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ABSTRACT

This issue contains copies of the five principal addresses given at the 1979 annual meeting of the National Association for Research in Science Teaching. The five papers speak to the theme of the meeting "The Impact of Learning Paradigms on Teaching and Research." Titles of the papers and their authors are: "The Implications of Paradigm-Based Research for Science Education Research" by Carl Berger; "The Reception Learning Paradigm" by Joseph D. Novak; "The Hierarchical Learning Paradigm" by Howard Jones and J. Michael Russell; "The Developmental Learning Paradigm" by Anton E. Lawson; and "The Impact of Paradigm-Based Research Upon Classroom Practice" by Rita Peterson. (Author)

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INVESTIGATIONS IN SCIENCE EDUCATION

Volume 5, Special Issue, 1979

NOTES FROM THE EDITORS

We are pleased to provide to the readers of INVESTIGATIONS IN SCIENCE EDUCATION the opportunity to read the principal addresses given at the 1979 meeting of the National Association for Research in Science Teaching in this special issue. Because the emphasis of these papers was on the impact of learning paradigms on teaching and research, their content appeared appropriate for publication in I.S.E.

We wish to thank Jack Renner, NARST President 1979-80, for agreeing to the publication of the papers and for his assistance in working with The Journal of Research in Science Teaching to obtain permission for this special issue of I.S.E. These papers will also appear in a future issue of JRST.

If any reader has some suggestions for future issues of I.S.E. and special topics that might be featured, we would welcome these ideas.

Patricia E. Blosser
Editor

Robert L. Steiner
Associate Editor

PREFACE

The papers included here are the five principal addresses given before the annual meeting of the National Association for Research in Science Teaching which was held in Atlanta, Georgia, March 21-23, 1979. The addresses were bound together by the theme of the meeting, "The Impact of Learning Paradigms on Teaching and Research."

The theme for the meeting grew out of the belief that to understand fully how to teach, the teacher must understand how the human being learns. Research in learning, therefore, needs to be examined. But research in any discipline follows and/or establishes certain paradigms. The need of science education, therefore, is to consider the impact of paradigm-based research in general and research with learning paradigms in particular. Furthermore, the impact such research would have on classroom practice needs to be explored.

To lead those attending the 52nd Annual Meeting of the NARST to achieve the goal of understanding the interactions among paradigm-based research, the learning paradigms, and their impact upon science education, five topics were isolated for attention. Those topics were each addressed by a different individual. The topics and the persons addressing them are:

1. *The Implications of Paradigm-Based Research for Science Education Research,* Dr. Carl F. Berger, University of Michigan.
2. *The Reception Learning Paradigm,* Dr. Joseph D. Novak, Cornell University.
3. *The Hierarchical Learning Paradigm,* Dr. Howard L. Jones and J. Michael Russell, University of Houston.
4. *The Developmental Learning Paradigm,* Dr. Anton E. Lawson, Arizona State University.
5. *The Impact of Paradigm-Based Research Upon Classroom Practice,* Dr. Rita Peterson, California State University, Hayward.

These addresses are published with the firm belief that such dialogue contributes to the definition and development of science education and the responsibilities it has to students in the schools.

John W. Renner
President, NARST, 1979-80

THE IMPLICATIONS OF PARADIGM-BASED RESEARCH FOR SCIENCE EDUCATION RESEARCH

Carl F. Berger
The University of Michigan

A paradigm as defined by Gage is a useful definition for science education. He described paradigms "As models, patterns, or schemata... They are useful ways of thinking which if researched will lead to the development of a theory (or model)" (1963, p. 95). Full exploitation of paradigm-based research in science education has not been overwhelming. To be sure, paradigms have been developed and research has been initiated. These include the research from "reception learning," hierarchical learning" and "developmental learning" to be presented by our colleagues in further sessions. Novak, Jones, and Lawson will all present learning paradigms from which much rich research can be done. This presentation will focus on the problems we as science educators and researchers must face before the full advantage and maximum impact of paradigms can be achieved. The implications of paradigm-based research may cause us to focus on our own outlook and to rethink some of the hard questions of what, when, and where and how to carry out our research.

To understand the implications for paradigm-based research an analysis of effective paradigm research may be a fruitful example. Such an analogous example in physics has caused a profound difference in the view of the physical world, radically changed at the most microscopic and macroscopic levels. This example involves the shift from scientific realism to scientific pragmatism and can best be stated in two quotes by leading scientists of the time. Lord Kelvin, commenting on the electromagnetic theories of Clerk Maxwell in 1884, stated:

> I am never content until I have constructed a mechanical model of the object I am studying. If I succeed in making one, I understand, otherwise I do not. Hence I cannot grasp the electromagnetic theory of light. I wish to understand the nature of light as fully as possible, without introducing things that I understand still less (Waismann, 1959, p. 147).

He thus typified the nature of the physical philosophy in the late nineteenth century. This view was also voiced by the American experimentalist (scientific), Hudson Maxim, who noted that, "There can be no effect without a cause... Truth is the exact accordance with that which is, has been or shall be" (1890, p. 4).

A comparison of these two statements with the definition of scientific realism (that the abstract concepts possess an equal or more genuine reality than the particular physical attributes to which they refer) indicates that scientific realism was on the doorstep of disillusionment. This disillusionment was highlighted by the problems of the wave-particle duality and its solution through quantum mechanics.

With the great triumph of wave mechanics by Maxwell in which he was able to resolve the entire electromagnetic spectra into a coherent mathematical model, it was felt description of light into the gamma ray region was complete. According to Blin-Stoyle, senior research officer in theoretical physics at Oxford University, Maxwell himself first attempted to write a description in terms of a mechanical model in 1861-62. It was not until 1864 that his great paper appeared presenting a theory of the electromagnetic model without any reference to a mechanical model (Blin-Stoyle, 1957, p. 23). However, experiments by Max Planck in 1900 showed inconsistencies in the ability of light to be expressed as simple wave patterns. Planck was able to resolve these difficulties with the development of a quantum theory. Einstein's photoelectric equation further reinforced the quantum theory on the premise that light also was emitted in discrete bundles called photons. The amount of energy in these photons is simply proportional to a constant times the frequency of the wave of light. Here the wave-particle duality first appears as we see the description of a particle, that discrete bundle, a photon, dependent in its description upon a wave characteristic, the frequency. At approximately the same time, Rutherford in England had discovered that the atom had a vast majority of its mass located in the center and Neils Bohr had developed quantum rules for the atom in 1913. Bohr pictured the atom as a strong positive nucleus with negative particles spinning in an outside orbit; as they spun, they gave off electromagnetic radiation in the form of light. The difficulty in classical mechanics (the mechanics that Maxwell predicted) was that as the energy of the negative particle is released the particle should spiral toward the nucleus of the atom, and an entire spectra of electromagnetic radiation should be observed. What is observed, however, is that only discrete or certain single energies or frequencies of light are emitted. This phenomenon could be explained only if the light were assigned a certain quanta property. Now the electrons must spin in particular discrete orbits, and again we see the duality of light. Light comes in a photon having both wave and particle characteristics together. There was no way to physically resolve these two models into a common-day analogy with which most of us are familiar. Bohr was well justified in stating in 1927:

> In the general problem of quantum theory, one is faced not with a modification of the theories describable in terms of usual physical concepts, but with an essential failure of the pictures in space and time on which the description of natural phenomena has hitherto been based (Bohr, 1934, p.34).

