DOCUMENT RESUME

ED 097 198 SE 017 478

AUTHOR	Connelly, F. Michael; Binns, Richard W.
TITLE	Logical Reasoning in Science Education [and an Annotated Bibliography].
INSTITUTION	ERIC Information Analysis Center for Science, Mathematics, and Environmental Education, Columbus, Ohio.
PUB DATE	Mar 74
NOTE	48p.; Occasional Paper Series - Science
AVAILABLE FROM	Ohio State University, Center for Science and Mathematics Education, 244 Arps Hall, Columbus, Ohio 43210 ($1.50)
EDRS PRICE	MF-$0.75 HC-$1.85 PLUS POSTAGE
DESCRIPTORS	*Annotated Bibliographies; *Cognitive Processes; *Curriculum; Educational Research; Instructional Materials; Learning; Logic; *Logical Thinking; Philosophy; *Science Education; Scientific Enterprise

ABSTRACT

This paper on logical reasoning in science education was written from a philosophical, rather than a psychological, orientation within an overall curricular framework. Six areas are treated within this curricular framework: philosophical consideration, logical structure in a field of enquiry, materials development and evaluation, epistemological characteristics, student development and use of logical reasoning in science, and evaluation-research activity. In each area, selected studies are cited and briefly discussed. Research methodology is stressed throughout the paper. An annotated bibliography intended primarily for the use of researchers in science education is included and consists of materials from educational and research journals, curriculum project newsletters, and doctoral dissertations. The references are classified according to the six areas of the paper, with those articles found most useful in developing the paper identified by asterisks. (PEB)

SCIENCE EDUCATION INFORMATION REPORT

SCIENCE EDUCATION INFORMATION REPORT

THE ERIC SCIENCE, MATHEMATICS AND ENVIRONMENTAL EDUCATION CLEARINGHOUSE
in cooperation with
Center for Science and Mathematics Education
The Ohio State University

SCIENCE EDUCATION INFORMATION REPORTS

LOGICAL REASONING IN SCIENCE EDUCATION

by

F. Michael Connelly
The Ontario Institute for Studies in Education
University of Toronto
Toronto, Ontario
CANADA

LOGICAL REASONING IN SCIENCE EDUCATION
AN ANNOTATED BIBLIOGRAPHY
by

F. Michael Connelly
and
Richard W. Binns

The Ontario Institute for Studies in Education
University of Toronto
Toronto, Ontario
CANADA

ERIC Information Analysis Center for Science,
Mathematics, and Environmental Education
The Ohio State University
1800 Cannon Drive
400 Lincoln Tower
Columbus, Ohio 43210

March, 1974

SCIENCE, MATHEMATICS, AND ENVIRONMENTAL EDUCATION INFORMATION REPORTS

The Science, Mathematics, and Environmental Education Information Reports are being developed to disseminate information concerning documents analyzed at the ERIC Information Analysis Center for Science, Mathematics, and Environmental Education. The reports include four types of publications. Special Bibliographies are developed to announce availability of documents in selected interest areas. These bibliographies will list most significant documents that have been published in the interest area. Guides to Resource Literature for Science, Mathematics, and Environmental Education Teachers are bibliographies that identify references for the professional growth of teachers at all levels of science, mathematics, and environmental education. Research Reviews are issued to analyze and synthesize research related to science, mathematics, and environmental education over a period of several years. The Occasional Paper Series is designed to present research reviews and discussions related to specific educational topics.

The Science, Mathematics, and Environmental Education Information Reports will be announced as they become available.

Occasional Paper Series - Science

The Occasional Paper Series (Science) is designed to review literature related to specific topics or educational programs related to the teaching and learning of science. We hope these papers will provide ideas for implementing research, suggestions for areas that are in need of research, and suggestions for research design.

Stanley L. Helgeson
and
Patricia E. Blosser
Editors

This publication was prepared pursuant to a contract with the National Institute of Education, United States Department of Health, Education, and Welfare. Contractors undertaking such projects under Government sponsorship are encouraged to express freely their judgment in professional and technical matters. Points of view or opinions do not, therefore, necessarily represent National Institute of Education position or policy.

TABLE OF CONTENTS

LOGICAL REASONING IN SCIENCE EDUCATION

F. Michael Connelly
The Ontario Institute for Studies in Education
Toronto, Ontario, Canada

In dealing with its topic this paper assumes a different and somewhat broader perspective than might be expected from the title: "different" in that "logical reasoning" per se suggests a psychological orientation, whereas mine is philosophical, and "broader" in the sense that the overall framework is curricular. Within this curricular framework six areas, rather than the suggested one, are treated. While this prevents an indepth treatment it permits a more adequate account of the curricular concerns of this paper. Research methodology is stressed throughout.

The following paragraphs contain a brief explanation of the curricular framework and its accompanying philosophical perspective. This is followed by a treatment of selected studies in each of the six areas - philosophical consideration, logical structure of a field of enquiry, materials development and use of logical reasoning in science, and evaluation-research. An account of each area describes its connection to logical reasoning, identifies its major methodological characteristics, and summarizes results of selected research.

THE CURRICULAR FRAMEWORK

Studies strictly focused on student reasoning are studies in pyschology. There is a long record of such research, some of which has been done in science education.[1] But such studies in science education without

[1] See, for example, Maurice Belanger, "Learning Studies in Science Education, Science and Mathematics Education," Review of Educational Research, Vol.39 (1969), pp.377-395.

reference to their curricular context, amount to no more than the doing of psychology with science subject matter. From a curricular point of view the inadequacy of such studies is seen in the problem of translating theoretical perspectives and research outcomes into curriculum plans, and in the fact that philosophical rather than psychological perspectives are of primary importance to science education. The following paragraphs treat each of these matters in turn.

Translation of Psychological Knowledge into Curricular Plans

One useful way of thinking about the translation problem is to see it as a question of moving from "is" to "ought" in which the singular "is" resulting from research on logical reasoning is connected with multiple possible "oughts" in curriculum planning. For instance, given controlled conditions such as student age, and degree and kind of teacher intervention, and guided by a notion of how concepts correspond to phenomena, it may be found that students develop specific and flexible reasoning strategies for the induction of concepts. Knowing this, what "ought" to be the curriculum developers' plans? For good reasons the developer may be uninterested in logical reasoning and simply ignore the research. Supposing, however, that he is committed to logical reasoning he will have to diagnose the characteristics and needs of his students and match these with the conditions under which the research was done. From this process, he may, quite tentatively, decide that "X" ought to be done. However, another planner with different-aged children, or in a different community with different socio-economic characteristics, may decide that some variant of "X" or even "Y" ought to be done.

But the translation problem is even more complicated since there are several viable conceptions of logical reasoning. For instance, following Belanger,[2] there is "concept learning," "problem solving," "inductive-deductive learning," "guided discovery," "creative thinking," and "critical thinking." The complication arises since the developer may be committed to a different conception of logical reasoning than that which guided the research. In such a situation, the developer may ignore the research,

[2] Ibid.

or he may decide to twist or modify the findings to more or less fit his notions.

The diversity associated with the "is-ought" character of the translation problem is further complicated by recognition of two major modifying agents, the teacher and the materials of instruction. These agents enter in not merely as annoyances to be circumvented, for example, by teaching-proofing of materials or by student remediation consistent with the materials, but as effective determiners in their own right. Accordingly, even when he has settled upon a set of "is-ought" connections based on his consideration of his students and of the conception of logical reasoning governing the research in question, the curriculum planner needs to give further consideration to the characteristics of the teachers and of the materials in which the ideas on logical reasoning will be embodied. This point has been dealt with on another occasion.[3] Suffice it here to note that matters such as the language adopted by the teacher and by the materials developer; the sense of authority on the truth and soundness of knowledge claims adopted by the teacher and the materials-developer; and the extent of independent student logical thinking encouraged, can potentially alter a student's development of logical reasoning ability. Thus, for the curriculum planner, what ought to be done is further conditioned. Taken together the various conditioning variables in curriculum planning are so important as to reduce the "is" to the status of another conditioning variable. Research outcomes are simply one of those variables considered by the planner as he matches curriculum variables of a particular setting.

To summarize these remarks on the translation problem, we note that there are <u>no necessary</u> curricular "oughts" for any "is" on logical reasoning, and there are multiple <u>possible</u> curricular "oughts" for any single "is". Furthermore, the "is" of a research finding is itself best seen as a conditioning variable on what "ought" to be done. Research aimed at being useful in practice avoids "controlling" the conditioning variables and, instead, takes them simultaneously into account. Various

[3] F. Michael Connelly, "The Functions of Curriculum Development," Interchange, Special Issue on School Innovation, Vol.3, Nos.2-3 (1972) pp. 161-175.

kinds of methodologies of such curriculum oriented research are described below for six areas.

