DOCUMENT RESUME

ED 028 067 SE 005 913

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Processes and Structure of the Physical Sciences for School Curricula. An Abstract of a Thesis Submitted in Conformity With the Requirements for the Degree of Doctor of Education.

Toronto Univ. (Ontario).

Pub Date 68

Note-30p.

EDRS Price MF-$0.25 HC-$1.60

Descriptors-Behavioral Objectives, *College Science, Curriculum Development, *Curriculum Planning, Discovery Processes, Doctoral Theses, *Elementary School Science, Instruction, Models, *Physical Sciences, Program Design, *Secondary School Science

Developed was a set of behavioral objectives which indicate (1) the processes of inquiry used by physical scientists, (2) the components which make up the structure of the physical sciences, and (3) the relationship among these various processes and components. A content analysis of a random sample of 50 books written by scientists and philosophers dealing with the nature of science served as source for the findings. Five summaries were developed. The first, which depicts science as a group of concepts, lists 28 conceptual divisions giving the components of science. The second lists 10 assumptions inherent in the scientific endeavor. The third lists nine rules which seem to govern the actions of scientists. The fourth gives a number of relational diagrams which depict science from the standpoint of the relationships among its various components and procedures. The fifth lists 87 activities of scientists as they engage in research. These are listed as activities a science student should participate in, if he is to emulate a scientist. This list of activities thus serves as a suitable source of behavioral objectives for a science curriculum. (GR)

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TABLE OF CONTENTS

The problem

The current emphasis in science curriculum construction is on the processes of inquiry used by scientists and the structure of science. At the present time there are few descriptions of processes and structure which are in a form readily usable by the curriculum builder or the curriculum evaluator. It is the intent of this study to develop a set of behavioral objectives and other representations which are indicative of (1) the processes of inquiry used by physical scientists, (2) the components which make up the structure of the physical sciences, and (3) the relationships among these various processes and components. The purpose of these objectives and representations is to function as checklists and be suggestive of topics and activities for the construction, modification, and evaluation of curricula which aim at emphasizing the structure of science and the processes of scientific inquiry.

Significance of the problem

Science, like most other objects of man's attention, has not escaped dualistic description. Science is conceived as being comprised of a content and a method. This conceptual dualism seems to have little basis in fact, since practicing scientists are unable to divorce the one from the other. Scientific content and scientific method are inextricably wedded through definition; for whenever scientific content is produced, the method used for its production is proclaimed as being part of the method of science.

Profitless as this content-method dualism may be for science, it has a definite utility when applied to the teaching of science. Education, whether in science or in any other discipline, is not primarily concerned with developing new knowledge. In education there is no analogical necessity for content to be functionally related to method in the way that it is in science. Science content has been taught using methods which are very different from the methods of science. It is this separation of content and method which is condemned by many persons interested in the improvement of science teaching and which is seen by them as both a distortion of science and a hindrance to learning. The separation of content and method should be minimized, and it is hoped that the results of this study will help bring content and method closer together.

Research design

The research design involves the content analysis of a random sample of fifty books (see the bibliography) which have been written by scientists and philosophers of science and which deal with the general subject of the nature of science. Statements about science were first identified and then grouped and summarized according to topic and the ideas expressed within a topic. This summary was then used as the basis for deriving a list of activities engaged in by scientists (these imply behavioral objectives,) a list of the components of science and their definitions, and a set of diagrams depicting some of the relationships among the various processes and components. Some tests of reliability were applied which indicated that the content analysis procedures as performed by the researcher were sufficiently reliable. A test for completion demonstrated that the number of different ideas encountered in the sample was sufficiently comprehensive.

Results

The findings of this study consist of a series of five summaries which present science from different vantage points. The first summary (components of science) depicts science as a group of concepts which are used to describe classes of constructions and statements used in science. The second and third summaries (assumptions of scientists and rules of scientists) refer to the assumptions made by scientists in their work and which, therefore, permeate much of science. The fourth summary (relational diagrams) presents science from the standpoint of the relationships among its various components and procedures. The fifth summary (activities of scientists) lists the activities engaged in by scientists as th endeavor to create scientific knowledge.

