification the determination of equations and causes becomes applicable. And, to culminate his efforts, the investigator may construct his models and analogues. An appreciation of this hierarchy of appropriateness makes understandable the differences in the stages of development of the physical, the biological, and the social sciences. Those disciplines which have yielded most easily to the application cf all four methods are physics and chemistry and are normally considered the furthest developed; on the other hand, those disciplines in which man has been able to advance but little beyond classification are the least developed.

A comprehension of these matters by physicists and chemists would do much to create in them a sympathetic attitude toward the problems of the social scientist. Such an understanding would do much to stop naive pronouncements such as "The social sciences are not really sciences", or "Those guys ought to wake up and begin to apply the scientific method", or the like. Rather, one who understands scientific methodology will realize that the social scientist who is busily classifying is doing exactly what he should be doing, but that he is attempting to do it in a matrix considerably more complex than that through which the physicist and chemist has already moved.

The values stemming from methodological study, which I have outlined above, have been argued to be general educational values. As such, of course, they are also values for the professional man—the M. D., the technician, and the engineer—and for the science major who is preparing to do research or to teach. For the latter, however—the science major—I believe there are some additional values to be achieved through study of method. The research man should be more effective in his work if he has some perspective of scientific method and if, in terms of that perspective, he comprehends more clearly what he is trying to do. The teacher, quite obviously, if he understands scientific methodology, will be better able to contribute to a richer general education of the general student and to aid in producing more effective research men.

In what I have said before I have talked of methodology. I should like to turn now to another aspect of philosophy of science which in my opinion deserves consideration in the science curriculum—the logical nature of scientific knowledge.

LOGICAL NATURE OF SCIENTIFIC KNOWLEDGE. Under this heading we can consider only two matters and those but briefly. They are mechanism and causality.

By mechanism I mean the philosophy of science which developed after the first great success of Newton's laws. In this philosophy it became the ultimate goal of every scientific endeavor to create a mechanical model in which material particles moved according to Newton's laws of motion. However, dual or wave-versus-particle nature of light, the lack of ether drift, the discovery of the quantum of action—these things all seem to be inconsistent with mechanism. Moreover, with the advent of quantum mechanics around 1925 physicists began to abandon mechanical models of the atom and to substitute mathematical models.

Yet it is quite true that we think in great measure in mechanistic terms. In our desperation to hang on to mechanistic terms we have introduced certain paradoxical, confusing, and ambiguous phraseology in which we speak of the particle nature of waves or the wave nature of particles. Now such figurative speech is, of course, necessary for the communication of ideas, but it is only acceptable when its users are quite clear about the metaphors being used. I think that such clarity of understanding can only be achieved by the study of the underlying philosophies of science. In my opinion an explicit consideration of the different possible philosophies would greatly increase the effectiveness of science education at the higher levels.

On the other hand at the general education level it seems to be imperative that we find ways to teach our students to think in terms other than mechanistic. Otherwise, the teachable aspects of physics and chemistry are going to antedate 1925. Then, in a few years our teaching of science will have a relation to modern science similar to that which Euclidean geometry bears to modern mathematics. On the other hand if he learns early in his schooling to grasp some non-mechanistic conceptions he will be able to take qualitative presentations of modern science in his stride.

Casuality, in spite of its variegated shades of meaning, has quite obviously been a very fruitful concept in the development of scientific knowledge. Pragmatically its employment should be continued wherever it yields results. However, it seems to me that one who thinks in terms of cause should understand as clearly as possible what he is doing. He should be prepared to parry the thrusts of logical positivists such as Philipp Frank[1] who literally drops the concept of cause out of the window.

One might also mention here that relativity theory destroys the ordinary notions of simultaneity and succession. Hence, for some observers, effects and causes appear in interchanged roles. Causalists have to make some kind of peace with these matters and they cannot really know their knowledge until they have done so. Such considerations, in my opinion, belong in the science curriculum which produces research and teaching personnel.

Scientific Knowledge and Reality. The questions to be asked here are of the sort: In what sense are atoms real? We know atoms only by inference, so, can we consider atomic structure in the same way that we can consider the structure of a chair? We have immediate sensory contact with chairs and can declare our statements about chairs to be true or false in terms of these sensory contacts. We have no such immediate contacts with atoms and statements alledged to be true about atoms must be regarded in quite a different light. I have in mind here such facts as that I was taught in college that all atomic nuclei after hydrogen contain protons and electrons—neutrons were not mentioned. In the literature and in the classroom this statement seemed to be just as true as the statement that all chairs have seats.

There are two points to be made here. One is that in atomic theory, our picture of atoms is simply our picture of atoms. It makes no more sense to refer to parts of the atomic theory as reality than it does to say that a photograph of a tree is a real tree.

The other point to be made in this connection is that since knowledge is only representation of reality, it is tentative. Atomic nuclei comprised of electrons and protons were parts of a picture which tentatively represented reality. We now have a new picture—one building nuclei out of protons and neutrons. Who knows just how tentative our new representation of reality may be?

CONCLUSION. Our science curriculum has concerned itself too much with facts and information. Even theories presented dogmatically become, in the minds of the students, simply facts and information. It seems to me that, if our teaching is to meet the challenge of his age, we must show more concern for the origins and the nature of knowledge.

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