Our consideration of these curricular complications of the translation problem serves to dispel simplistic notions of the potential power of psychological studies. But such consideration has the danger of swamping the researcher and science educator in a sea of diversity and circumstance. To prevent this effect, it remains for us to take a stand, a philosophical one as earlier noted, and to generate a relatively simple framework for dealing with logical reasoning.

A Philosophical Stand[4]

For purposes of this paper two points will serve as indicators of the reasons for seeing science education problems from a philosophical perspective. One point is that curriculum, however conceived, rests on the classical question "What knowledge is most worth learning?" Problems of knowledge are only superficially seen in terms of the constructs and understandings of particular fields of enquiry. In their more useful generic sense these questions are epistemological and are concerned with the nature of knowledge and of knowing. It is the hypothetical connections between knowledge and knowing, and of the learner's personal power and freedom in logical reasoning that guides the selection of particular curricular content and the forms of logical reasoning worthy of developing.[5] Given these connections it is possible to frame specific psychological research questions on logical reasoning that have to do with empirical capability under specified conditions of, for example, developmental stage. Briefly stated, psychological perspectives are herein seen as secondary and derivative of philosophical perspectives. This first point is well illustrated in the six areas treated below.

---

[4]See, F. M. Connelly, "Significant Connections Between Philosophy of Science and Science Education," Studies in Philosophy and Education, Vol. VII, No.9(in press).

[5]A more extensive and detailed connection is developed in F.M. Connelly's "Patterns of Enquiry and Conceptual Knowledge Structures in the Curriculum" (working paper)

The second point in support of the philosophical stand is derived from my observations on the science curriculum development activity of the 1950's and 60's. While this activity began with philosophical concerns for knowledge and for enquiry, it was largely dominated by the works of a few psychologists, notably, Bruner, Ausubel, Gagné and, to a certain extent, Piaget. An examination of the science curricula governed by the first three of these psychologists shows that each inadequately conceptualizes scientific knowledge and leads to unsupportable instructional recommendations.[6] The identified limitations are the result of implicitly embodying conceptions of knowledge and knowing in curriculum materials which were derived from psychological notions of cognitive structure and of how it develops and functions, rather than from philosophical considerations of knowledge structures and of how they develop and function in fields of enquiry and in the mind.

This brief account of the philosophical perspective is not intended as a defence of the perspective but only to introduce the philosophic orientation of the curricular framework. We now turn to the framework itself.

Philosophically Oriented Curriculum Framework

The philosophically oriented curricular framework used in this paper is schematically represented in Figure 1. The figure is to be taken as a useful representation for purposes of this paper and not as a hypothetical model or quasi theory about logical thinking. The arrows indicate one thing having an effect on another and the boxes represent important variables, subject to research, which determine the development of logical thinking in instructional settings. Labels A-E indicate those areas with which the author is most directly concerned and on which this paper is focused. For each of areas A-E the connection between the area and logical reasoning is described and is followed with a description of one or more studies. Each of these is described according to its aim, methodology, and significant outcomes. Methodology is emphasized and its significance relative to logical thinking is stressed.

---

[6] Ibid.

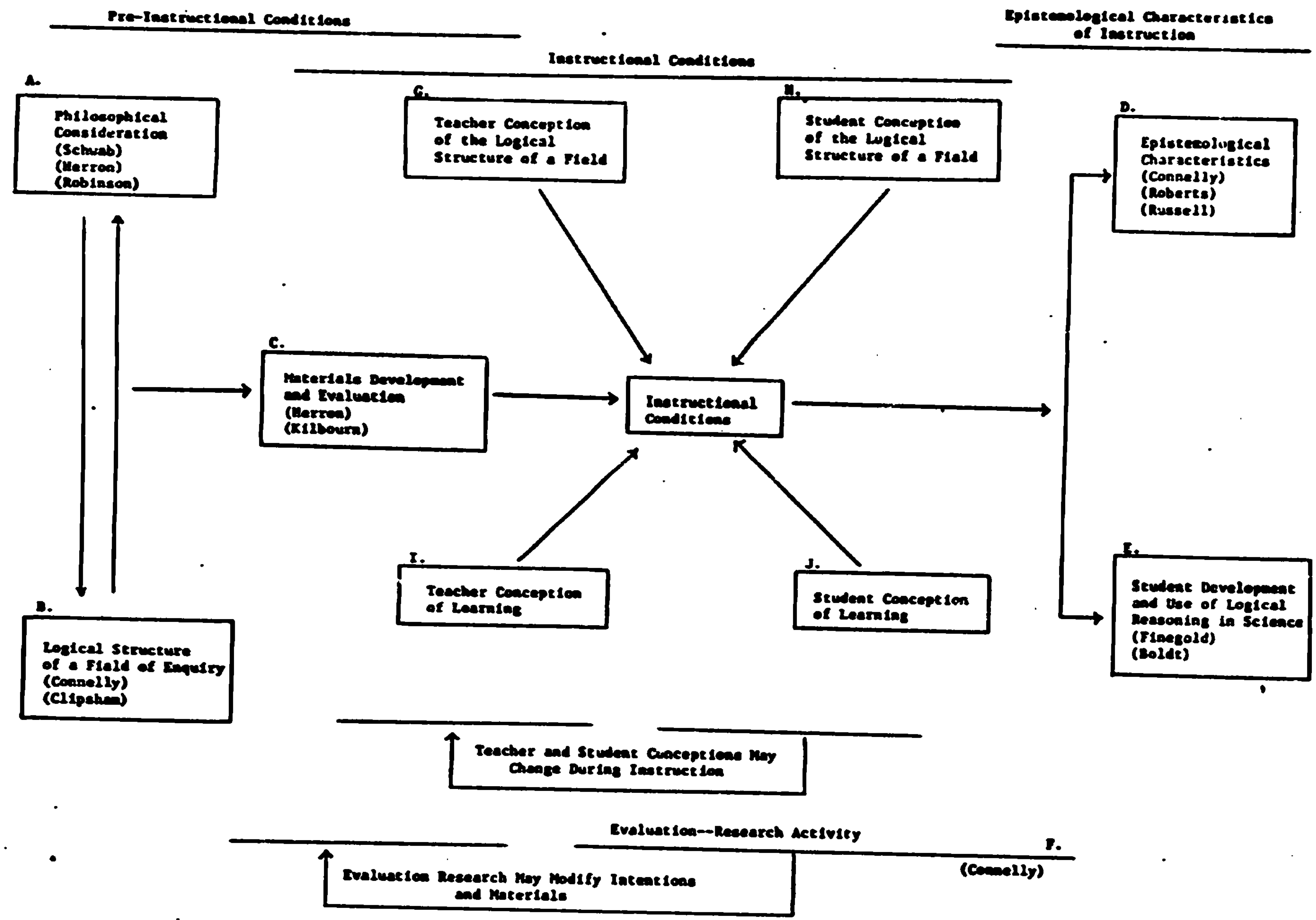

Figure 1: A Philosophically Oriented Curricular Framework for the Consideration of Student Logical Reasoning Ability in Science*

*Listed Authors—are treated in the text

THE SIX AREAS

A. *Philosophical Consideration*

The connection between this area ahd logical thinking has already been established in my introductory remarks. Suffice it to say that the philosophical aspects of greatest significance are epistemological; concerns which have found their way into the science education literature under the headings of "structure of knowledge" and "enquiry". The writings of Schwab, Herron and Robinson are described below.

Schawab's aim was to provide a set of principles adopted by scientists in the course of enquiry[7] and to describe their educational possibilities.[8] I have used Schwab's methodology in my study of ecology described in the next section and I will not repeat the account here. The significant outcome of Schwab's work is an account of five forms of principle of enquiry. Principles of enquiry serve to bound subject matter for purposes of investigation and they provide the analytic terms and the patterns of enquiry in terms of which our understanding of the meaning of knowledge claims in science is enriched. An important element in this enriched meaning is the increased understanding of the limitations and tentativeness of knowledge claims seen against a background of selected and omitted data and against a principled interpretation of data.

The significance of this work for logical reasoning is that science students are provided with a framework for viewing scientific knowledge and, given an appropriate instructional methodology, for developing habits of thought with respect to the recovery of meaning and the evaluation of scientific knowledge. These points are described more fully in my account of area "B".

---

[7]See, for example, J. J. Schwab, "What Do Scientists Do?" Behavioral Science, Vol.5, No.1 (1960), pp 1-27; and G. W. Ford and Lawrence Pugno (eds.), The Structure of Knowledge and the Curriculum (Chicago: Rand McNally and Co., 1964).

[8]See, for example, J.J. Schwab, "Enquiry, The Science Teacher, and The Educator," School Review, Vol.67 (1960), pp 176-195; and, "The Teaching of Science as Enquiry," The Teaching of Science (Cambridge: Harvard University Press, 1962).