1. Components of science

Science is divisible into a number of concepts which are used to describe classes of things and classes of statements. For the most part these divisions seem to be made along the dimension of function, although there are a few concepts which serve more than one function in science (e. g., the concept of "facts.") The divisions are, therefore, not mutually exclusive. The following is a list of these conceptual divisions as found in this study:

Assumptions
Attitudes
Descriptions
Events, phenomena
Experiments
Explanations
Extraneous elements
Facts
Hypotheses, auxilliary
Hypotheses, grand
Hypotheses, limited
Instruments
Language
Laws, empirical
Laws, nomic
Laws and theories, scientific
Laws and theories, statistical
Laws and theories, universal
Mathematics
Models
Objects
Perceptions
Postulates
Predictions
Properties
Rules
Skills
Technological devices

2. Assumptions of scientists

Scientists may or may not believe their own assumptions but, for the purposes of science, they act as though the assumptions were true. The following is a list of some of their assumptions:

1. A real world exists.
2. There are pervasive and repeating structures.
3. There are pervasive and repeating relationships.
4. Successful prediction is the criterion of a valid theory.
5. The law of causation is universal.
6. The influence of remote bodies is negligible.
7. Small changes follow a linear law.
8. Two substances or systems never differ in just one property alone.
9. There is a direct correspondence between events and perception of events.
10. Relationships are unaffected by time.

3. Rules of scientists

Scientists seem to be governed by a set of rules which, if violated, would have a crippling effect on the progress of science. The following is a list of some of these rules:

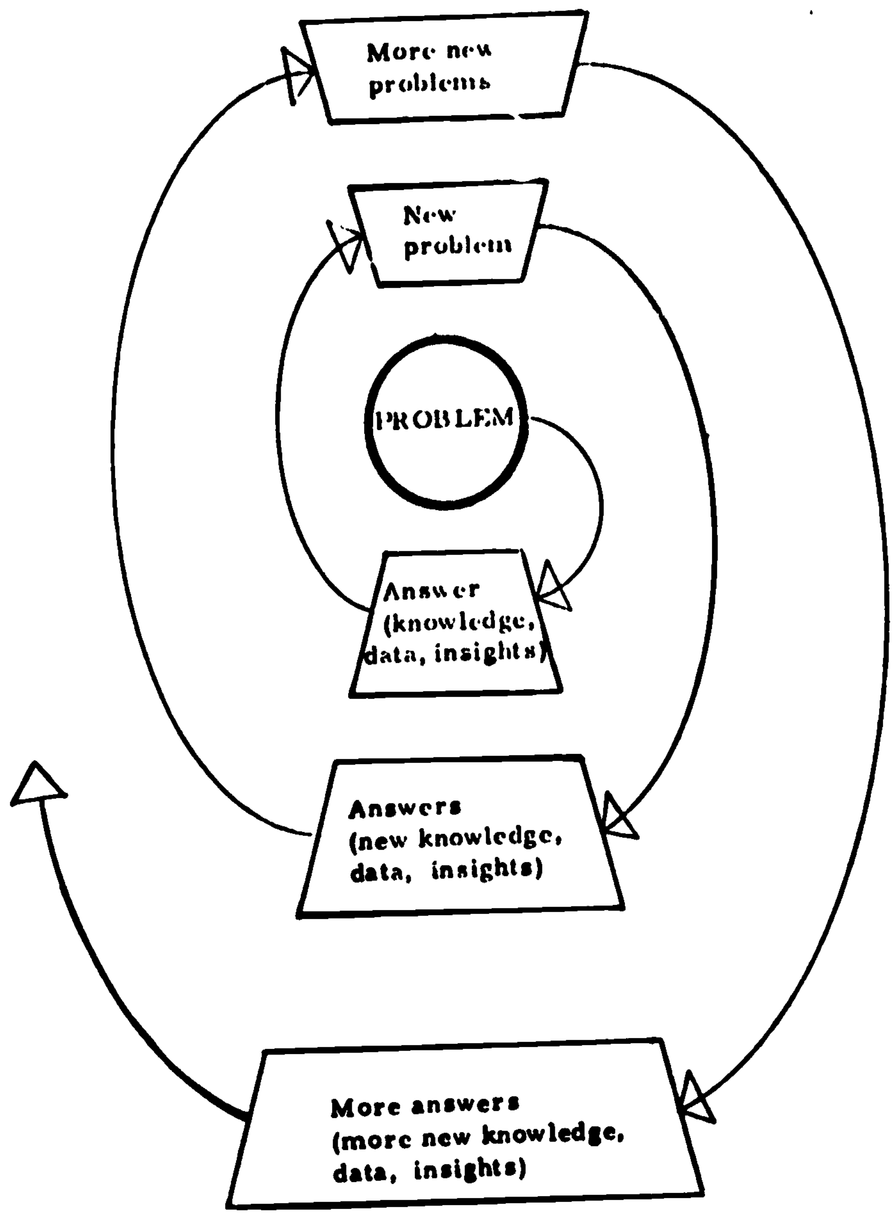
1. Abstain from issuing prohibitions that draw limits to the possibilities of research.