The particle nature <u>can</u> be resolved by finding the position of certain objects, in this case a photon or an electron. The wave-like structure <u>can</u> be determined by finding the energies of such structures. In a mathematical treatise involving matrix algebra, Heisenberg was able to show that no matter how exact these measurements could be made, one would not be able to determine both the position and the energy of ave particles. Furthermore, a physical model of reality of these wave particles could not be devised. To use Heisenberg's words:

> Atoms...possess geometrical qualities in no higher degree than color, taste,... The atom of modern physics can only be symbolized by a partial differential equation in an abstract multi-dimensional space.... Every type of visual conception we might wish to design is, eo ipso, faulty (1952, p. 38).

Heisenberg was able to derive a relationship which describes the uncertainty by which one can achieve the exactness of position or energy by a simple relationship which merely states that the probability of finding the position times the probability of finding the energy is equal to Planck's constant. This was a momentous development for it means that if we try to ascertain the position of the electron with a high degree of accuracy we cannot ascertain the energy of the electron; and by sheer definition, if the photon is a sharply defined bundle of energy we shall have infinitesimally small accuracy in determing its position. This feature has been termed by Waismann of Oxford as the decline and fall of causality (Waismann, 1959, p. 84).

As exciting and profound as the conceptual changes in the view of our Universe, as important for us were the processes that were also changing at that time. A few of them are...

1. The use of new technology: Devices such as the "down-wind apparatus" of Rutherford as well as beginning cyclotrons of Lawrence provided the necessary physical experiments needed to test the rapidly changing theories (Romer, 1960, p. 45).

2. The use of new supportive techniques such as matrix mathematics: To quote from the Strange Story of the Quantum,

   > Schrodinger decided to create an atomic theory out of such ideas. Concealing the secret of his manipulations, he made a few mathematical passes, uttered a judicious selection of mathematical invocations and incantations, such as Hamilton's Partial Differential Equation, Minimal Integrals, and Quadratic Forms in Phase Space, and magically produced, as if from nowhere, a full-grown wave equation with remarkable powers (Hoffman, 1959, p. 115).

3. The heavy communication that occurred in the physics community such as the Solvay Conference of 1930;

4. The strong support from unusual sources such as the support for the Royal Danish Academy of Science from Karlsberg Brewery (Gamow, 1966, p. 49)(perhaps we could enlist the assistance of the Coor's Brewery); and

5. A way of formulating new ideas and fitting seemingly disparate ideas together through team rather than individual research (Gamow, 1966, p. 161).

Both the processes and the products of paradigm research in physics during the first thirty years of the twentieth century highlight quite well the problems we face in science education and make up the implications for science education research if we are to really research in science education paradigms. From the above example, by analogy, six problems emerge that are critical if we are to achieve paradigm research.

The *first problem* is lack of replication. Each new graduate thesis or dissertation must be unique and have little relation to any other research. It is all too common to find in the initial paragraphs of many theses the comment, "Little work has been done in this field." It is important that we replicate studies in different settings; that we modify the boundary conditions in either the basic research variables or sampling variables until we have a firm grasp of what will or will not work, where the paradigms will and will not fit.

A *second problem* is a strong lack of formulation or reformulation. When science education theories are presented, they are often presented in a framework of "take it or leave it." If the research done shows no clear-cut evidence, little attempt is made to reformulate the theory, but mainly it is discarded.

A *third problem* is that our paradigms lack predictability. To be viable each paradigm should have a series of predictions that can be tested. For it is within the ability to test that we find a direct move toward models and theories. The use of paradigms is crucial, but if they do not yield theories or models then we have a difficult and fragmented future ahead.

A *fourth problem* is a growing implication that all science education must have immediate practical application to classroom practice. Having been a full-time school teacher for eight years and a part-time teacher for another five years, I can sympathize with the need to bring the implications of the research into the classroom. I cannot, however, support the idea that this is a necessary prerequisite to research in science education. Immediate application in the classroom prevents the in-between steps needed before the final testing of a paradigm is carried out. Further, science education in the future must take place in a multiplicity of settings. Those of us who have been to the Chicago Museum of Industry, the Ontario Science Center, the Exploratorium, or to the Lawrence Hall of Science can attest to this. New areas for science education even include shopping centers as bases for learning. Implication for practical application in common settings, therefore, can be extremely stultifying and may, indeed, prevent us from expanding our educational horizons out of classroom teaching with implications of "back to the basics" where all too often science education is not even considered a "basic."

A *fifth problem* involves time. The half-life of our educational problems can be considered orders of magnitude longer than the half-lives of many atoms, and yet our research is often such a short look at phenomena that Gamow himself would be hard pressed to predict any change, much less an exponential model.

The *sixth problem* is that there is a lack of looking for unified theory. Again our paradigms in science education are looked upon as mutually exclusive. It is as if we are in a wave particle duality of our own. Science education is clearly neither waves nor particles but is reflected by complex interactions of students, materials, external world and teachers. Perhaps it will not be possible to describe such a milieu in a single unique way. However, to argue for one or another paradigm may prevent us from realizing that all such paradigms may fit into a larger construct.

How can we use the previous physics analogy to help resolve these problems? One aspect involves the development and use of a technology to increase our communication. We are no longer in a favored climate (if we ever were). We do not have the luxury of being endowed by Karlsburg Beer, much less Coor's. As Cavendish once extolled to his colleagues who had few funds, "We've got no money, so we've got to think" (da C. Andrade, 1964, p. 188).

There is hope, however. The micro-computer is an interesting and enlightening device to increase communication and offer us our basic "cloud chamber" that may enable us to test new theories. Already interactive programs have been written such as Lunetta's "Critical Incidents in Teaching" (1978). Communication networks have been written such as CONFER, a computer-based communication system that allows incredible expansion of individual contact of ideas (Parnes, 1977). We must constantly search for new ways to use new technology in developing and communicating our ideas.

Perhaps the most critical implication of the analogy mentioned for paradigm-based research lies in the use of the tools of our trade. When dealing with a multivariate system we can no longer utilize the simple mathematical processes that lie at the base of univariate studies such as multiple T tests. Multiple variables call for multivariate methods. Path analysis must replace traditional correlational methods. Multiple regression analysis must replace analysis of variance with its attendant categorical variables, continuous variables, and unequal sample size problems. Profile analysis and principle component analysis must replace SCR factor analysis and the analysis of variance.

It is apparent that much can be gained from secondary or meta analysis of data already at hand using techniques designed by Glass (1976, pp. 3-9)--if we are willing to share such data with colleagues who may examine it with new directions in mind.

To conclude, the solution of problems of replication, the inclusion of new technology such as microcomputers and the willingness to use new sophisticated statistical methodology, even if it means we must treat them as "black boxes," can move science education research ahead. The greatest implication for the use of paradigm research in science education can best be found from a quote in the book The Restless Atom by Alfred Romer:

> Do not think for a moment, though, that now you know the "real" atom. The atom is a (paradigm), a theory, a hypothesis; it is whatever you need to account for the facts of experience. A good deal has happened since the closing point of this story, and the atom has been changing to keep up. A good deal will happen in the future, and the changes in the atom will continue. A paradigm in science, remember, last only as long as it is useful (1960, p. 175).