Herron's work is closely allied theoretically to that of Schwab. His aim was to provide a methodology for revealing, comparing and contrasting accounts of enquiry found in a diversity of philosophic positions and subsequently in a diversity of science curricula.[9] His recommendation is one of the more interesting described herein and is useful both in philosophical analysis and in graduate level teaching. Herron advanced five commonplaces of enquiry - agent, method, scientific data, fact and what passes for fact, scientific knowledge and dynamics of revision. The commonplaces constitute a set of topics which any reasonably complete account of scientific enquiry should be expected to treat. Herron's metaphorical account of them reads:

> The situation might be likened to a game of "mosaic making" in which all participants must use the same given universe of pieces. A player is not required to construct a "complete" mosaic and, hence, need not use all of the pieces at his disposal. The individuality of each "artist's" mosaic resides in the permutations and combinations of the pieces, set in relationship to one another. Our position in this "game" would be to identify and describe each of the available pieces in such a way that our account will be useful in characterizing any one of the mosaics in terms of the pieces used in its construction and the matter in which they relate to one another.[10]

Herron demonstrated the usefulness of his commonplaces in a comparative account of the works of John Dewey, Albert Einstein, Charles S. Pierce, and William Whewell, and in the evaluation of curriculum materials as described in area C. The significance of Herron's recommended methodology for logical reasoning in science derives from the fact that different philosophical systems see knowledge and its generation in different ways and these differences yield different forms of reasoning appropriate to them. Contrast, for example, the appropriate instructional "reasoning" goals for a curriculum using Einstein's idealized approach to knowledge with one using Pierce's pragmatic approach.

---

[9] Marshall D. Herron, "The Nature of Scientific Enquiry," School Review, Vol.79 (1971), pp.171-212.

[10] Ibid., p.178

Whereas Herron was concerned to understand philosophic diversity, Robinson's aim was to give an account of enquiry which was, as much as possible, common to all sciences.[11] The methodology used by each author was similar, namely, to read a variety of philosophic accounts in search of common features. But whereas Herron's analytic features were revealing of diversity, Robinson's were descriptive features shared in common by different writers. The major notions put forward by Robinson were "correlational procedures," "exact procedures," "rules of correspondence," "metaphysical principals," and "constructs." These were weaved into an integrated network which in and of itself stands as a philosophic statement. The physical and biological sciences were seen to differ in their degree of emphasis on correlational procedures.

The significance of Robinson's methodology and findings for logical reasoning is that a common orientation to thinking about knowledge claims in science could be adopted for all sciences. Such an orientation could be of use, say, in providing a basis for "reasoning" goals in general science courses. Robinson did not make instructional recommendations which would lead to specific training in logical reasoning about scientific knowledge but he did provide an extensive set of "understandings" which would provide the orientation within which such reasoning would take place.

B Logical Structure in a Field of Enquiry

The significance of this area for logical reasoning is located in the fact that the design of curriculum materials inevitably, whether deliberately sought or by implication, sets out a conceptual framework of the subject field. Prior logical analysis of the field ensures that sound philosophical conceptions (area A) are both tested and used in the organization of content prior to materials production. The writings of Connelly and Clipsham are described below.

The first aim of Connelly's study was to give an account of ecological method useful in the construction of a curriculum aimed at illuminating

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

the significance and soundness of ecological knowledge.[12] A second aim was to develop instructional recommendations associated with this account which would yield student capability in the recovery of meaning and in the evaluation of ecological knowledge claims. The method was to read a wide range of research papers and to classify the logical forms seen to be operating there. This identification of forms was based on the way problems were bounded for enquiry, on the kind of data that passed as evidence, on how interpretations of the evidence were made, and on the terms in which the research findings were presented. These four attributes led to the identification of an overriding principle of enquiry in the research. In turn, an account of the attributes in terms of principles led to the description of a characteristic logical pattern of enquiry. In short, conditions were seen to be imposed on the problem, data, interpretation, and research outcome by the guiding principle of enquiry.

The significance of this account of method for logical reasoning is that the resulting forms of knowledge - that is, the principles of enquiry - are forms of knowledge as experienced. This follows from the fact that research papers are the recorded experience of men operating on subject matter to achieve knowledge and a state of understanding. Thus, the principles of enquiry are at once forms of knowledge and forms of experience. They are a structure of the world of living things as experienced in enquiry. As such, they give the logical framework for understanding the nature of ecology and for understanding the development of ecological ideas.

From the point of view of the curriculum, the structure of ecological experience becomes a structure for a learner's experiencing of ecology; that is, it becomes a framework into which the learner fits, interprets, and evaluates knowledge claims in ecology. Thus, the forms for the research study of ecology and for the logical reasoning required of the student with respect to ecology are one and the same.

---

[12] F. Michael Connelly, "Conceptual Structures in Ecology with Special Reference to An Enquiry Curriculum in Ecology" (unpublished Doctoral dissertation, University of Chicago, 1968).

Clipsham is currently utilizing a similar methodology for examining issues at the science society interface[13] by applying the biological principles of enquiry described by Schwab and Connelly. He is elaborating a conception of patterns of argumentation to account for the prescriptive policy oriented literature associated with science; and he is elaborating a comparative terminology, largely derived from Aristotle's physics and ethics, for simultaneously talking about science and science society issues in a single curriculum.

The significance of Clipsham's work for logical reasoning is to distinguish between reasoning modes appropriate to science and to science society issues and to describe the conditions to be fulfilled by a curriculum aimed at encouraging a recognition and use of the appropriate reasoning modes on the part of students.

C. Materials Development and Evaluation

Curriculum materials embody the theoretical ideas of developers and may be more or less transparent to those ideas. Even when materials are not explicitly designed in terms of the development of logical reasoning abilities, their organization will reflect on logical reasoning possibilities. Accordingly, certain unintended learnings with respect to logical reasoning will likely follow. The significance of investigations of curriculum materials is that their potential for the development of logical reasoning may be assessed. A comparative evaluation of their potential with the developer's intentions may be advanced, as in the work of Herron described below, or against an independent standard provided by the evaluator, as described in the work of Kilbourn.

Herron's aim was to evaluate the degree to which four National Science Foundation texts reflected stated developer intentions on enquiry and the structure of knowledge.[14] His methodology was to apply the notion of

---

[13] John Clipsham, "Organizing an Enquiry Curriculum for the Study of Issues at the Science-Society Interface," (dissertation in progress, Toronto: The Ontario Institute for Studies in Education).

[14] Herron, Ibid.

commonplaces described in area A; his accounts of enquiry for five philosophers; and Schwab's more general notions about scientific enquiry described in area A, to each of the selected textbooks. While his analytic armory was more sophisticated than required by the textual material, he was able to show that each of the texts gave inadequate accounts of enquiry. The significance of his study is seen, for example, in his finding that the CHEM Study course had only 25% of their exercises devoted to encouraging students to reach generalizations inductively and that there was a decided empirical orientation in the materials such that techniques of accurate observation and controlled experimentation were emphasized. From the point of view of logical reasoning CHEM Study students would tend to rely on the teacher and the text for assumptions and starting points required in reasoning about knowledge claims and they would, furthermore, tend to emphasize empirical over conceptual aspects in their reasoning.

The aim of Kilbourn's study was to develop a method for analyzing knowledge claims in textbooks.[15] He utilized Scheffler's three conditions of knowledge - truth, evidence and belief - as his recommended methodology. For each of these he used further philosophic writings to develop a set of five questions to be asked about propositional knowledge claims in a text. He demonstrated the usefulness of his terms by analyzing a six-page passage on human evolution from the BSCS Blue Version text. Whereas Herron's method was to read the entire text and, using selected examples, to make general statements about it, Kilbourn's method was to select a specific passage and to undertake a detailed analysis of it.

Kilbourn's study makes no instructional recommendations nor, for that matter, any direct evaluative comments on the analyzed passage. Its significance for logical reasoning lies in its power for revealing textual provision for answering the question "How do we know X?"

---

[15] Brent Kilbourn, Analyzing the Basis for Knowledge Claims in Science Textbooks: A Method and a Case Study. Background Paper No.6, The Explanatory Modes Project, Douglas A. Roberts, Principal Investigator (Toronto: The Ontario Institute for Studies in Education, 1971).

D. *Epistemological Characteristics*

This area consists of epistemological studies of classroom instruction. The significance of this area for logical reasoning lies in the fact that during instruction the determining elements of logical reasoning come to bear on the learner. The work of Connelly, Roberts and Russell is described below.

