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ABSTRACT

Analyzed is the relationship of different guiding principles of inquiry to the "topics" of inquiry: problems, facts, hypotheses, interpretations, and conclusions or outcomes. The idea of structure-function is given as an example of one guiding principle in biological inquiry, and homeostasis as another. It is argued that the guiding principle used determines how the subject matter is analyzed, so that problems, facts, hypotheses, interpretations and outcomes will be seen differently and related to each other in different ways under different guiding principles. The implications of this analysis for curriculum development are discussed. (EB)

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THE ROLE OF PRINCIPLES OF ENQUIRY IN THE CONDUCT OF ENQUIRY AND IN CURRICULUM DEVELOPMENT[1]

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Curriculum Development and the Notions of Unity and Diversity in Scientific Method

For years textbook writers, teachers, and science educators acted as if there was a scientific method. "The Scientific Method" was the common phrase. Few, of course, hold this view any longer. Unity has been replaced with diversity. We now read of the methods and patterns of scientific enquiry and of the method described by philosopher X, and the method described by philosopher Y. From the perspective of curriculum development and instructional practice, however, it is not obvious that the newer notion of diversity is the more adequate one. In fact, as I will show there are curricular merits in both. A comparison of the two views suggests three criteria to be fulfilled by an adequate curricular statement of scientific method.

First, in contrast to the tone of much criticism of the unity notion by proponents of diversity, the difference between the two positions lies primarily in the degree of generality by which they account for scientific method. From the perspective of curriculum development, both extremes are inadequate simply because they do not give direction in the selection and organization of content. At the one extreme, the unity notion is so general that any enquiry, including the sort of thinking pursued in daily life, may be included. Accordingly, any content will do, and we are no better off than we would be without a description of method. At the other extreme, the diversity view is so specific that each research paper is seen to have its own method. Accordingly, virtually all contents must be included and we are, again, left without curricular guidance. In the first case one example is illustrative of all possibilities; while in the latter case one example illustrates only itself.

Our examination of these extremes leads to our first criterion of a curricular statement of scientific method: *An adequate statement of method is sufficiently general to include reasonably large amounts of the subject matter under consideration, and is sufficiently specific to exclude subject matter with significantly different method.* This suggests that in curriculum development an analysis and description of the significantly different methods of enquiry of the field of study should be made.

Second, one of the strengths of the unity notion is that its traditional statement, drawn from Dewey's Logic,[2] refers to a commonplace set of topics in enquiry, namely problem, fact, hypothesis, interpretation, and conclusion. These topics are, of course, normally accounted for by the various statements following from the diversity view but, since the account is in terms of a particular theory of enquiry, the possible meanings of the topics may be lost to the learner. In short, the significance of these topics in understanding scientific methods may be minimized as the student becomes involved in methodological detail. The contribution of the diversity view to our understanding of these topics is in showing that the topics play legitimately different roles in different enquiries. For instance, facts may be seen as given by the subject matter, selected for a particular problem or invented to fill the demands of a particular hypothesis. We have arrived at our second criterion of a curricular statement of scientific method: *An adequate statement of method treats the topics of problem, fact, hypothesis, interpretation, and conclusion and, depending on the subject matter, allows for different ways of seeing the topics.*

Third, one of the strengths of the diversity notion is that the various statements of the methods exhibit various relations among the common topics.

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2 Dewey, John. Logic: The Theory of Inquiry. Holt, Rinehart, and Winston, Inc., Chicago, Illinois, 1938.

For instance, in some cases problems are seen as growing out of previous statements of outcomes whereas in other cases unexplained facts are seen to give rise to problems. In still other cases problems are seen as arising from conflicting possible interpretations of facts while in other cases problems are seen as the starting point for enquiry. This situation is in contrast to the four or five step-by-step linear relation in the unity view. Our third criterion of a curricular statement of scientific method emerges: *An adequate statement of method allows for different possible relations among the common topics.*

Let us turn to our description of method, based on the work of Schwab[3] and Connelly[4]. We shall then return to the three criteria and show how the method is in accordance with these criteria.

Principles of Enquiry

Enquiry begins and is governed by conceptions of how the subject matter may profitably be analyzed for enquiry. These conceptions are not ordinarily recognized by the enquirer but, rather, they exist as unstated principles of enquiry. Principles dictate the way in which the enquirer should divide his subject matter into parts, and they further dictate the kinds of questions to be asked of the subject matter. An example of such a guiding conception is the notion of structure-function in biology. Enquiry governed by the principle of structure-function

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3 Schwab, Joseph J. "What Do Scientists Do?" Behavioral Science 5: 1-27; 1960.

4 Connelly, F. Michael. "Conceptual Structures in Ecology with Special Reference to an Enquiry Curriculum in Ecology." Unpublished Doctoral Dissertation. Department of Education, University of Chicago, Chicago, Illinois. 1968.

begins by analysing the subject matter into component parts. For example, an ecological community may be divided into producers, consumers, and decomposers; and a cell may be divided into the nucleus, cytoplasm, mitochondria, and vacuoles. The research then seeks to describe the functions of each of the parts. The following description of the biological principle of homeostasis is a more extensive illustration.[5]

The Principle of Homeostasis

According to this principle, the biological subject matter is organism-as--part-of-entire-world. "Organism" is distinguishable from "environment" only by virtue of its maintained inhomogeneity with the raminder of the object. The mechanisms by which this individuality is maintained are called "homeostases."