2. Never leave anything unexplained.
3. Never explain physical effects, such as reproducible regularities, as accumulations of accidents.
4. Never abandon the search for universal laws and for a coherent theoretical system.
5. Never design the rules of scientific procedure in such a way that they protect any statement against falsification.
6. All statements must be inter-subjectively testable.
7. Maintain complete freedom of thought about all things in the natural world.
8. Eliminate personal prejudice.
9. Restrict inquiry to things which can be seen and measured.

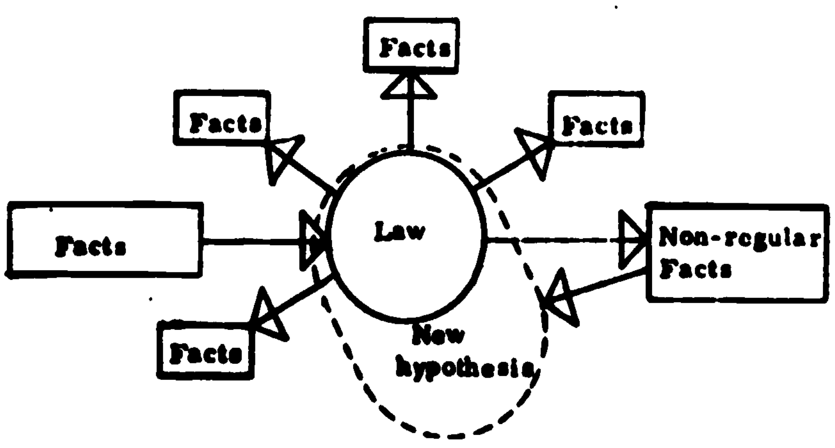
4. Relational diagrams

Th! summary consists of a group of diagrams which are representative of the relationships and sequences found in this study. Diagrams such as these omit a great deal of information and, therefore, should be used as organizing outlines rather than as sources of information. The background information needed to understand the diagrams can be found in chapter iii of the thesis.

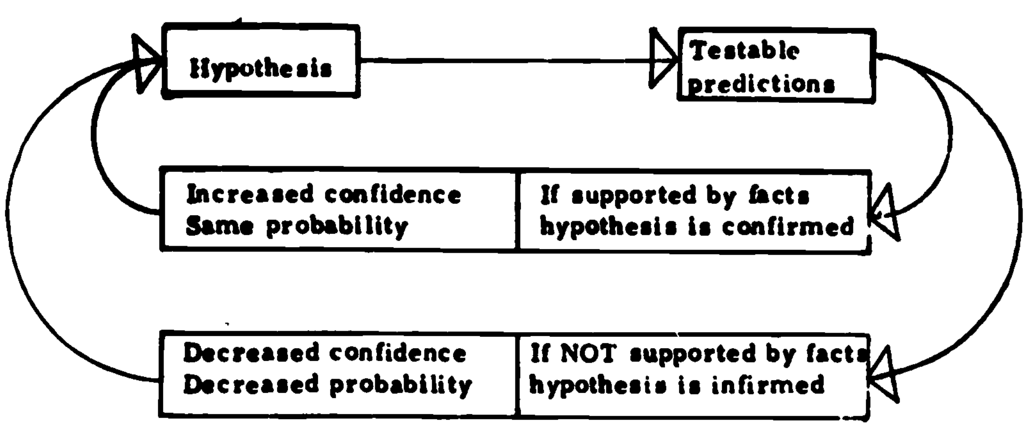
"The process of acquiring the results of research, knowledge, and insights moves in a path of expanding spirials."



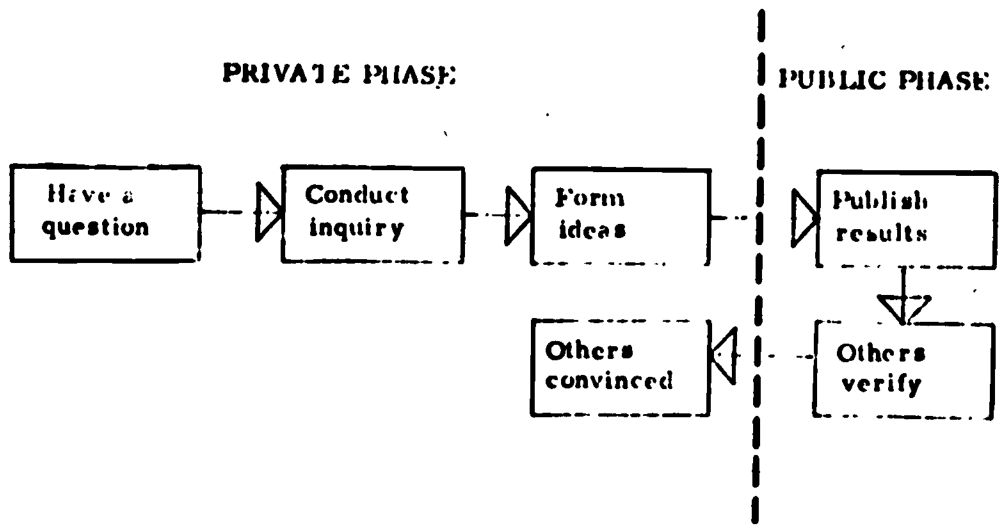
"Once the law is no longer in doubt, the regular facts lose their interest. It is the non-regular facts that form the premise for a new hypothesis."