Connelly's work is aimed at describing epistemological characteristics in instruction within the context of a particular orientation to the philosophy of science and a particular mode of instruction.[16] Methodologically, the notion of commonplaces has been adopted and work has tentatively begun with five: the teacher, the student, the materials of instruction, the phenomena of science, and the ideas of science. These topics provide the bounding elements for conceptualizing instruction in epistemological terms. For each topic two questions are asked, "What is the role of (e.g., the materials) in instruction?" and "What is the relationship of (e.g., the materials) to (e.g., the ideas) of science?" For instance, for the first question, two of the possible roles of materials in instruction are as the authoritative source on the content of science or as the stimulus to discussion. To illustrate the second question, note that materials and ideas may be related, such that materials are seen as the embodiment of ideas which need only to be extracted; as an auxiliary resource to science ideas developed otherwise in instruction; or, as data sources for stimulating independent student induction of science ideas. The procedure has been to develop an instrument of about forty items on an agree-disagree continuum and to apply it to teachers on a pre-post instructional basis. Furthermore, it is planned to use the framework, but not the instrument, for analyzing classroom discourse. The significance of this work is that the instructional correlates of students' logical reasoning in science may be identified.

---

[16] This work is part of The Patterns of Enquiry Project, directed by F.M. Connelly in association with Merlin Wahlstrom and Menahem Finegold. For a brief description of this project see, Finegold and Connelly, Orbit, 11 (1972) pp.3-7.

Roberts has undertaken an extensive series of studies in this area through his work with graduate students. The aim of this work is to describe, and ultimately evaluate, the worth of science instruction in general.[17]

Whereas Connelly's approach to the epistemology of instruction is to develop analytic notions of instruction from a direct examination of it (guided, of course, by a broad-based philosophical concern), Roberts and his students deliberately explore a variety of philosophical positions in order to generate useful analytic frameworks for the analysis of instruction. For example, Russell used Toulman's The Uses of Argument to generate a framework for analyzing science teaching episodes.[18]

E. Student Development and Use of Logical Reasoning in Science

This area consists of studies in children's reasoning processes in the context of instruction. Its significance for logical reasoning is that the topic is treated in a subject-matter context, rather than as an abstract generalized process. The work of Boldt and Finegold is described below.

Boldt's aim was to attempt a conceptualization of children's science learning in terms of Kuhn's notions of "prescience paradigm" and "prescience paradigm shift."[19] Using these notions Boldt's emphasis was on the conceptual frameworks, i.e. the paradigms, which would account for children's handling of laboratory results. In Boldt's view, logical reasoning is a function of the paradigms used by children and, as these paradigms shift so, it might be expected, would the child's reasoning.

---

[17] Douglas A. Roberts, About The Explanatory Modes Project, Bulletin No.2 (Toronto: The Ontario Institute for Studies in Education, April, 1972).

[18] Thomas L. Russell, "Analyzing the Kind of Authority Suggested by Arguments in Science Teaching" (Qualifying Research Paper, Department of Curriculum, The Ontario Institute for Studies in Education, 1971).

[19] Walter B. Boldt, "Application of Thomas S. Kuhn's View of Science to Teaching: An Exploratory Study," paper presented to the National Association for Research in Science Teaching (Vancouver: University of British Columbia, 1969), Mimeo.

Boldt's method was to train fourteen teachers whose role was to facilitate "natural" responses from children investigating physical phenomena and to collect "ongoing" data on these responses. Students were brought into a one-to-one clinical instructional setting with teachers. A variety of laboratory exercises in mechanics were used and both the physical and intellectual activities of the child were studied. Post clinical sessions were held by Boldt with the teachers. Using videotapes and the diagnostic clinical sessions as data, Boldt applied Kuhn's notions to the students' activity. Only tentative results were obtained. For example, the ideas about the causes of motion of swinging objects by both an eleven and a twelve year old bore striking resumblance to the Aristotelian concept of motion; a notion which Boldt calls a "prescience paradigm."

The significance of this work is that it constitutes a philosophically derived methodology for the developmental study of children's logical reasoning in science. Furthermore, as Boldt speculates, an understanding of the development of logical reasoning in science would suggest a diagnostic teacher role in encouraging the development of increasingly powerful paradigms in children's reasoning about science.

Finegold is currently developing a methodology for investigating logical reasoning of individual students during and after instruction.[20] Analytic terms are being developed to assess the quality and range of student participation in discussion. "Quality" refers to the contribution made to an understanding of the status of knowledge claims and "range" refers to the extent to which a student deals with enquiry generally and the extent to which he deals with elements in patterns of enquiry. An example of the potential usefulness of the tentative methodology is seen in Finegold's pilot study of two class lessons where he found that students were, in general, dependent upon the teacher for guidance in thinking about knowledge claims.

---

[20] Menahem Finegold, "The Character of Enquiry into Enquiry Discussion as a Mode of Instruction in Physics" (Dissertation Proposal, Toronto: The Ontario Institute for Studies in Education).

F. *Evaluation-Research Activity*

The significance of this area for logical reasoning is that it explicitly treats a complex of associated curriculum considerations. Its aim is to provide descriptions of the matrix of interactions among the instructional conditions and the epistemological characteristics of instruction (see Figure 1 for areas bounded by each of these).

The methodology used in the Patterns of Enquiry project is to field test a set of theoretically sound curriculum materials in a variety of circumstances and to describe the various identified relationships.[21] Questions of the following order are asked: "To what extent do each of the components of the instructional recommendations associated with materials show in instruction and what is the balance among them?", "To what extent is the matrix of interactions comprehended by the instructional recommendations" and, conversely, "what is left out by them?" and "How do different balances among components of the instructional recommendations hang together with identifiable differences in teacher, students, and other conditioning factors?" Given the resulting set of relationships it is possible to make sense of the variability in learner outcome measures associated with logical reasoning. For example, intercorrelations among the conceptions of knowledge embodied in the materials, the teacher's conception of a logical structure of his field, the students' conceptions with respect to scientific knowledge claims, and the reasoning capabilities expressed in instruction, may be identified. The effect of this research is to give a picture of how both theoretical and actual characteristics of logical reasoning hang together.

The significance of my study for logical reasoning is that it makes possible the provision of multiple pictures of how materials hang together in theory and practice. We intend to make our "pictures" available to teachers for purposes of permitting them to intelligently assess the materials for their own situations and we hope, among other things, to circumvent the disillusionment that occurs when the wrong people use the wrong materials for ambitious ends, such as the development of students' logical reasoning in science.

---

[21] For an extended account of what is involved in evaluation-research see my "The Functions of.....," ibid.

LOGICAL REASONING IN SCIENCE EDUCATION

AN ANNOTATED BIBLIOGRAPHY (1) (2)

F. Michael Connelly
The Ontario Institute for Studies in Education
University of Toronto
Toronto, Ontario

and

Richard W. Binns
The Ontario Institute for Studies in Education
University of Toronto
Toronto, Ontario

This bibliography is intended primarily for the use of researchers in the field of science education. It provides a comprehensive overview of educational research studies associated with "logical reasoning in science education", which were completed and published through the end of 1972. It was compiled for the preparation of a paper of the same title by the senior author and includes a review of the following types of sources: educational and research journals, curriculum project newsletters, and doctoral dissertations.

The bibliography is divided into categories in terms of a philosophically oriented curriculum framework described in Connelly's paper. The bibliography focuses on related studies in item areas: A. philosophical considerations, B. logical structure in a field of enquiry, C. materials development and evaluation, D. epistemological characteristics, E. student development and use of logical reasoning in science, F. evaluation-research, G. teacher conception of the logical structure of a field, I. teacher conception of learning, J. student conception of learning. An eleventh category (K) includes studies which, for one reason or another, do not fit this framework and yet pertain to the topic in general.

(1) The asterisks throughout the bibliography identify those articles most useful in developing the attached paper and framework for this bibliography. These articles are cited in the paper.

(2) Mr. Brent Kilbourn, Research Officer with the Patterns of Enquiry project, assisted in the preparation of this bibliography.

A. PHILOSOPHICAL CONSIDERATIONS

Atkin, Myron J. Science Education: 'Process' and 'Content' in Grade Schools. Science, 151:103. March 4, 1966.

Letter to the editor. A useful criticism of Gagne's article in January 7 issue.

Berlin, Barney M. and Gains, Alan M. "Use Philosophy to explain the Scientific Method." Science Teacher, 33:52. May 1966.

A brief report of a curriculum innovation based on the notion that knowledge changes in science. Readings in the philosophy of science are introduced into the Princeton, Time, Space and Matter course.

Bronowski, J. "Science in the New Humanism." Science Teacher, 35:13-16:72. May 1968.

A brief philosophical analysis in science in terms of

I How does science work? - Inquiry into logic,
II Why does science work? - Inquiry into philosophy,
III Human and social requisites necessary to make science work - Inquiry in ethics.

Cohen, Robert Sonne. "Individuality and Common Purpose: The Philosophy of Science." Science Teacher, 31:27-33. May 1964. (1)

An address given to NSTA on nature and philosophy of science. "What do these reflections on the ambiguous character of science imply for the school?" It lists 11 Goals and Values for science teaching.