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THE RECEPTION LEARNING PARADIGM

Joseph D. Novak
Cornell University

Introduction

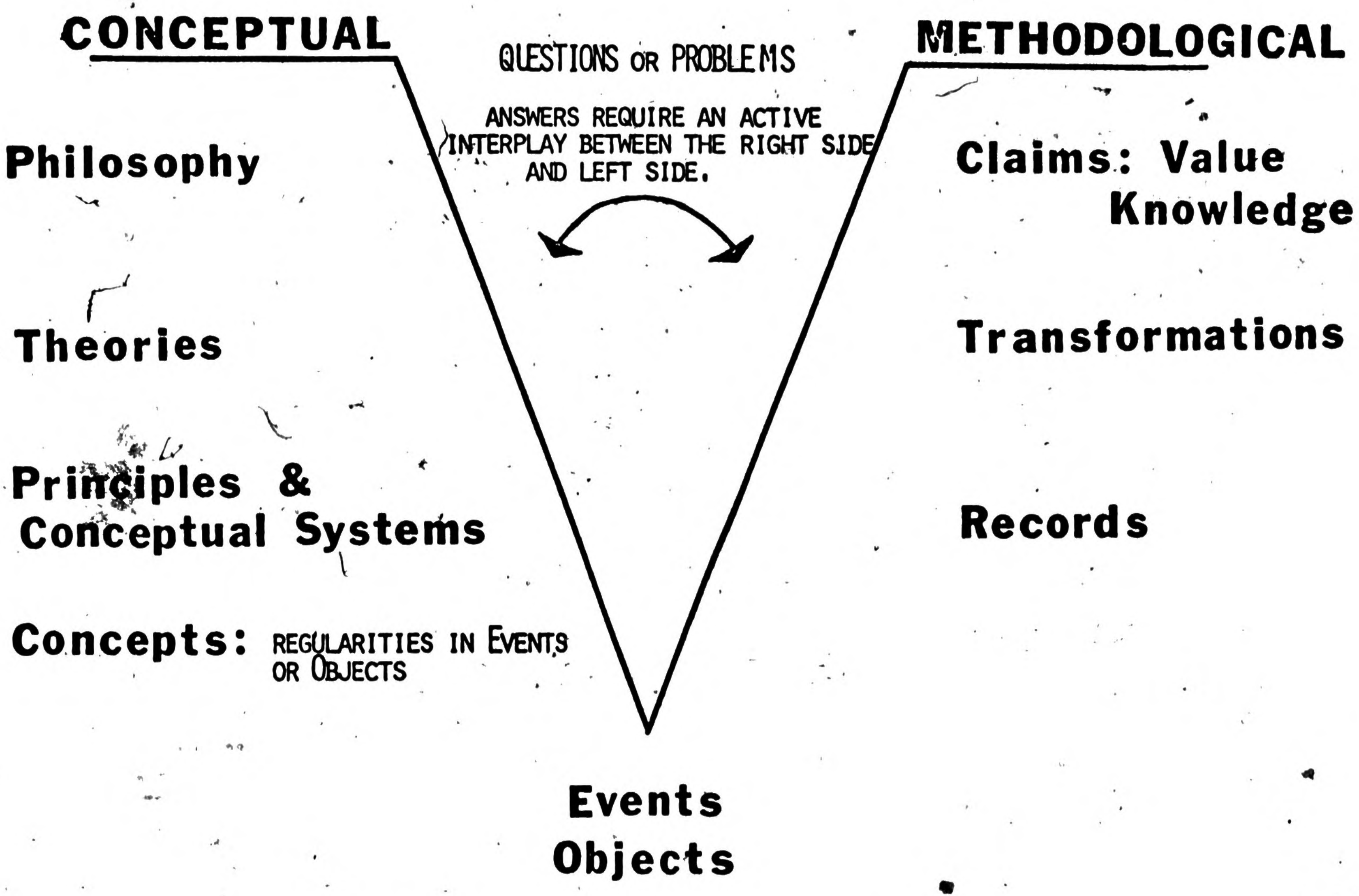
For some two decades my colleagues and I have pursued the question: Can education be a rational enterprise? We have defined a rational enterprise as one that involves the invention of theories and concepts that reliably predict regularities in the world around us, regularities that are real or constructed (as in mathematics). A rational enterprise is also one which employs methods to modify theories or concepts, as Toulmin (1972) has explained. In recent years, we have become increasingly convinced that the answer to our basic question is *yes*, and we have been proceeding to elaborate an educational theory and concepts that can be functional and to obtain empirical evidence to support and/or modify the theory and concepts. The outcome of this work is summarized in a recent book, *A Theory of Education* (Novak, 1977a).

More recently, Gowin (1978) has suggested a useful heuristic device for viewing the nature of any rational, knowledge making enterprise. We have come to refer to this as Gowin's Epistemological V, shown in Figure 1. The "basic point" of the V is that a rational enterprise always points toward a study of *objects* or *events*. Objects are anything we can observe and events are anything that happens or can be made to happen.

The primary achievement of a rational enterprise is the *invention of concepts*. Gowin defines concepts as *regularities* in events or objects designated by some sign or symbol. Dog, for example, is the sign English speaking people use to designate the variety of living things that have four legs, a tail and bark. *Truth* is a more elusive regularity to define, but we all have a functional meaning for this concept label, albeit jurors may debate at length on what is the truth in a given litigation. Records we will define as what we note when we observe objects or events.

One aspect of genius is to select what objects or events are of interest to observe and what kind of records to make. So it was Mendel's genius that led him to a theory which guided him to select pea flower, color, height, etc. to observe and to record the frequency of these traits in progency. Watson and Crick's genius led them to construct alternative molecular models for DNA. The product of such genius is new concepts (new regularities) such as Mendel's factors and Watson and Crick's double helix, and reformulation of the guiding theory which may subsequently be stated more explicitly. New concepts lead to new ways to observe old objects or events and new ways to select new objects or events worthy of scrutinizing and recording. New concepts also give new ways to observe, record or transform records (e.g., R. A. Fisher's *t* statistic).

GOWIN'S EPISTEMOLOGICAL V



CONCEPTUAL

Philosophy

Theories

Principles & Conceptual Systems

Concepts: REGULARITIES IN EVENTS OR OBJECTS

QUESTIONS OR PROBLEMS

ANSWERS REQUIRE AN ACTIVE INTERPLAY BETWEEN THE RIGHT SIDE AND LEFT SIDE.

METHODOLOGICAL

Claims: Value Knowledge

Transformations

Records

Events
Objects

FIGURE 1. Gowin's (1978) Epistemological V can be used as a heuristic for viewing the nature of science for the science of education.

An Epistemology for Education

We can use Gowin's V as a tool to study the nature of knowledge and knowledge production in education. This assumes, of course, that we consider education to be a rational enterprise, and that we hold a philosophical view that the study of educational objects or events can be rationally conceptualized, as suggested in Figure 2. Many teachers and "professional" educators tacitly operate as though education occurs by some mysterious force and their educational epistemology is no more related to rational disciplines than astrology is related to science. If Gowin's V has some validity, we should find it possible to use this heuristic to examine the process of knowledge making in education.