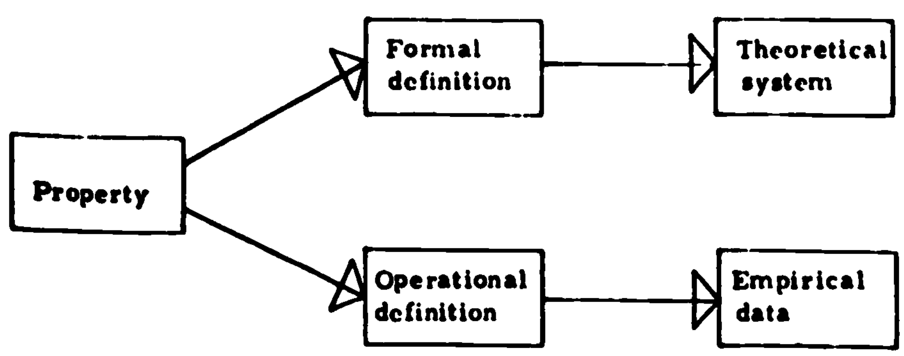
"Confidence in a hypothesis is increased by numerous consistently successful predictions."



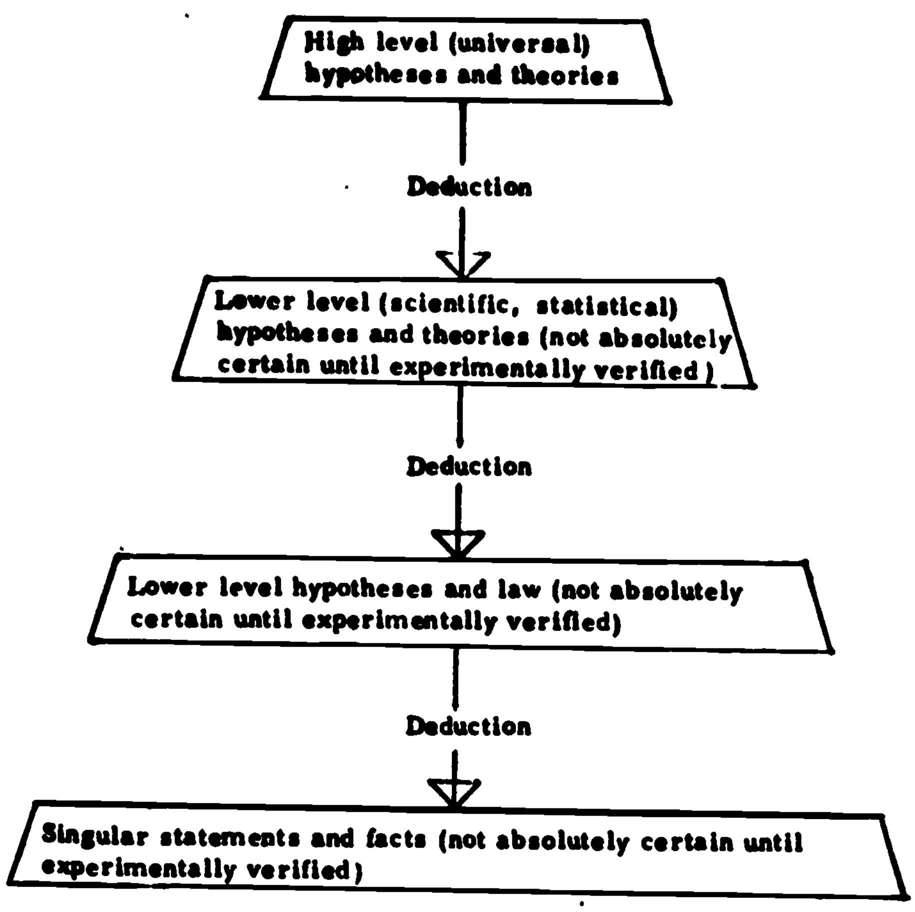
"Science is both a public and a private affair."