Conklin, Kenneth R. "The Integration of the Disciplines." Educational Theory, 16:225-38. July 1966.

A theoretician explores whether there are any integrating factors common to both science and axiology. Says meta-physical inquiry provides such a unifying bond.

Connelly, F. Michael "Significant Connections Between Philosophy of Science and Science Education." Studies in Philosophy and Education, Vol. VII, No.9 (in press).

A critique which argues that science education ought to take stands on philosophical issues based on the character of science education practice and not on the character of the philosophical position. Some of the characteristics of taking a stand are described.

Connelly, F. Michael "The Role of Principles of Enquiry in the Conduct of Enquiring and in Curriculum Development." The Science Teacher, 37:9:23-26. December 1970.

A comparison of curricular statements on scientific method, a description of six very general characteristics of enquiry and general characteristics of knowledge claims.

Fox, Fred W. "Education and the Spirit of Science - The New Challenge." Science Teacher, 35:58-9. November 1966.

Comment on the NEA publication Education and the Spirit of Science.

Gagne, Robert M. "Elementary Science: A New Scheme of Instruction." Science, 151:49-53. January 7, 1966.

Description of philosophy and procedures of Science - A Process Approach.

Glass, H. Bently "The Most Critical Aspect of Science Teaching." Science Teacher, 34:19-23. May 1967.

Argues for a humanistic approach to science education. This approach amounts to getting students enquiring, and being concerned with attitudes. In these terms he discusses the laboratory, curriculum development and teacher training.

Hawkins, David "Education and the Spirit of Science - Critique of a Statement." Science Teacher, 33:18-20. September 1966.

An evaluation of the NEA publication Education and the Spirit of Science.

*Herron, Marshall D. "The Nature of Scientific Enquiry." School Review, Vol.79:171-212. 1971.

A philosophical framework of commonplaces of scientific enquiry is developed and applied to the writings of selected philosophers and to selected well-known science curricula. Includes the results of a study on teacher understanding of scientific enquiry.

Hoffmaster, Edmund S.; Lotham, James W.; and Wilson, Elizabeth D. "Design for Science." Science Teacher, 31:15-17. November 1964.

Attempt of Montgomery Country Schools (Maryland) to build a Theoretical model for science teaching. Relates substantive elements to behavioral elements.

Hurd, Paul Dehart "Scientific Enlightenment for an Age of Science." The Science Teacher, 37:1:13-15. January, 1970

A statement about the reorganization of curriculum development in terms of a cultural context which represents a new viewpoint about the purposes for teaching science.

Jevons, F.R. "A 'Science Greats' Course." Physics Education, 2:196-99. 1967. (1)

Course in Philosophy of Science at U. of Manchester designed to "produce high - calibre scientific generalists. .... to train people for interpreting science to the public and administrating scientific activities.

Kilbourn, Brent "The Use of Stephen C. Pepper's World Hypotheses as a Basis for Detecting World Views Projected in a Biology Text Book: Development and Application of an Analytical Scheme." (Dissertation in Progress, Toronto: The Ontario Institute for Studies in Education).

This is the development and case-study application of a scheme for detecting world views projected to students in verbal material.

Kline, Morris "The Liberal Education Values of Science." Science Teacher-32:22-4. November 1965.

Argues that science is a proper part of Liberal Education. The position has implications for nonscientific knowledge and values, esthetics, and cultural values.

McGuire, Francis J., S.J. "Join in the Scientific Adventure!" Catholic School Journal, 67:42-5. December, 1967.

Describes a particular philosophy of science (moderate realism) and argues that it ought to be the basis for curriculum.

Meyer, G.R. "New Concepts in Science Education in Secondary Schools." Australian Journal of Education, 9:137-54. 1965.

Describes the Wyndam unified science course. This embodies a view of the unity of nature and of the sciences.

Neville, P. "No Place for Absolute Truth: The Role of Philosophy and Perception Studies in Science Teaching." School Science Review, 49:859-67. 1968.

Argues that certain philosophical problems of science be included in curriculum. Gives some illustrations largely from Nuffield.

Paskse, Gerald H. "Science for Humanists." Liberal Education, 53:252-63. 1967.

Concerned with problem of education in science for the non-specialists at college level.

Ramage, Hugh P. "Principles and Perspectives for Educational Biology." Journal of Biological Education, 1:117-25. 1967.

Biology ought to be part of general science education. A semi-philosophical conception of biology arguing for a focus on the organism.

Raven, Ronald J. "Toward a Philosophical Basis for Selecting Science Curriculum Content." Science Education, 54:2:97-103. April 1970.

Argues for using an epistemological approach in curriculum development.

Roberts, Douglas A. "Science as an Explanatory Mode." Main Currents in Modern Thought, 26:5. May-June, 1970.

Science, magic, and religion are examined to support the position that explanatory modes vary not only in philosophical features, but also in psychological consequences to the explainer. Curriculum considerations focus on the potential of science as a context for teaching about the process of explanation.

Robinson, James T. "Philosophy of Science: Implications for Teacher Education." Journal of Research in Science Teaching, 6:99-104. 1969.

Implications for teacher education concern three variables in teacher behavior: verbal, pupil task selection and the selection of instructional materials.

*Robinson, James T. The Nature of Science and Science Teaching. Belmont, California: Wadsworth Publishing Company, Inc., 1968.

Writings on the nature of scientific inquiry are examined with emphasis on H. Margenau's constructionist view of the nature of reality. Implications are drawn for science education.

*Schwab, Joseph J. "Enquiry, The Science Teacher, and The Educator." School Review, 67: 176-195. 1960.

Similar to Schwab's "The Teaching of Science as Enquiry."

Schwab, Joseph J. "Structure of the Disciplines: Meanings and Significances." Structure of Knowledge and the Curriculum. (Edited by G.W. Ford and Lawrence Pugno.) Chicago: Rand McNally and Co., 1964. pp. 6-30.

Sets forth a conception of the disciplines in terms their membership and organization, syntactical structure and substantive structure.

Schwab, Joseph J. "The Structure of the Natural Sciences." The Structur of Knowledge and the Curriculum. (Edited by G.W. Ford and Lawrence Pugno.) Chicago: Rand McNally and Co., 1964. pp. 31-49.

Focuses on developing the notions of stable and fluid scientific inquiry of relating these to the long term syntax of the disciplines.

*Schwab, Joseph J. "The Teaching of Science as Enquiry." The Teaching of Science, Cambridge: Harvard University Press, 1962, pp.3-103.

Schwab develops and uses the distinction between "stable" and "fluid" enquiry in science. In response to the need for public support of science, he prescribes and gives a rationale for methods appropriate to teaching science as fluid enquiry.

*Schwab, Joseph J. "What Do Scientists Do?" Behavioral Science, 5:1: 1-27. 1960. G.W. Ford and Lawrence Pugno (eds.) The Structure of Knowledge and the Curriculum. Chicago: Rand McNally and Co., 1964.

The basic philosophical paper setting forth the concept and kinds of principles of enquiry operating in science. Describes a set of methodological decision points confronted by scientists during enquiry.

Showalter, Victor "Unified Science: An Alternative to Tradition." Science Teacher, 31:24-6. February 1964.

Justifies and expounds on his model in the title.

Troost, Cornelius J. "On the Teaching of Origins." Science Teacher, 35:30-1. December 1968.

This article asks teachers to discuss philosophy. It is interested in the questions of cause and God and uses the "infinite regress" argument.

Williams, Curtis A. "Biology and the Evolution of Science." Science Teacher, 7:22-3. November 1963.

An article on nature of science stressing:

- Science evolves,
- Man as a selective force,
- Historical triumphs.

B. LOGICAL STRUCTURE IN A FIELD OF ENQUIRY

Brown, Walter R. "Defining the Processes of Science." Science Teacher, 35:26-28. December 1968.

An attempt by a team in India to define in operational terms the objective "to teach the processes of science". Enquiry is seen as a matter of problem solving and amounts to Dewey re-phrased in Bloom terms. Breaks down each of the following:

a) Application of Generalizations to New Stiuations
b) Collection of Data
c) Analysis of data
d) Synthesis of data
e) Evaluation of data

*Clipsham, John "Organizing an Enquiry Curriculum for the Study of Issues at the Science-Society Interface." (dissertation in progress, Toronto: The Ontario Institute for Studies in Education).

A study which examines the science-society interface by applying biological principles of enquiry. The significance of Clipsham's work for logical reasoning is to distinguish between reasoning modes appropriate to science and to science-society issues and describe the conditions to be fulfilled by a curriculum based on analysis of the methodologies of enquiry and argumentation for the development of skills needed for critical thinking and responsible action.