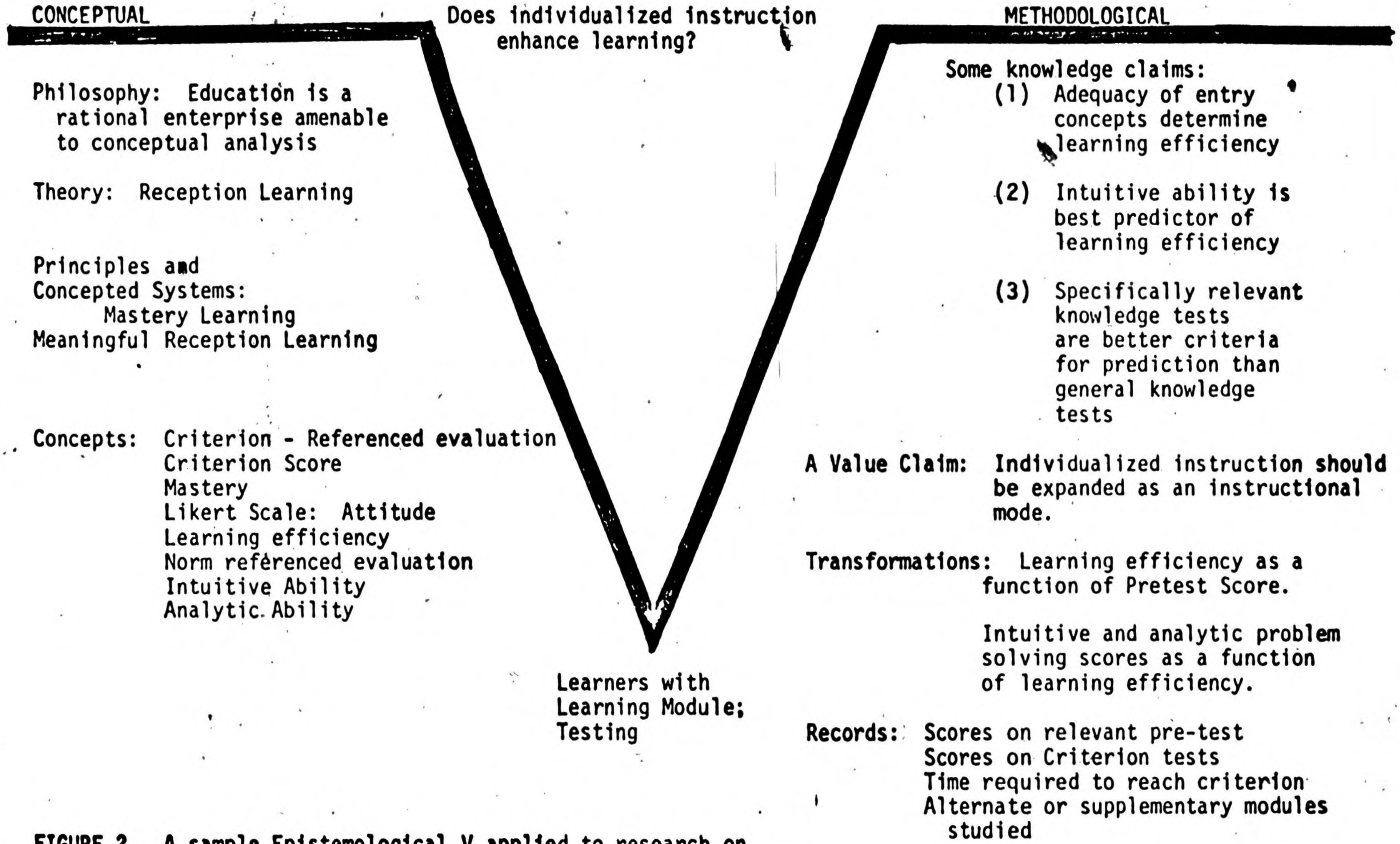
In Figure 2, I have suggested some of the elements that should be considered under the general theory of reception learning, with special reference to mastery learning (see Bloom, 1968, 1976). The events under study are the interplay between learning modules, pretests for knowledge of physics, intuitive and analytic ability, and criterion-referenced tests for achievement on study modules. Sample data transformations and knowledge claims would be as shown in Figure 2, and also a sample value claim. The research "mapped" on to the "V" in Figure 2 would be studies of the type reported earlier (Thorsland and Novak, 1974; Naegele, 1974; Castaldi, 1975).

Reception Learning as Theory for School Learning and Instruction

The label "reception learning" has been given a variety of interpretations, so for the purposes of this paper, I will define reception learning as that form of learning where the regularities to be learned and their concept labels are presented explicitly to the learner. In contrast, discovery learning in its pure form requires that the regularities in objects and/or events are first discovered by the learner, abstracted from the general context in which they occur and perhaps given a concept label, although the latter is not part of discovery learning per se. In actual practice, discovery learning occurs primarily with very young children in the process of concept formation, as when children discover that all things with four legs, a tail and bark are called dogs by older persons, or when new discoveries are made in a discipline. Most discovery learning in school settings is actually various levels of guided discovery learning, and we have a continuum from a pure reception mode of learning to pure discovery mode of learning.

However, we must also consider the cognitive functioning and psychological set of the learner as new knowledge is internalized. Here we must distinguish between rote learning wherein new knowledge is arbitrarily incorporated into cognitive structure in contrast to meaningful learning wherein new knowledge is assimilated into specifically relevant existing concepts or propositions in cognitive structure. Since the nature and degree of differentiation of relevant concepts and propositions varies greatly from learner to learner, it

A SAMPLE EPISTEMOLOGICAL V FOR EDUCATION



CONCEPTUAL

Does individualized instruction enhance learning?

METHODOLOGICAL

Philosophy: Education is a rational enterprise amenable to conceptual analysis

Theory: Reception Learning

Principles and Concepted Systems:
Mastery Learning
Meaningful Reception Learning

Concepts:
Criterion - Referenced evaluation
Criterion Score
Mastery
Likert Scale: Attitude
Learning efficiency
Norm referenced evaluation
Intuitive Ability
Analytic Ability

Learners with Learning Module; Testing

Some knowledge claims:
(1) Adequacy of entry concepts determine learning efficiency
(2) Intuitive ability is best predictor of learning efficiency
(3) Specifically relevant knowledge tests are better criteria for prediction than general knowledge tests

A Value Claim: Individualized instruction should be expanded as an instructional mode.

Transformations: Learning efficiency as a function of Pretest Score.

Intuitive and analytic problem solving scores as a function of learning efficiency.

Records:
Scores on relevant pre-test
Scores on Criterion tests
Time required to reach criterion
Alternate or supplementary modules studied

FIGURE 2. A sample Epistemological V applied to research on individualized instruction.

follows that the extent of meaningful learning also varies along a continuum from almost pure rote to highly meaningful. Figure 3 schematizes the rote ↔ meaningful learning continuum as distinct from the reception ↔ discovery mode of information acquisition. A clear distinction between these two continua has been one of the important contributions of David Ausubel's (1968, 1978) learning psychology. Description of the major elements of his theory go beyond the scope of this paper and can be found elsewhere (Novak, Ring and Tamir, 1971; Novak, 1977a, 1977b). Some of the key elements of his theory as they relate to a paradigm for science education research are discussed below.