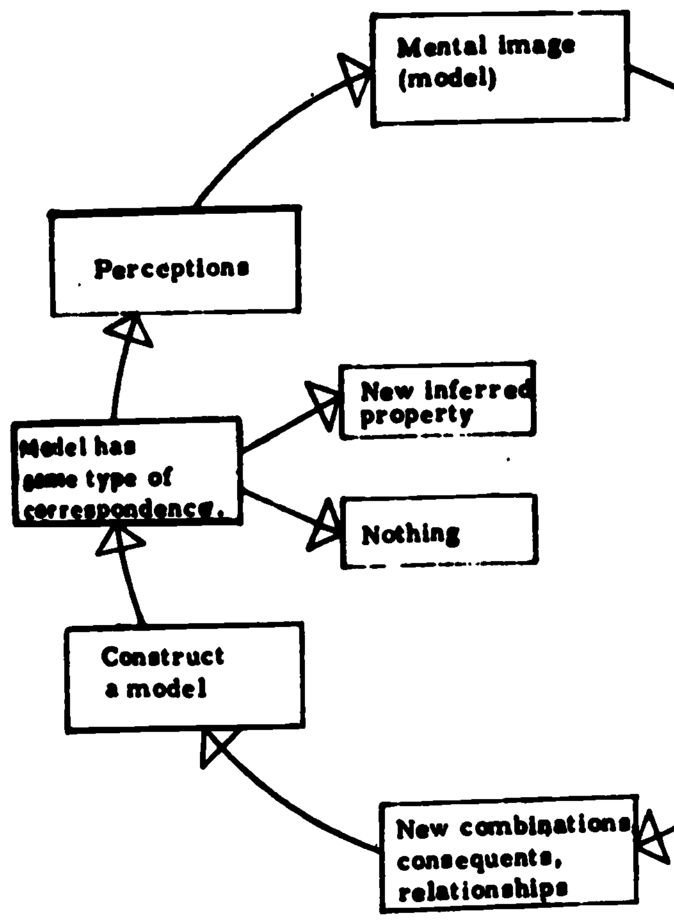
"Every property has at least two definitions. One links it to the theory, the other to empirical data."



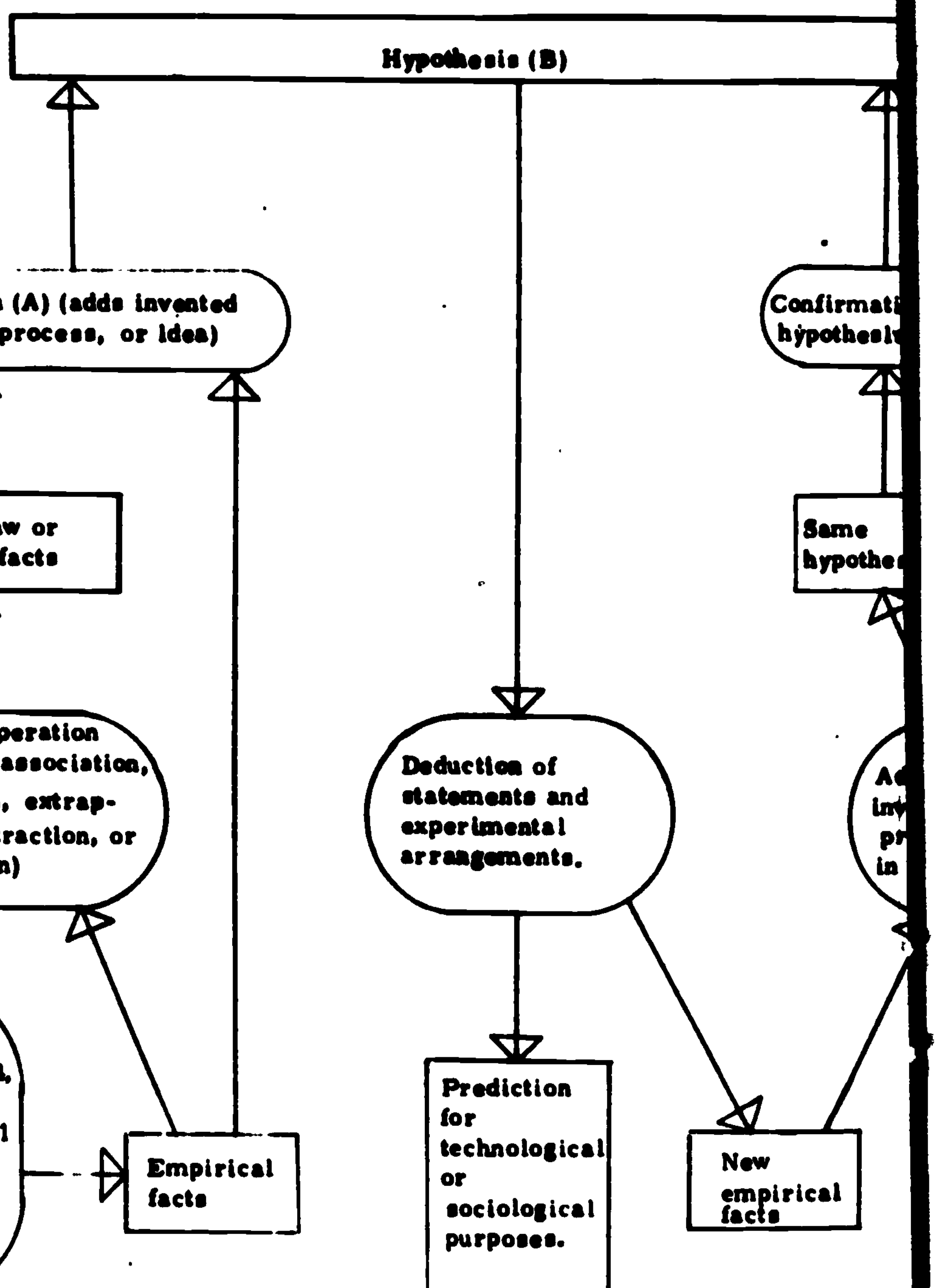
"Within a theoretical system statements on the lower levels can be deduced from those on the higher levels."