The aims of research are, first, to discover what materials, substances, conditions, or constituents are homeostatically maintained in a state of relative balance and, second, to discover the mechanisms for maintaining these homeostases. Accordingly, the research treats pairs of elements as reacting to one another. Research concerned with discovering mechanisms proceeds by modifying one element and by recording changes in the second element. Claude Bernard's study of the control of blood sugar level is a physiological case in point.[6] Bernard first establishes the relative constancy of blood sugar level in dogs by varying their starch intake. Next, under conditions of no starch intake, he attempts to

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5 The principles of biology, as described generally by Schwab, are reported in Connelly. "Conceptual Structures in Ecology."

6 Bernard, Claude. An Introduction to Experimental Medicine. trans. by Henry Copley Green. Macmillan Co., New York, New York, 1927.

trace the control of the sugar content of blood by determining the sugar level in blood entering and leaving a number of organs. From these data, he discovers that the liver acts as an agent of compensatory withdrawal through storage, and as an agent of compensatory replacement through release of the stored sugar.

One of the error sources in research conducted according to the conception of homeostasis lies in the fact that two or more controlled factors may be mutually or commonly controlled. This is the case for carbon dioxide pressure and oxygen pressure in the blood. As Haldane notes, "If we diminish rapidly and very considerably the pressure of oxygen in the inspired air," the two factors interact in such a way that "the final result is a compromise, in which the breathing is only slightly increased."[7]

Fact

Facts are commonly treated as if they were fixed bits of evidence given to enquiry by the subject matter. Thus, it is common to say, "What are the facts?", as if this was the sole basis for judgment of an idea or theory. As we have seen, the principle governing enquiry dictates how the subject matter is to be analyzed. Accordingly, the principle dictates what will and will not pass for a fact in enquiry. For example, an enquiry using the structure-function conception will look for parts that are factually described in terms of size, shape, composition, and relationship to other parts.

Facts are best seen as selected representatives. Given enquiries using given conceptions, select a sample of data upon which the enquiry is based. Gregor Mendel, for example, in his well-known studies of inheritance, was exclusively

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7 Haldane, J.S. The Philosophical Basis of Biology. Doubleday, Doran and Co., New York, New York. 1931, pp. 53-54.

concerned with traits showing discrete inheritance, such as tall-short, green--colorless, wrinkled-round. Mendel deliberately rejected all traits showing other forms of inheritance, such as size, a trait showing continuous variation.[8]

Mendel's work is especially interesting since it points up still another aspect with respect to data, namely, that data are often experimentally constructed, some would say "created," by the enquiry. The data on which Mendel's 3:1 ratios are based--for instance, 3 round peas: 1 wrinkled pea--are not found naturally. Plants growing in the wild do not exhibit 3:1 ratios. The ratios appear as artifacts of a highly controlled experimental situation. It is also of interest to note that in no case do the data give 3:1 ratios. The famous ratios are abstractions from actual ratios that are only close to the abstractions; for example, from 3.16 : 0.94. The experimental construction of empirical ratios and the subsequent abstractions are in accordance with Mendel's rational principle, which leads him to look for formal mathematical laws applicable to a wide range of situations.

Problem

A problem arises in enquiry when certain aspects of data in given situations are explainable, and others are not. The determination of which data fit and are explainable depends on the state of knowledge with respect to the problem, and on the particular principle governing the enquiry. The first of these, the state of knowledge, simply reflects the fact that enquiry is an ongoing process. The products of any given enquiry become starting points for still other enquiries. For example, Mendel begins his paper by pointing out that ornamental plants exhibit regularities in their inheritance, and that some characteristics disappear in one

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8 Mendel, Gregor. "Experiments in Plant Hybridization," in Classic Papers in Genetics. James A. Peters, Editor. Prentice-Hall Inc., Englewood Cliffs, N.J. 1959.

generation and appear in the next. For principles governing enquiry, we notice that different conceptions provide different terms for problem formulation. For instance, in studies on the circulatory system, one way of stating a problem on heart motion, based on a structure-function conception, is to ask, "What structures are associated with the motion of the heart?". Another way of stating the problem, based on a homeostasis conception, is to ask, "What are the imputs, translocations, and outputs of the heart?".

Hypotheses

Hypotheses are best thought of as being tentative explanatory ideas. These ideas grow out of known facts (some of which fit, while others do not) appropriate to a given problem and are used to explain the lack of factual fit, and to make predictions about other possible facts. Situations, often experimental, are devised to gather these possible facts. Taken together, both sets of facts--the facts with which the enquiry begins and the possible facts--act as the bases for modification and verification of the hypotheses. The form in which a hypothesis is framed depends on the principle of enquiry. Thus, in our circulatory system example, a hypothesis guided by structure-function will refer to parts and functions, while a hypothesis guided by homeostasis will refer to a balance of factors, imputs, and outputs.