The use of Gowin's V to examine the epistemology underlying any educational inquiry is not dependent on the use of any specific theory. However, we cannot legitimately work in the framework of one theory and then invoke principles or concepts that are derivative from another theoretical framework. One of my criticisms (Novak, 1977a, pp. 125-128) of Gagne's learning model (1965, 1970) is that it derives from behaviorist theory that eschews consideration of <u>concepts</u>, and then proceeds to employ concepts from cognitive learning theory to explain concept learning, rule learning and problem solving. The eclectic who invokes whatever concepts are convenient on the "left side" of the V to explain what happens on the "right side" is building on epistemological quicksand. The concepts employed must be consistent with the general theory guiding the enquiry.

Perhaps one of the most popular theories applied to education studies today is the developmental psychology of Jean Piaget. One of the reasons for the success of Piaget's developmental theory is the power and consistency it has shown for critically observing selected educational events, guiding the record making (clinical interview) and record transforming processes and the development of knowledge claims. The genius of Piaget has been analogous to that of Mendel who carefully selected traits to be observed, devised clever ways to record and transform data and showed the consistency between theory and evidence. Useful as Piaget's work has been, I have argued elsewhere (Novak, 1977a; 1977b) that there are alternative theoretical models that are more relevant to learning events and to a generally broader array of other educational events.

Information processing psychology, the most popular reception learning theory today, derives from earlier "cybernetic" (Smith and Smith, 1966) theories and is rapidly becoming embraced by many psychologists who previously were ardent behaviorists. The cybernetic learning theories had their origins in the early 1950s and have advanced in part through their identification with computer models for learning which have experienced tremendous impetus from the exponential rate of advance in computer technology. However, early pioneers such as Estes (1950) suggest caution in hoping for too much too soon from information processing theory (Estes, 1978, p. 6).

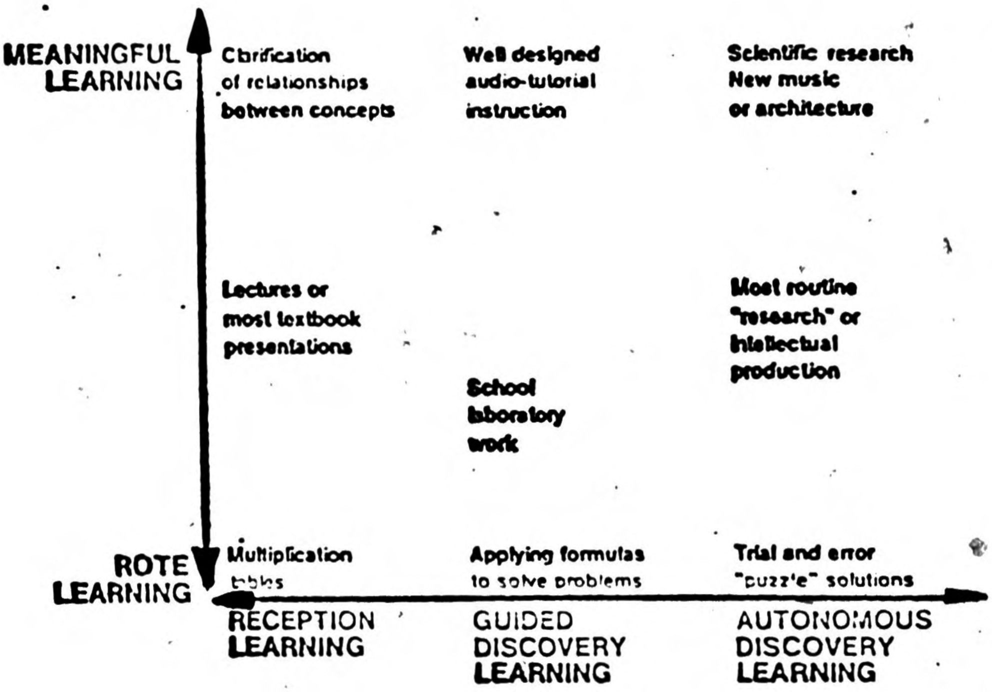


Figure 3. The rote-meaningful, reception-discovery learning continuums. (From A Theory of Education, p. 101. Reproduced with permission.)

> Though anyone's judgment at this point is necessarily speculative, my own is that the computer analogy has proven to have definite merits and has been of substantial value in the early stages of a new approach to cognitive psychology. But this analogy also has sharp limitations. In important ways it seems that the human brain and the computer operate on different principles (see, for example, Anderson, 1977). In some current theorizing by the most enthusiastic devotees of the information -processing approach, we are beginning to see the results of trying to rely too strongly on an analogy of limited validity. But over the greater part of the field, we are seeing instead the emergency of new combinations of theoretical ideas and methods that may be considered inelegant in terms of the inhomogeneity of their origin but that are dictated by the demands of new findings.

While we hope that information processing theories as a basis for learning studies do not achieve the blatant dogmatic adherence that characterized behaviorist theories in the 1940s and 1950s, we would encourage careful study and consideration of this theoretical view as an alternative for science education.

Ausubel's Assimilation Theory

Reception learning strategies have had a long history going back to the writings of early Greeks and Romans. However, David Ausubel was first to formulate a comprehensive theory relevant to a wide array of educational events. His Psychology of Meaningful Verbal Learning (1963) and later Educational Psychology: A Cognitive View (1968) set forth a system of concepts in a theoretical framework that has, in our view, powerful heuristic value for study of a wide array of educational events. Our research program has employed his theoretical views since 1964 (when we abandoned cybernetic theory) and we have found the theory very helpful in guiding the selection of educational events for study, types of assessment measure to use, alternative ways to transform data, and the interpretation of relevant knowledge claims. Some of our work has suggested modifications in Ausubel's theory and these are reflected in his more recent book (Ausubel, Novak and Hanesian, 1978).

Another important characteristic of Ausubel's learning theory is its consistency with what we regard as key principles from modern epistemology, curriculum theory, and instructional theory. Firstly, meaningful learning, a key concept in Ausubel's theory, is dependent upon the idiosyncratic concepts individuals hold, which in turn are derived from the current concepts held in the society impinging on the individual. There is close harmony between the central role of concepts in current epistemologies and the role of concepts in Ausubel's description of the process of meaningful learning.