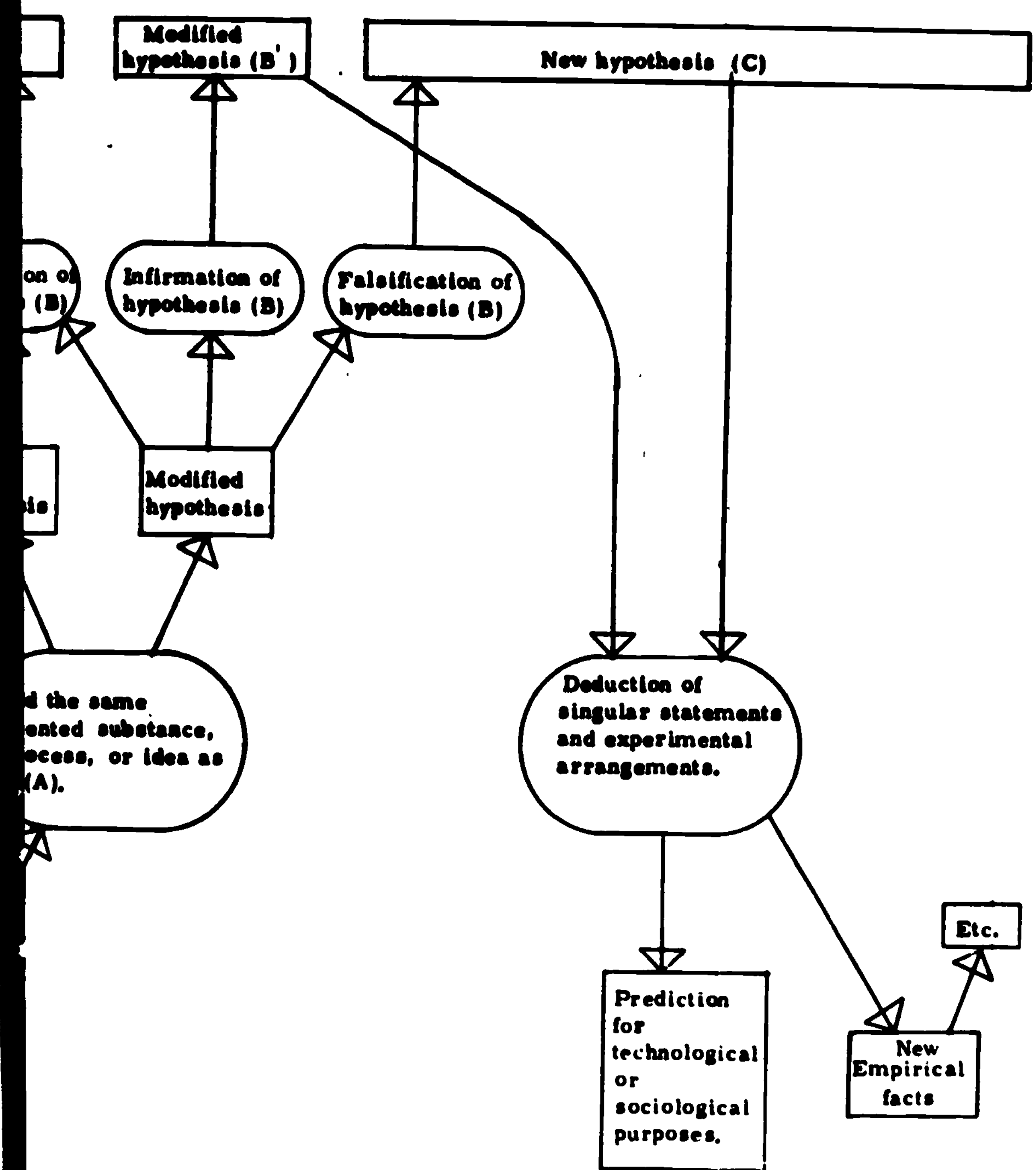
"The difficulties with objects and events are avoided by assuming or inventing properties which can be manipulated independent of time and other experimental limitations."