Connelly, F. Michael "Conceptual Structures in Ecology with Special Reference to An Enquiry Curriculum in Ecology " (unpublished Doctoral dissertation, University of Chicago, 1968).

A philosophical analysis of the principles and patterns of enquiry operating in the field of ecology along with an account of curricula possibilities for an enquiry curriculum.

Connelly, F. Michael "Enquiry Materials in Science Teaching: Part I; Conceptions of Enquiry." The Crucible, February 1970.

This is an analysis of different uses of the term "enquiry". Two meanings for the term are treated in parts II and III of this series.

Connelly, F. Michael "Enquiry Materials in Science Teaching: Part II; Enquiry as Logic." The Crucible, April 1970.

This is an analysis of "enquiry" in terms of guiding conceptions, fact, problem, hypotheses, interpretation, and outcome.

Connelly, F. Michael "Enquiry Materials in Science Teaching: Part III; Enquiry into Enquiry." The Crucible, June 1970. (See section VII)

This describes a discussion method for teaching aimed at an understanding of enquiry as logic.

*Connelly, F. Michael "Patterns of Enquiry and Conceptual Knowledge Structures in the Curriculum." (Mimeo, The Ontario Institute for Studies in Education)

A paper which deals with the hypothetical connections between knowledge and knowing, and of the learner's personal power and freedom in logical reasoning that guides the selection of particular curricular content and the forms of logical reasoning worthy of developing.

Evans, C.K. "Science as a System of Inquiry -- Focus for General Education Programs." Doctor's thesis. Gainesville: University of Florida, 1965. Abstract: (Dissertation Abstracts 26:10:5783-84. 1966.)

This study discusses a general education course in science at the college level. The course presents science as a system of inquiry.

Glass, Bentley "Theory into Action" - A Critique. Science Teacher, 32:29-30, 82-83. May 1965.

Criticizes major conceptual schemes as being "positively harmful" as a basis for organizing the study of biological Sciences.

Itzkoff, Seymour W. "Physics and History." Science Education, 50:485-89. 1966.

A comparison of theory building in physics - biology - sociology. The curriculum argument is for general understanding of theory for general science education.

Kikoin, I. and Reznikov, L. "Modern Physics for Modern School." Soviet Education, 9:26-8. June 1967.

Course should be based on "a completely discernible group of fundamental physical principles."

It is necessary to reveal the power of physics research methods.

Klopfer, Leopold E. "Integrated Science for the Secondary School: Process, Progress and Prospects." Science Teacher, 33:27-31. November 1966.

This paper describes the Natural Science courses at Chicago which are organized in terms of logical processes of enquiry.

Mason, Herbert L. "Formal Relations in Elementary School Science." Science Education, 50:1966-69. 1966.

Emphasizing formal logic in science and apply it to topics such as plant anatomy.

NSTA Conference of Scientists. "Conceptual Schemes and the Processes of Science." Science Teacher, 31:11-13. October 1964.

An account of scientific conceptual schemes and how they may be useful in science curriculum planning.

Reznikov, L.I. "Paths of Development of the Content and Structure of the Secondary-School Physics Course." Soviet Education, 7:53-9. March 1964.

The study of physics is playing an even greater role in the system of general, polytechnical and vocational education.

Shamos, Morris H. "The Role of Major Conceptual Schemes in Science Education." Science Teacher, 33:27-30. January, 1966.

Justification of "Major Conceptual Schemes." Refers to Theory into Action. Attemps to answer Glass who is opposed to these schemes.

Smith, Herbert A. "The Teaching of a Concept - An Elusive Objective." Science Teacher, 32:103-12. March 1966.

An attempt to get at all implications of what we mean when we say we will teach "concepts" in science. Reprinted as an NSTA monograph.

Soviet Education. "Science and the School Subject." <u>Soviet Education</u>, 8:3-24. November 1965.

A conference on the relationship of the nature of science to the total school curriculum. A summary of Soviet views.

Verzilin, N.M. "The Problem of Concept Development in the Educational Process." <u>Soviet Education</u>, 9:8-19. June 1967.

"The object of this article is to acquaint the teaching community with the basic tenets of the theory of concept development, using the example of teaching methods in biology subjects."

Weinberg, Alvin M. "The Two Faces of Science." <u>Journal of Chemical Education</u>, 45:74-7. 1968.
Face 1 - Search for new knowledge
Face 2 - Codification of Consolidated knowledge

Implications for science education of increasing levels of abstraction produced by conflict of the two faces.

Woodburn, John H. "Science Defined Versus Indefinable." <u>Science Teacher</u>, 34:27-30. November 1967.

Attempted to arrive at an operational definition for science for science teachers. Replies from 16 outstanding scientists and concludes there is as yet no "good" definition.

C. MATERIALS DEVELOPMENT AND EVALUATION

Allen, Frederick S. "Science for the Nonscientist." Educational Record, 48:268-75. Summer 1967.

A historian outlines a curriculum (with his justification for it) which would yield an understanding of the history of science by the nonscientist.

Binns, Richard W. and Olson, John An Enquiry into Conceptions of Matter and Change: Their Roles in the Formulation of Theories of Plant Nutrition. Classroom Discussion Module, the Patterns of Enquiry Project, F. Michael Connelly, Principal Investigator (Toronto: Department of Curriculum, The Ontario Institute for Studies in Education, 1973). Trial edition.

This unit, designed for an enquiry-discussion teaching approach, has these goals: (1) an understanding of the major theories of matter, change, and plant nutrition from 500 B.C. to the 18th century; (2) An understanding of how the parts (e.g., problems, fact, interpretation) of patterns of enquiry contribute to the "status" of knowledge claims; (3) The reading skills and habits of mind that allow students to recover the meaning and assess the status of knowledge claims.

Bishop, George D. "The New Approaches to Teaching Science. How 'New'?" British Journal of Educational Studies, 15:307-13. 1967.

Gives an entertaining historical survey to demonstrate that current science curriculum development is the business of "old wind in new bottles".

Butts, David "Science -- A Process Approach - Parts One Through Four." Commission on Science Education - Newsletter, 2:2-4. January 1966.

Describes AAAS: Science - A Process Approach.

Commission on Science Education Commission on Science Education - Newsletter 1:1-12. December 1964.

Describes the processes involved in AAAS: Science - A Process Approach. First issue of this newsletter.

Connelly, Geraldine The Role of Paleontology in the Formulation of Theories of Hominid Evolution. Classroom Discussion Module. The Patterns of Enquiry Project, F. Michael Connelly, Principal Investigator (Toronto: Department of Curriculum, The Ontario Institute for Studies in Education, 1971). Trial edition.

This unit, designed for an enquiry-discussion teaching approach, has these goals: (a) An understanding of the major theories, hominid types, excavation sites and prominent researchers in the study of hominid evolution; (2) An understanding of how the parts (e.g., problems, fact, interpretation) of patterns of enquiry contribute to the "status" of knowledge claims; (3) The reading skills and habits of mind that allow students to recover the meaning and assess the status of knowledge claims.

*Finegold, Menahem and Connelly, F. Michael "The Patterns of Enquiry Project." Orbit, 11:3-7. 1972.

A teacher oriented description of a five year curriculum development project on patterns of scientific enquiry.

Finegold, Menahem and Olson, John An Enquiry into the Development of Optics: Conceptions of Light and Their Role in Enquiry. Classroom Discussion Module. The Patterns of Enquiry Project, F. Michael Connelly, Principal Investigator (Toronto: Department of Curriculum, The Ontario Institute for Studies in Education, 1972). Trial edition.

This unit, designed for an enquiry-discussion teaching approach, has these goals: (1) An understanding of the major theories in optics from 300 B.C. to the early 19th century; (2) An understanding of how the parts (e.g., problems, fact, interpretation) of patterns of enquiry contribute to the "status" of knowledge claims; (3) The reading skills and habits of mind that allow students to recover the meaning and assess the status of knowledge claims.

Fischler, Abraham S. "Implications of Structure for Elementary Science." Science Education, 52:277-84. 1968.

Makes a rhetorical attempt to tie psychological to logical in a curriculum. The paper roams over topics such as curriculum development, scientific enquiry, student enquiry, and so on.

Kerr, John F. "Science Teaching and Social Change." School Science Revies, 47:301-09. 1965-1966.

This article refers to old and new science courses and uses Nuffield as example of one of the new ones.

It attempts to look at some recent changes in science teaching .....as the result of a complex interplay between educational and social forces. There is a plea for teachers to get involved in producing a theory of change in education.

*Kilbourn, Brent Analyzing the Basis for Knowledge Claims in Science Textbooks: A Method and a Case Study. Background Paper No.6, The Explanatory Modes Project, Douglas A. Roberts, Principal Investigator (Toronto: Department of Curriculum, The Ontario Institute for Studies in Education, 1971.)