Secondly, Ausubel's description of "advance organizers," and their role in facilitation on meaningful learning, together with the emphasis on concept learning as the central learning task, is highly compatable with Johnson's (1967) model for curriculum. Johnson defines curriculum as an ordered sequence of intended learning outcomes (ILO's) where the major ILO's are the concepts the teacher selects from the discipline under study. Johnson's distinction between curriculum and instruction, where the latter invokes selection of specific examples or activities designed to achieve the ILO's of the curriculum, nicely complements the emphasis in Ausubel's theory summarized as:

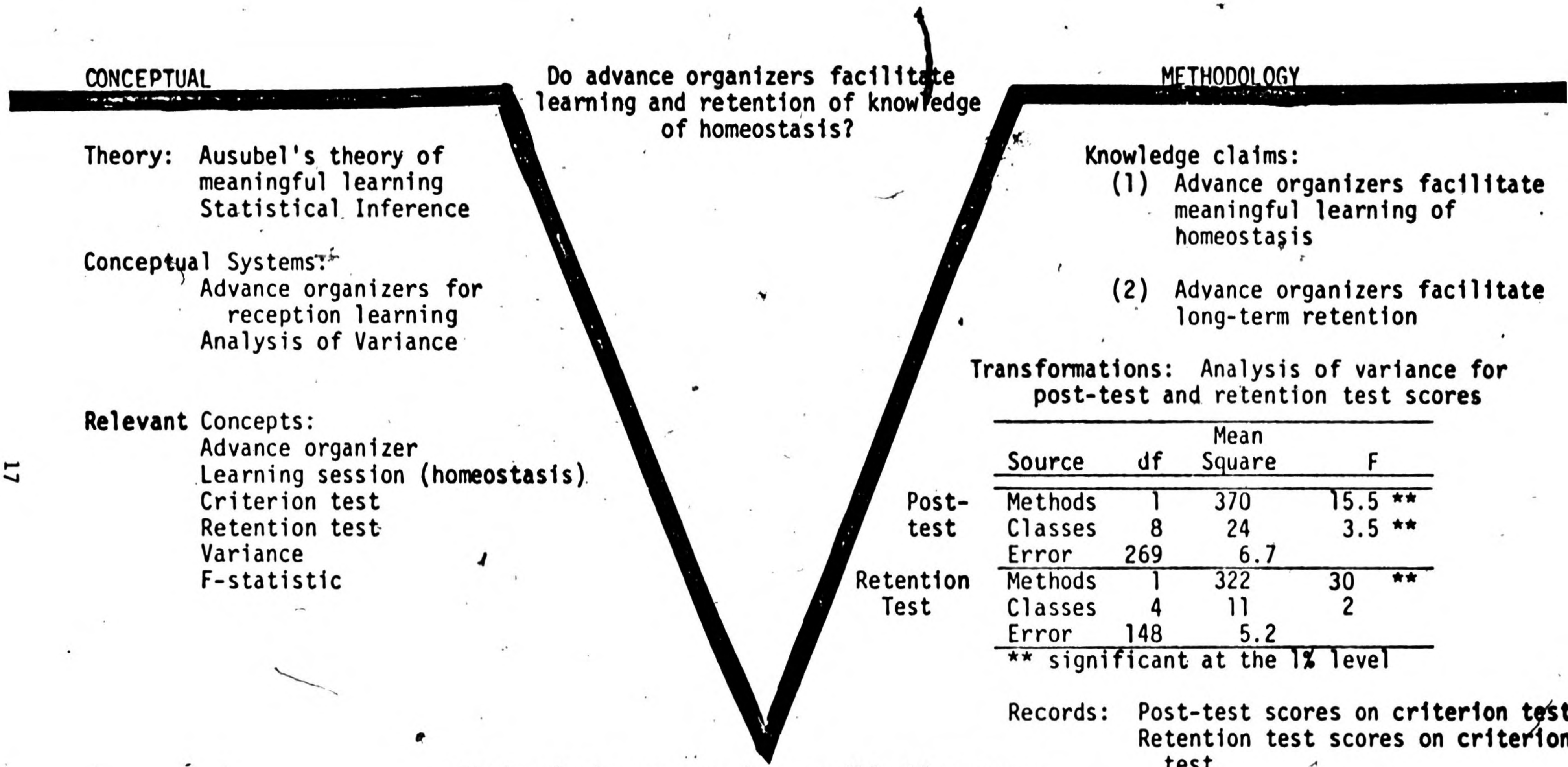
> If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly (1968, p.iv).

The challenge of the instructional designer is to select examples or activities that will allow the learners to assimilate new concepts to be learned (or new elaboration) into the idiosyncratic conceptual framework they already have.

An example of a research study guided by Ausubel's theory of meaningful reception learning is Kuhn's (1967) study on the use of advance organizers in college biology. Figure 4 shows how this research would be viewed under Gowin's epistemological V heuristic. We see that Kuhn's research was guided by the general learning theory framework proposed by Ausubel (1963) and that it employed the system of concepts governing the use of advance organizers and also the statistical procedure of analysis of variance. Some of the relevant concepts utilized are also shown in Figure 4. It is obvious that the <u>structure of the events</u> observed as well as the data analysis procedure are guided by the Ausubelian theory and a theory of statistical inference. In turn, the knowledge claims have relevance to Ausubel's theory and relevant concepts, providing significant validation. Thus we see the inextricable interplay between theory, observations and knowledge claims, and the important relevance Ausubel's theory has to curricular and instructional planning.

Thirdly, Ausubel's theory supports and elaborates some of the concepts in Carroll's (1963) model for school learning, later elaborated by Bloom (1968) in his ideas on <u>mastery</u> learning and Bloom's research findings reported more recently (1976). Although Ausubel recognizes important genic differences in learning capability, the quote above points out that careful consideration of the "anchoring" concepts a learner has will influence the <u>rate</u> and quality of meaningful learning. Carroll and Bloom's view that most students can master most school subject matter if they are guided and given time to master relevant concepts necessary for later learning is explainable through Ausubel's learning concepts on the nature and role of advance organizers, progressive differentiation of concepts and integrative reconciliation of concepts.

Finally, there is also the affective domain to be considered and here Ausubel's theory provides important guidance in the positive



CONCEPTUAL

Do advance organizers facilitate learning and retention of knowledge of homeostasis?

METHODOLOGY

Theory: Ausubel's theory of meaningful learning
Statistical Inference

Conceptual Systems:
Advance organizers for reception learning
Analysis of Variance

Relevant Concepts:
Advance organizer
Learning session (homeostasis)
Criterion test
Retention test
Variance
F-statistic

Knowledge claims:
(1) Advance organizers facilitate meaningful learning of homeostasis
(2) Advance organizers facilitate long-term retention

Transformations: Analysis of variance for post-test and retention test scores

	Source	df	Mean Square	F
Post-test	Methods	1	370	15.5 **
	Classes	8	24	3.5 **
	Error	269	6.7	
Retention Test	Methods	1	322	30 **
	Classes	4	11	2
	Error	148	5.2	

** significant at the 1% level

Records: Post-test scores on criterion test
Retention test scores on criterion test

Study of advance organizer or "blank" passages
Study of examples of homeostasis in animals
Criterion post-test and retention test (three weeks later)

FIGURE 4. Kuhn's (1967) research study of the use of advance organizers shown as represented on Gowin's V.

affective results that accrue from competence or achievement motivation that derives from successful meaningful learning. While other factors also influence positive affective growth, the primary avenue through which schools can contribute, he would contend, is through encouragement of practices that augment meaningful learning.