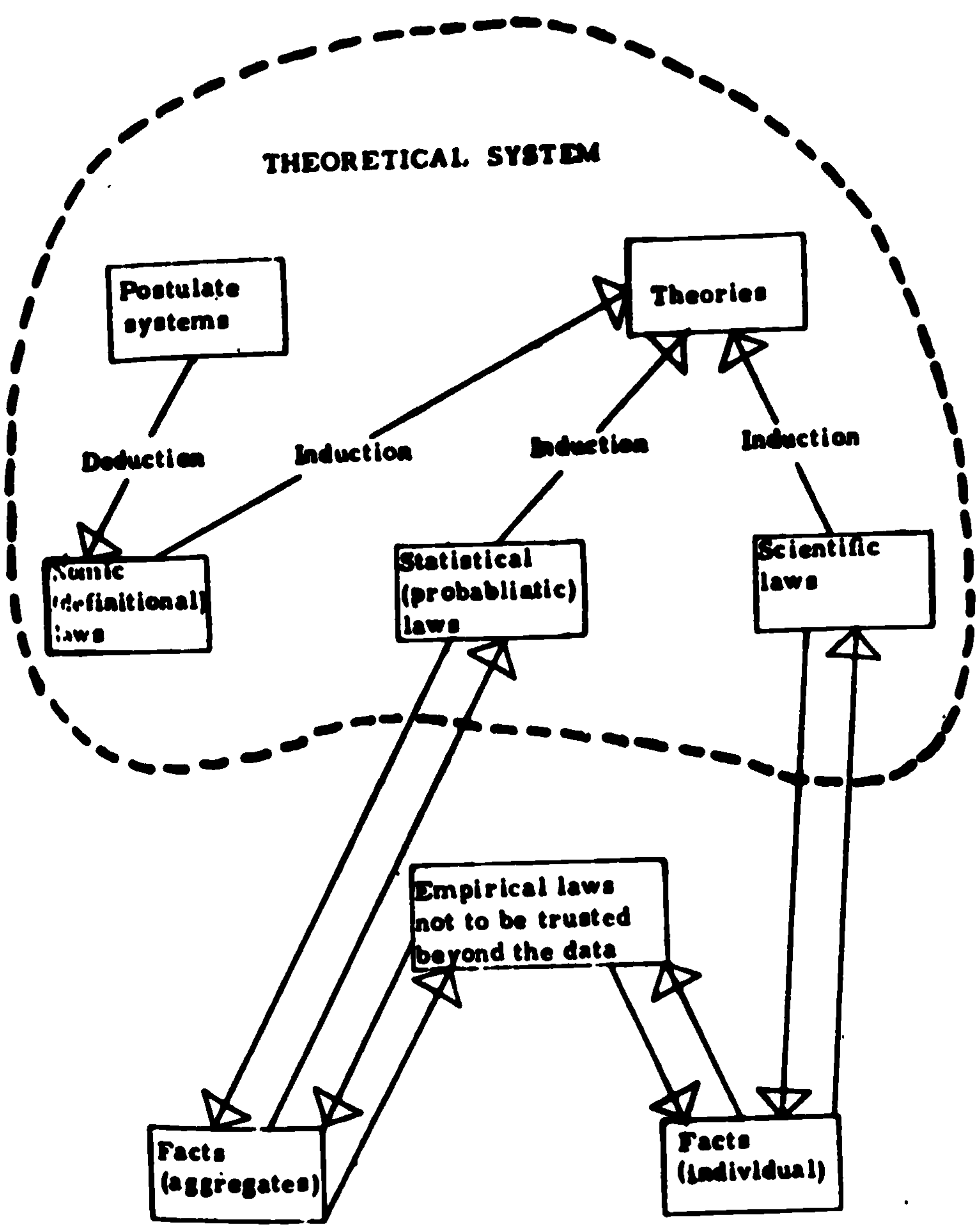
THE HYPOTHE


Hypothesis (B)
Imagination (A) (adds invented substance, process, or idea)
Confirmati
hypothesi
Empirical law or generalized facts
Same
hypothe
Logical operation (correlation, association, interpolation, extrapolation, abstraction, or concretion)
Deduction of statements and experimental arrangements.
Physical, physiological, or psychological operator
Empirical facts
Prediction for technological or sociological purposes.
New empirical facts

SIS CYCLE


Modified hypothesis (B')
New hypothesis (C)
on of (B)
Infirmation of hypothesis (B)
Falsification of hypothesis (B)
is
Modified hypothesis
d the same ented substance, ocess, or idea as (A).
Deduction of singular statements and experimental arrangements.
Etc.
Prediction for technological or sociological purposes.
New Empirical facts

"There are several types of laws in a theoretical system."