Interpretation

The movement from given facts (some of which fit, while others do not) to hypotheses; from hypotheses to given facts and new facts generated by the hypotheses; and back again to a revised hypothesis, may be thought of as a process of interpretation. Facts and hypotheses are not directly connected in the sense that one inevitably gives rise to the other. The process is analogous, in some respects, to light filtration in which the analogue of interpretation is a light filter. Thus, white light passed through a red filter comes out red, and when passed through a blue filter it comes out blue. Furthermore, both binary orange light (orange composed of red and yellow) and binary green light (green composed of yellow and blue) come out yellow when passed through a yellow filter. Returning to interpretation, and in analogy with the two filtration cases, we say that the same facts can give rise to different explanatory ideas, depending on the interpretation; and that different facts can give rise to the same explanatory ideas, depending on the interpretation. The "filter" in this interpretation process is the conception or principle governing the enquiry. The direction of movement, as an interpretation is made, is guided by the principle. For instance, two biologists looking at the same data on heart motion will explain the motion in different ways if one thinks in terms of structure-function and the other in terms of homeostasis.

Outcome

The outcomes of enquiry, whether limited statements of knowledge, of concepts, or of full-blown theories, arise from the processes described previously. Outcomes amount to the best explanations available at any point in time. They are not, as commonly treated in science textbooks, fixed and final products of enquiry.

Outcomes are developed in terms of certain principles and depend on certain kinds of selected and constructed facts. Often in a discipline there are competing statements of theory and of concept definition. These differences arise, of course, because of the different governing principles and different possible facts that can be chosen for enquiry. Learning theory in psychology is a case in point and, in biology, the competing claims of different plant ecologists are illustrative.[9] Palmer has described an excellent example in his paper on honey bee communication,[10] in which the familiar von Frisch dance description and interpretation is challenged.

To summarize, we have described six very general characteristics of enquiry: principle of enquiry, fact, problem, hypothesis, interpretation, outcome. From the perspective of curriculum development and instructional practice, these characteristics of enquiry give rise to five very general characteristics of statements of knowledge:

1. The meaning of a statement of knowledge depends on the logic, the pattern of enquiry, that gave rise to the statement. In this sense, textbooks tend not only to reduce the complexity of meaning but, in stressing one or another single meaning and definition, tell lies.
2. Knowledge, as found in journals and books, is not true or right but, rather, the most adequate account of the world at any given time.

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9 Connelly. "Conceptual Structures in Ecology." Concepts such as "dominance," "succession," and "tolerance" are given different meanings and are thereby used differently by ecologists using different ecological principles of enquiry. Furthermore, in three of the five ecological problem areas, four principles are used, giving rise to a total of eighteen significantly different forms of ecological knowledge.

10 Palmer, Wendel K. "A Student Investigation of Classical and Recent Research Papers on Honey Bee Communication Designed to Illustrate, Through Discussion, Patterns of Scientific Enquiry." The Workshop on Enquiry Materials Development in Science, Prepared for The Ontario Institute for Studies in Education. The University of Toronto, Toronto, Ontario. Summer, 1969.

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3. Knowledge statements change in the ongoing process of enquiry. Enquiry does not terminate in the sense suggested by textbooks.
4. Knowledge is neither solely discovered nor solely invented. There is a sense in which enquiry imposes ideas on subject matter, and a sense in which ideas grow out of the subject matter. Some people prefer to call this process "construction."[11]
5. Logical processes of enquiry have intellectual and material components. The processes are not, as most proponents of laboratory instruction would have it, a mere matter of manipulating and working with things in a laboratory. Nor, as most textbooks suggest, are these processes adequately seen as a formalized sequence of steps.

Summary

Let us summarize by showing how our description of enquiry meets the three curriculum development criteria for statements of scientific method. First, the general statement of the method is divisible into as many types as there are principles of enquiry operating in the subject matter. There are, for instance, four such principles in biology: antecedent - consequent, structure-function, homeostasis, and regulation.[12]

Second, our description of method includes the commonplace topics of enquiry. The way each topic is treated depends on the principle of enquiry, so that, for

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[11] James T. Robinson. "The Nature of Science and Science Teaching." Wadsworth Publishing Company, Inc., Belmont, California. 1968.

[12] Connelly, "Conceptual Structures in Ecology."

example, in one enquiry an appropriate fact is one of structure, while in another enquiry an appropriate fact is one of interaction. The description of the use of a particular principle of enquiry includes an account of the commonplace topics and gives rise to a characteristic pattern of enquiry.

Third, the commonplace topics are related to one another according to the dictates of the particular principle and the corresponding pattern of enquiry. Interpretation plays a special role, since all of the logical movements among the commonplaces--such as fact to hypothesis, problem to hypothesis, hypothesis to tentative outcomes, outcomes to possible facts--are movements of interpretation in terms of the guiding principle.