Another example from our research program that illustrates the usefulness of Ausubel's reception learning paradigm is a study done by Naegele (1974). In this piece of research, Naegele focused attention on the role of prior knowledge for the facilitation of learning, as predicted under Ausubel's theory. Facilitation of learning means that students will score higher on a criterion test, or learn a unit of study material in less time. Naegele combined these two parameters into an index of <u>learning efficiency</u>, where the latter is defined:

$$\text{Learning efficiency} = \frac{\text{Test score on unit test}}{\text{Study time for unit}}$$

Figure 5 shows the resulting learning efficiencies for students who entered study with different competencies as measured by a pretest for knowledge of physics. We see that students with higher physics pretest scores appear to be more efficient learners in units 1, 2a, and 2b. However, by unit #3, the students with low physics pretest scores are significantly more efficient learners than those with high pretest scores. At first this appears to be an anomoly until one considers the following relevant curriculum factor. Units 1, 2a, 2b and 3 all deal with kinematics and unit 3 is highly dependent on concepts introduced in the three preceding units. The data suggest that the low physics pretest group may have been less efficient in learning early units but their extra study effort did result in acquiring <u>specifically</u> relevant concepts needed for unit 3. Since the course was a "mastery learning" program, time was available to the low physics pretest group to master relevant concepts. Students' natural tendency to "coast along" in study units for which they have already considerable knowledge (units 1, 2a and 2b) probably contributed to the high physics pretest group's less than significantly higher learning efficiencies in these units and their significantly lower learning efficiency in the more demanding unit 3. The same significant "reversal" effect on learning efficiency was observed again in units 4 and 15, also units at the end of a conceptual sequence building on earlier units. The results are both explainable by Ausubel's reception learning paradigm (adequacy of prior <u>relevant</u> concepts is the most important factor influencing learning) and also give credence to the importance of careful planning of learning sequences stressed in Johnson's (1967) curriculum model. The value of Bloom's mastery learning strategy is also illustrated in that there was a general trend in both groups to become more efficient learners and differences between the high pretest knowledge group and the low pretest knowledge group were essentially zero in the final summary unit, R1 (which was a "tough" unit and took everyone more time). Naegele's study is one kind of research study schematized in Figure 2.

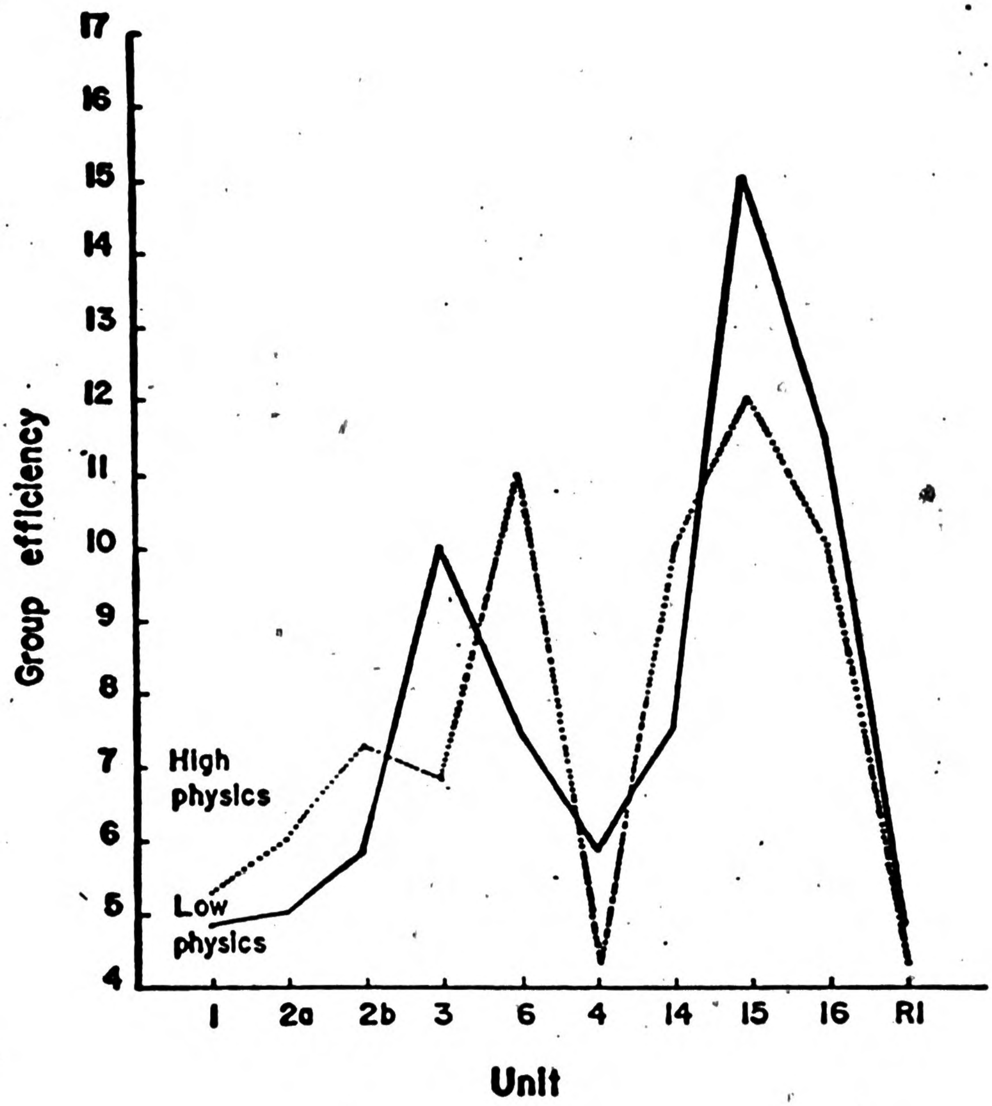


Figure 5. Group efficiency on each unit for two pretest groups; low math-low physics vs. low math-high physics. (from *A Theory of Education*, p. 237, by J.D. Novak, 1978).

In summary, I have tried to show that research in education, as well as the design of instruction, can be importantly influenced by the paradigm that guides our work. As Kuhn (1962) points out, and Lakatos (1976) better elaborates, advances in a discipline arise from systematically employing a paradigm to guide our work and there are at any time competing paradigms. The crucial factor is that we are guided in our work by <u>some</u> paradigm, for ultimately all paradigms are modified or discarded and the issue is not whether our guiding paradigm is true but whether it is useful. My contention is that a paradigm for reception learning, especially that of Ausubel, can be enormously useful to science education. The value of other relevant paradigms are brought together in A Theory of Education (Novak, 1977a).

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THE HIERARCHICAL LEARNING PARADIGM

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If there is a Holy Grail in education it is the "Fool-Proof, Guaranteed Learning Situation." The search for this mysterious panacea has been in process for centuries by both practitioners and theoreticians.

In the absence of an instructional analogue to Benjamin Spock's Baby and Child Care, a book that has shepherded many of us through the early stages of parenting, teachers have continued the search for more effective ways to transmit knowledge, skills and positive attitudes to their charges. Greater and lesser degrees of success have been achieved.

From the other end of the spectrum, theoreticians have attempted to identify learning and teaching generalities and specificities that fit within models or paradigms. Since learning and teaching became topics of serious intellectual study, a number of theoretical premises have been developed, discarded, modified, castigated, praised, and sometimes even implemented into the classroom.

Like many paradigms, the Hierarchical Learning Paradigm evolved as the result of input from both practitioners and theoreticians. In keeping with the semi-humorous premise that "there is nothing as practical as a good theory," the paradigm provides science curriculum developers the rare opportunity to conceptualize agreed-upon science goals and objectives in a reality-oriented, learner-centered way. The paradigm provides opportunities to identify valid, ordered sequences of instruction: prerequisites mean more than the student merely completing Biology I before Biology II. The paradigm permits the teacher to diagnose students' limitations and strengths more effectively, thus permitting more adequate individualization and personalization of instruction. Sub-parts of the paradigm also provide clues for the development of teaching techniques and strategies that will probabilistically influence the acquisition of skills, knowledge and attitudes. Finally, instead of focusing on possible limitations implied by some theories of developmental readiness, there is an air of optimism about the basic premises of the hierarchical model. Learner readiness is viewed in terms of the "number and kind of previously learned intellectual skills" (Gagnè, 1968, p. 290). This premise encourages the educator to diagnose learners' deficiencies and work with learners until necessary prerequisites have been mastered. It is a proactive means to deal with compensatory educational problems.