5. Activities of scientists.

The following list is a summary of the activities of scientists as described in the books included in this study. These activities can likely be used as behavioral objectives for an appropriate science curriculum.

A student who is emulating the scientist will

1. describe perceptions,
2. magnify, diminish, qualify, combine perceptions,
3. control the perceptual act,
4. distinguish between perceptions and properties,
5. analyze objects and events,
6. classify objects and events,
7. observe regularity in events,
8. explain events,
9. relate events to laws, theories, and assumptions,
10. devise (physical) properties,
11. detect properties,
12. demonstrate properties,
13. measure properties,
14. correlate properties with other properties,
15. select facts (eliminate "false" facts,)
16. interpret facts,
17. interpret facts in more than one way,
18. interpolate, extrapolate, generalize, and synthesize facts,
19. relate, correlate facts with other facts,
20. deduce facts from theory, law, hypothesis,

A student who is emulating the scientist will

21. compare deduced facts,
22. relate facts to a hypothesis,
23. deduce facts which include extreme cases,
24. assign probabilities to deduced facts (predictions),
25. present facts in a way that they can be tested,
26. examine small discrepancies between facts and theories,
27. devise hypotheses,
28. select one hypothesis from among many competing hypotheses,
29. simplify statements,
30. test hypotheses by internal consistency (logic),
31. test hypotheses by logical form (empirical, falsifiable, etc.),
32. test hypotheses by comparison with accepted theories,
33. decide whether a hypothesis is empirically confirmed of practically falsified,
34. find exceptions to hypotheses, laws, and theories,
35. explain small discrepencies by a bold new hypothesis,
36. modify a hypothesis to accommodate new facts,
37. reject untestable hypotheses,
38. devise auxillary hypotheses,
39. make analogical inferences,
40. make cause and effect inferences,
41. find multiple causes.
42. reduce cause and effect to a functional relationship,

A student who is emulating the scientist will

43. devise laws (nomic, empirical, statistical, and universal,)
44. group laws into theories,
45. group theories into transcending theories,
46. find new combinations in new theories,
47. apply theory to technology,
48. agree upon a standard of measurement,
49. compare measurement with a standard,
50. find the measurement error,
51. find the limit of detection,
52. devise ways for extending range of measurement,
53. make measurement as precise as possible,
54. repeat measurements over time and space (absolute),
55. make measurements close together (comparative),
56. devise experiment with methods, instruments of measurement,
57. devise,experiment with instruments, new instruments,
58. experiment (for discovery),
59. perform imaginary experiments,
60. devise models (mental pictures, mechanical models),
61. devise mathematical models,
62. test mathematical models by observation and experiment,
63. ascribe properties to models,
64. devise new mathematics,
65. translate mathematics into language,
66. devise symbols for perceptions, facts, events, properties,

A student who is emulating the scientist will

67. relate, correlate, manipulate symbols,
68. accumulate knowledge,
69. locate and state problems,
70. substitute simpler, more abstract problems,
71. consider details in operations which were disregarded,
72. find meaning by examining operations,
73. find meaning by examining purposes,
74. devise and use both formal and operational definitions,
75. carry out inquiry fully,
76. check all work carefully,
77. use knowledge of predecessors,
78. write reports,
79. interchange ideas,
80. use precise vocabulary (new words and new meanings for old words),
81. distinguish between science and quackery,
82. experience conviction of truth,
83. experience feeling of satisfaction,
84. read current publications,
85. look to other fields for possible new instruments,
86. work in a group which includes different skills and knowledge,
87. avoid extraneous influences (e. g., unsupported opinions, scholastic logic, moral considerations, religious considerations, political considerations, mental set).

Usefulness of this study

For the results of this study to be useful in curriculum development it is assumed that the curriculum under consideration has a significant, if not a primary, commitment to the processes of inquiry and the structure of science. To the extent that this commitment is recognized, and to the extent that this study is successful in fulfilling its purpose, it is believed that the findings and constructions herein reported will prove useful to curriculum developers and curriculum evaluators. The findings can serve as (1) the bases for suggesting curricular units and activities, (2) a checklist of objectives for comparison with the behavioral objectives of an existing curriculum,(3) the starting point for the establishment of an empirically determined hierarchy of behaviors,and/or (4) the basis for constructing instruments for evaluating pupil progress.

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