A scheme is developed for analyzing the basis for knowledge claims in science texts, and is applied to sections on hominid evolution in a biology text. The scheme is based on Scheffler's treatment of truth, evidence, and belief as conditions for knowledge.

Marantz, Samuel A. "The Structure of Physics: A Teaching Objective." Physics Teacher, 4:309-11. 1966.

The structure of Physics is a conscious aim in teaching physics. Delineates the elements necessary for depicting the structure.

Morris, G.C. "Objectives of Secondary School Courses in Chemistry." Australian Journal of Education, 8:192-208. 1964.

Review article on objectives based on literature, syllabuses, examination papers, examiners comments.

Murphy, Glen W. Algae "A Simple Tool for Teaching Scientific Method." Science Teacher, 33:56-7. May 1966.

A simple "how-to-do-it" exercise using field and laboratory work with algae and focused on a modification of the "5-step" formulation of scientific method.

Palmer, Wendell and Dienes, Barbara <u>Honey Bee Communication: An Enquiry into Two Conceptions of Animal Behavior</u>. Classroom Discussion Module. The Patterns of Enquiry Project, F. Michael Connelly, Principal Investigator (Toronto: Department of Curriculum, The Ontario Institute for Studies in Education, 1972). Trial edition.

This unit designed for an enquiry-discussion teaching approach, has these goals: (1) An understanding of major theories of honey bee communication; (2) An understanding of how the parts (e.g., problems, fact, interpretation) of patterns of enquiry contribute to the "status" of knowledge claims; (3) The reading skills and habits of mind that allow students to recover the meaning and assess the status of knowledge claims.

Renner, John W. "A Case for Inquiry." <u>Science and Children</u>, 4:30-3. March 1967.

Argues that to construct good elementary science curriculum, one should know what science is. Then discusses teacher's role in such a program. Little discussion of the nature of inquiry.

Roberts, Douglas A. <u>The Mole as an Explanatory Device: How Do You Know A Mole if You See One?</u> Sample Teaching Materials, The Explanatory Modes Project, Douglas A. Roberts, Principal Investigator (Toronto: Department of Curriculum, The Ontario Institute for Studies in Education, 1972.) Trial edition.

This secondary chemistry manual uses the mole concept to help students understand the role of such conceptual devices in science. Considerations from analytic philosophy are used to identify the use of different truth strategies in science and different kinds of statements which appear in all science texts and scientific writings.

Slawson, Wilbur S. "Basis of Science Curriculum Development in the Future." <u>Science Teacher</u>, 35:22-6. March 1968.

Conceptual Schemes vs. Big Ideas vs. Unifying Themes. Argues for establishing a coherent conceptual scheme of all the sciences as a basis for curriculum construction; a Platonic view of our state of scientific knowledge.

Soviet Education. "On the Draft of a New Program for General Biology." <u>Soviet Education</u>, 8:15-27. January 1966

Gives content of new courses and outlines some of the reasons for selecting particular content areas.

Trieger, Seymour "New Forces Affecting Elementary-School Science." Science and Children, 1:22-4. October 1963.

Examines differences in philosophy of New and Old Science courses at the elementary school level.

D. EPISTEMOLOGICAL CHARACTERISTICS

Campbell, Douglas C. Epistemological Posture as an Intellectual Variable. Background Paper No.3. The Explanatory Modes Project, Douglas A. Roberts, Principal Investigator (Toronto: Department of Curriculum, The Ontario Institute for Studies in Education, 1971).

"Epistemological Posture" is proposed as a new and potentially useful psychological construct concerning individuals' unsystematic (or systematic) attitudes and beliefs about the nature of truth and knowledge.

Fish, Alphoretta S. and Saunders, T. Frank "Inquiry in the Elementary School Science Curriculum." School Science and Mathematics, 66:13-22.

A useful article describing classroom discussions on a continuum from content centered to enquiry centered.

Ivany, J.W. George "On the Logical Analysis of Inquiry." Science Education, 55:3:347-352. 1971.

A paper which indicates incongruities which arise from the use of an inquiry teaching model.

Munby, A. Hugh "The Use of Three Philosophical Models of Teaching to Analyze Selected Science Lessons." (Unpublished Doctoral dissertation, University of Toronto, 1973.)

An analytical scheme is developed and applied to lesson transcripts. Part one concerns the view of science provided for (Realism or Instrumentalism, after Nagel's terms). Part two concerns the provision made for students to assess knowledge claims rationally and independently of their teacher (Intellectual Independence and Intellectual Dependence).

Munby, A. Hugh Three Philosophical Models of Teaching Used to Analyze Science Teaching. Background Paper No.5, The Explanatory Modes Project, Douglas A. Roberts, Principal Investigator (Toronto: Department of Curriculum, The Ontario Institute for Studies in Education, in press).

A scheme based on Scheffler's three philosophical models of teaching (impression, insight and rule models) is developed and applied to lesson transcripts to show the provision made for students to know certain propositions in science.

Prusso, K.W. "The Development of a Scheme for Analyzing and Describing the Epistemological Criteria Adhered to in Secondary School Natural Science Classroom Communication." (Unpublished Doctoral dissertation, Temple University, 1972).

A scheme is developed which incorporates four models of knowledge (Institutional, Rationa, Empirical, Pragmatic) and three dimensions (kinds of meaning, strategies, nature of support). The scheme is used to analyze science lessons to determine whether they are epistemologically consistent with science.

*Roberts, Douglas A. <u>About the Explanatory Modes Project</u>. Bulletin No.2 (Toronto: The Ontario Institute for Studies in Education, April 1972).

This bulletin briefly describes the Explanatory Modes Project. The project concerns the application of philosophical analysis to issues in science education, and concentrates on comparing science as <u>one</u> way-of-explaining phenomena with other ways-of-explaining, (e.g., magic and religion).

*Russell, Thomas L. <u>Towards Understanding the Use of Argument and Authority in Science Teaching</u>. Background Paper No.7, The Explanatory Modes Project, Douglas A. Roberts, Principal Investigator (Toronto: Department of Curriculum, The Ontario Institute for Studies in Education, in press).

Teacher's classroom statements were analyzed for the extent to which they suggested a rational attitude toward authority. R.S. Peter's discussion of "traditional" vs. "rational" attitudes toward authority and S.E. Toulmin's concept of an "argument-pattern" provide the framework for the scheme.

Segal, Sol "Secondary Education and the Philosophy of Science." <u>Science Education</u>, 50:91-4. February 1966.

Discussion of idealism - realism and by implication, the importance of this philosophical argument for science curriculum.

Tricken, R.A.R. "The Sceptical Physicist." <u>Physics Teacher</u>, 2:64-9. February 1964.

Deals with the question of the use of science as a vehicle for liberal education. Argues that for training of the mind (which he equates with a liberal education) questions on the Theory of Knowledge are important.

Voelker, Alan M. "Concept Teaching and the Nature of the Scientific Enterprise." <u>School Science and Mathematics</u>, 69:3-8. 1969.

An attempt to tie science, student learning and curriculum together. This is done by treating science as a process of concept formation.

E. STUDENT DEVELOPMENT & USE OF LOGICAL REASONING IN SCIENCE

Anderson, O. Roger "A Quantitative Method to Assess Content Structure in Verbal Interaction." Journal of Research in Science Teaching, 9:305-321. 1972.

A description of a quantitative method of analyzing structure in classroom dialogue and its use with science classroom verbal interaction.

*Boldt, Walter B. "Application of Thomas S. Kuhn's View of Science to Teaching: An Exploratory Study." paper presented to The National Association for Research in Science Teaching (Vancouver: University of British Columbia, 1969), Mineo.

This paper conceptualizes children's science learning in terms of Kuhn's notions of "prescience paradigm" and "prescience paradigm shift". The emphasis is on the conceptual frameworks, i.e., the paradigms, and logical reasoning becomes a function of the paradigms.

*Finegold, Menahem "The Character of Enquiry into Enquiry Discussion as a Mode of Instruction in Physics." (Dissertation in progress, Toronto: The Ontario Institute for Studies in Education).

An analysis of classroom discussion in terms of its adequacy of reflecting the nature of science in general and the nature of physical enquiry in optics.

Ivany, J.W. George and Oguntonade, Christopher B. "Verbal Explanation in Physics Classes." Journal of Research in Science Teaching, 9:353-359. 1972.

A verbal explanation analysis instrument is implemented to study classroom transcripts in terms of verbal styles and interpretation of physics as enquiry.

Lundstrom, Donald and Lowery, Lawrence "Process Patterns and Structural Themes in Science." Science Teacher, 31:16-19. September 1964.

Sees inquiry as a series of processes which child can accomplish in sequence. These form basis for their science instruction program.

Moorland, Richard B. "Science Education, and the Self." Elementary School Journal, 68:114-18. 1967.

Concerned with the dichtomy between scientist and non-scientist.

Raun, Chester E. and Butts, David P. "The Relationship between the Strategies of Inquiry in Science and Student Cognitive and Affective Behavioral Change." Journal of Research in Science Teaching, 5:261-8. 1967-1968.

Strategies of Inquiry in Science and Student Cognitive and Affective Behavioral Change.

"Processes" and strategies of science are related. Inquiry oriented curriculum science must be concerned with strategies of inquiry. If exposed to situations that focus on individual inquiry one could expect changes in student's cognitive and affective behaviours. Long reference list. An experimental study.

Scott, Norval "Strategy of Inquiry and Styles of Categorization: A Three-Year Exploratory Study." Journal of Research in Science Teaching, 7:95-102. 1970.

Report of an investigation into the long-term effectiveness of Suchman's Inquiry program on children's behavior.

Shavelson, Richard J. "Learning from Physics Instruction." Journal of Research in Science Teaching, 10:101-111. 1973.

An investigation of learning and remembering from physics instruction.

Van Deventer, W.C. "Evaluating Students' Understanding of Ideas in Junior High School Science." The Science Teacher, : :51-54. November 1970.

A study which attempts to measure scientific reasoning and understanding with the use of open-ended, idea-centered materials and experiences.

F. EVALUATION-RESEARCH

Case, Robbie and Fry, Cathy "Evaluation of an Attempt to Teach Scientific Inquiry and Criticism in a Working Class High School." Journal of Research in Science Teaching, 10:135-142. 1973.

A study designed to determine whether critical thinking can be taught when the students do not come from upper or middle SES homes.

*Connelly, F. Michael "The Functions of Curriculum Development." Interchange, Special Issue on School Innovation, 3:2-3:162-175. 1972.

A contrast of external curriculum development and user-based curricular development according to ends, starting points, methodologies, and functions.

Glass, Gene V. "The Wisdom of Scientific Inquiry on Education." Journal of Research in Science Teaching, 9:3-18. 1972.

A proposal concerning the development of evaluation methodology in science education.

Gallagher, James J. "A Summary of Research in Science Education for the Years 1968-1969: Elementary School Level." Journal of Research in Science Teaching, 9:19-46. 1972.

A review covering research related to science instruction at the elementary school level. Criteria for inclusion in the bibliography were: significance of the question investigated, validity of research design, rigor of data interpretation, and adequacy of reporting.

Hall, Gene E. "Teacher-Pupil Behaviors Exhibited by Two Groups of Second Grade Teachers Using Science - A Process Approach." Science Education, 54:4:325-335. October 1970.

An evaluative analysis which purports to identify areas of differences in the teaching behaviors of teachers teaching a recently developed science curriculum.

Ivany, J.W. George "The Assessment of Verbal Inquiry in Junior High School Science." Science Education, 53:4:287-293. October 1969.

A study concerned with evaluating inquiry training in children and the test of an instrument designed to measure inquiry skills.

Jungwirth, E. "An Evaluation of the Attained Development of the Intellectual Skills Needed for 'Understanding of the Nature of Scientific Enquiry' by B.S.C.S. Pupils in Israel." Journal of Research in Science Teaching, 7:141-151. 1970.

An instrument is developed and implemented concerning biologic enquiry in an analytic mode and constructive mode. A discussion of subsequent analyses is presented.

Klopfer, L.E. and McCann Donald C. "Evaluation in Unified Science: Measuring the Effectiveness of the Natural Science Course at the University of Chicago High School." Science Education, 53:2:155-164. March 1969.

Report of an evaluative study to investigate the effectiveness of a unified natural science course.

Link, Frances R. "An Approach to a More Adequate System of Evaluation in Science." Science Teacher, 34:20-4. February 1967.

Discusses evaluation generally and argues that evaluation ought to focus on scientific attitudes. He then lists 20 such objectives.

Munson, Howard R. "Evaluating the New Science Teaching." Elementary School Journal, 68:126-30. 1968.

Names process areas (e.g. observing, predicting) built into new science courses and argues for developing evaluation instruments for them.

Schuck, Robert F. "The Influence of Set Induction upon Student Achievement and Perception of Effective Teaching." 7:35-40. 1970.

Report of a study which measures effectiveness of set induction techniques and conceptions of pupils and teachers.

G. TEACHER CONCEPTION OF THE LOGICAL STRUCTURE OF A FIELD

Kazlov, Trudi "The Nature of Science: A Translation." Science Education, 50:492-94. December 1966.

This makes an argument for a kind of teacher behavior in terms of "nature of science."

Lado, George T. and Anderson, Hans O. "Determining the Level of Inquiry in Teachers' Questions." Journal of Research in Science Teaching, 7:4:395-400. 1970.

An investigation into level of inquiry in teachers' questioning behavior and its role in student achievement.

Welch, Wayne and Pella, Milton O. "The Development of an Instrument for Inventorying Knowledge of the Processes of Science." Journal of Research in Science Teaching, 5:64-68.

This is a report on the development of the Science Process Inventory instrument.

H. STUDENT CONCEPTION OF THE LOGICAL STRUCTURE OF A FIELD

Grobman, Arnold B. "Science Education Today - Public Policy Tomorrow." NEA Journal, 56:8-10. March 1967.

Curriculum argument in milieu terms (training public policy determiners). Asks for concept learning and inquiry learning.

Ivany, George J.W. "Psychological Aspects of Structure in Science." Science Teacher, 33:36-7. May 1966.

Ivany argues for teaching the spirit of science which includes revealing the mechanism by which scientific concepts are subjected to scrutiny and modification.

I. TEACHER CONCEPTION OF LEARNING

*Belanger, Maurice "Learning Studies in Science Education, Science and Mathematics Education." Review of Educational Research, 39:377-395. 1969.

A review article which treats "concept learning" "problem-solving," inductive-deductive learning," "guided discovery," "creative thinking," and "critical thinking" in science education.

Brandwein, Paul F. "Man's Cumulative Record - And His Methods of Intelligence." The Science Teacher, 38:3:26-28. March 1971.

An article concerned with teacher concepts of learning as a method of intelligence.

Feifer, Nathan "The Teacher's Role in the Discovery Approach: Lessons from the History of Science." The Science Teacher, 38:8:27-29. November 1971.

A view of teaching methodology which emphasizes guided discovery.

Ivany, J.W. George and Neujahr, James L. "Inquiring into Science Teaching." The Science Teacher, 37:2:31-34. February 1970.

A description of ways in which science teachers can analyze learning and conditions of instruction.

Johnson, Paul E., Curran, Thomas E. and Cox, David L. "A Model for Knowledge of Concepts in Science." Journal of Research in Science Teaching, 8:1: 91-95. 1971.

A model is proposed to account for learned relations among concepts in physics. Data collected from graduate students in physics indicate that the psychological relations of association and similarity are consistent with the model. The role of these relations in evaluating conceptual knowledge is discussed.

Lewis, D.G. "Objectives in the Teaching of Science." Educational Research, 7:186-89. 1965.

Review article on objectives of science teaching which emphasizes non-content matters.

Renner, John W. and Stafford, Donald G. "Inquiry, Children, and Teachers." The Science Teacher, 37:4:55-57. April 1970.

A report describing the effects of teacher education in inquiry upon classroom behavior.

Renner, John W. "Why Change Science Teaching?" School Science and Mathematics, 64:413-20. 1964.

Repair needed in Secondary School science curriculum because observing and classifying facts constituted a proper scientific experience. Process side was missing. Proper experience of science requires process and up-to-date content and problem solving, not problem doing.

Walters, Lou and Boldt, Walter "A View of Science and Some Teaching Strategies." Science Education, 54:2:173-178. April 1970

The presentation of a teaching strategy adapted from scientific tradition and its relationship to learning.

J. STUDENT CONCEPTION OF LEARNING

Holton, Gerald "Science for Nonscientists: Criteria for College Programs." Journal of General Education, 15:257-75. 1964.

College oriented.

Holway, P.H. "A - level Papers in Biology as Tests of Scientific Thinking." Journal of Biological Education, 2:207-18. 1968.

Using Popper's The Logic of Scientific Discovery, test questions in A- level papers were analyzed and their questions grouped so as to reflect the extent to which they tested scientific thinking. Papers placed in 3 groups.

1. Information questions
2. Method questions
3. Neutral questions

Toomey, D.M. "Students' Conceptions of the Student's Role." Educational Sciences, 4:2:58-64. 1971.

Report of research into freshman conceptions of their role in the educational process. The results are discussed in terms of three conflicting influences upon students.

Wong, Harry K. "Inquiry Training in a Biological Research Program. Motivating students to want to learn how to learn." School Science and Mathematics, 65:593-6. 1965.

Great ideas of science approach applied to Biology.