The paradigm, as all paradigms do, has its limitations and detractors. There are those who castigate its perceived rigidity and dehumanized specification of "behavioral objectives." The difficulty in implementing it into practice is also viewed as a major practical drawback for the paradigm. In addition, even its strongest proponents note serious scope limitations with respect to the paradigm. The hierarchical paradigm focuses primarily on the instruction and acquisition of intellectual skills and has little to add to the specification and achievement of other important dimensions of school learning—especially attitude learning.

In this paper, basic premises of the hierarchical paradigm will be presented. This will be followed by a brief statement describing basic procedures used in past studies to construct and validate learning hierarchies. This will be followed by a brief synopsis of how proponents of the paradigm might explain some well-known issues in child development. A comparison of the paradigm with Mastery Learning follows. Lastly, a summary statement is presented.

Background of the Paradigm

Like many theoretical elements in education and psychology there is probably no one definitive genesis for the Hierarchical Learning Paradigm. A strong impetus came, certainly, from the successes of training programs for military personnel during and after World War II. Many of these training programs consisted of learning tasks, carefully sequenced so that learners, even those starting with bare minimal background, were able to master prerequisite skills and eventually able to achieve the stated terminal skill. Using well-known psychological principles (e.g., small bits of new information, reinforcement, repetition, contiguity), programmers were able to design and implement high effectiveness training elements.

Like all other forms of instruction, programmed materials depend to a great extent on the clarity of instructions given to the learner. Unlike some other kinds of instruction, programmed instruction does not have the luxury of "fine tuning" instruction based on learner verbal and non-verbal feedback. In essence, a programmer must plan and implement more carefully beforehand. Once the learner enters the program, there is really little the programmer can do until revision time. For this reason, three additional requirements are necessary to build materials—the use of clearly stated objectives, insistence on appropriate practice opportunities and an inordinate attention to sequence.

Clearly Stated Objectives

Objectives are specified in measurable terms, thus providing a more precise means for assessing student mastery. Significant learning outcomes were specified using "action" verbs, different action verbs for different kinds of learning outcomes. In an early statement, Gagne and Paradise (1961) made it clear that they were more interested in learning outcomes that permitted the learner to respond to a *class* of tasks. The type of learning was referred to as "productive learning." Productive learning is that kind of learning typically emphasized in most school curricula and was distinguished from "reproductive learning" in that the latter focused on responses to *specific* tasks. In breaking with some earlier programmed instruction efforts, Gagne thus challenged programmers to look at ways to teach concepts, rules and even problem-solving techniques to learners. In his book (1965, 1970, 1977), Gagne has identified a number of unique learning outcomes: Cognitive Strategies (including problem solving), Motor Skills, Verbal Information, Attitudes and four different kinds of Intellectual Skills (discriminations, concrete concepts, defined concepts and rules). The specificity of objectives for each of the kinds of learning is evidenced in Figure 1. The reader obviously has a personal position about the use of behaviorally-stated objectives in science instruction. For purposes of this paper, however, it should be noted that the use of behaviorally-stated objectives is essential to the hierarchical paradigm.

INTELLECTUAL SKILL	
DISCRIMINATION	Distinguishes among given crystal systems.
CONCRETE CONCEPT	Identifies muscle types from microscopic pictures.
DEFINED CONCEPT	Classifies terrain, by using a definition, into arid and non-arid areas.
RULE	Given Coloumb's principle, demonstrate the relationship between electrostatic charges and distance.
HIGHER-ORDER RULE	Generates, by synthesizing applicable rules, a relationship between the density, mass and volume of an object.
COGNITIVE STRATEGY	Originates the solution to the reduction of air pollution, by applying a model of electrostatic attraction.
VERBAL INFORMATION	States the major issues involved in the regulation of nuclear power plants.
MOTOR SKILL	Performs simple acid-base titrations.
ATTITUDE	Chooses science fiction reading as a leisure activity.

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Figure 1

Example Objectives for Gagne's Types of Learning

Appropriate Practice Opportunities

The statement of objectives in behavioral terms also serves another purpose in this paradigm: the objectives permit the identification of conditions in the learning environment which should influence the student's acquisition of the objectives. Gagne argues that learners come to learning situations with an entire array of previously learned capabilities—"internal conditions." These internal conditions, in fact, were found by Gagne et al to be better predictors of student achievement than other indicators of student abilities, such as grades in previous courses and general intelligence (cf. Gagne and Paradise, 1961; Gagne, 1962; Gagne et al, 1962; Gagne and Bassler, 1963).

Within the learning event learners experience a set of "external conditions"—predictable and controlled manipulations of the learning environment around them. The external conditions necessary for learning each of the types of learning in Figure 1 are different. Effective teachers have long recognized that some techniques and strategies are more effective for some objectives than others. If a science teacher wants his/her students to "identify vertebrate animals," the teacher would be wise to provide examples and non-examples of vertebrates for students to explore. This technique, whether accomplished through the exploration of continuous presentations of real animals, mock-ups, models, or photos and coupled with appropriate reinforcement is a useful means for teaching the concept "vertebrates." Similar techniques remain somewhat constant, the topics differ. The reader might note that these conditions are similar to those described by Bruner et al. (1967) for the teaching of concepts. In fact, Gagne's identification of these and other external conditions for all learning types are those derived from well-known learning studies. The point, however, remains—there are specific external conditions that follow from the precise statement of objectives that will probabilistically influence a learner's achievement of the objectives. Furthermore, the lack of necessary external conditions will probabilistically lead to non-learning of the objectives.

Attention to Sequence

That there is a need for sequences in instruction is evident from the fact that school learning takes place over a period of time. The accomplishment of one objective in a student's educational life is preceded and followed by other learning events. Except in very simple linear learning sequences (A—B), the acquisition of knowledge is a complex excursion through a labyrinth of learning experiences.

In some instances, sequences do not play as great a role in determining effective learning. If all skills and knowledge of a given course are independent (that is, the learning of one element does not depend on the learning of another) then the different elements could be taught in any sequence (cf. Payne, Krathwohl and Gordon, 1967).

However in cases where there is some relationship between learning outcomes, sequence becomes essential. Ausubel (1960) provides evidence that meaningful contexts should be provided to the learner in advance of verbal learning outcomes. This, of course, implies sequence. There is probably a more efficacious sequence as well in the learning of attitudes and values as postulated by Bandura (1969). For a complete discussion of learning sequences in instruction, the reader is referred to Briggs (1968).

In the hierarchical paradigm, sequence is of paramount importance. As noted earlier, paradigm proponents accept the existence of other types of learning. However, the primary function of the paradigm is that of detailing the sequential learning of intellectual skills. It is held that the learning history of an individual is "cumulative in character" (Gagne, 1977, p. 145). A learner's ability to master high levels of learning is dependent on his bringing prerequisite knowledge and skills to the learning task.

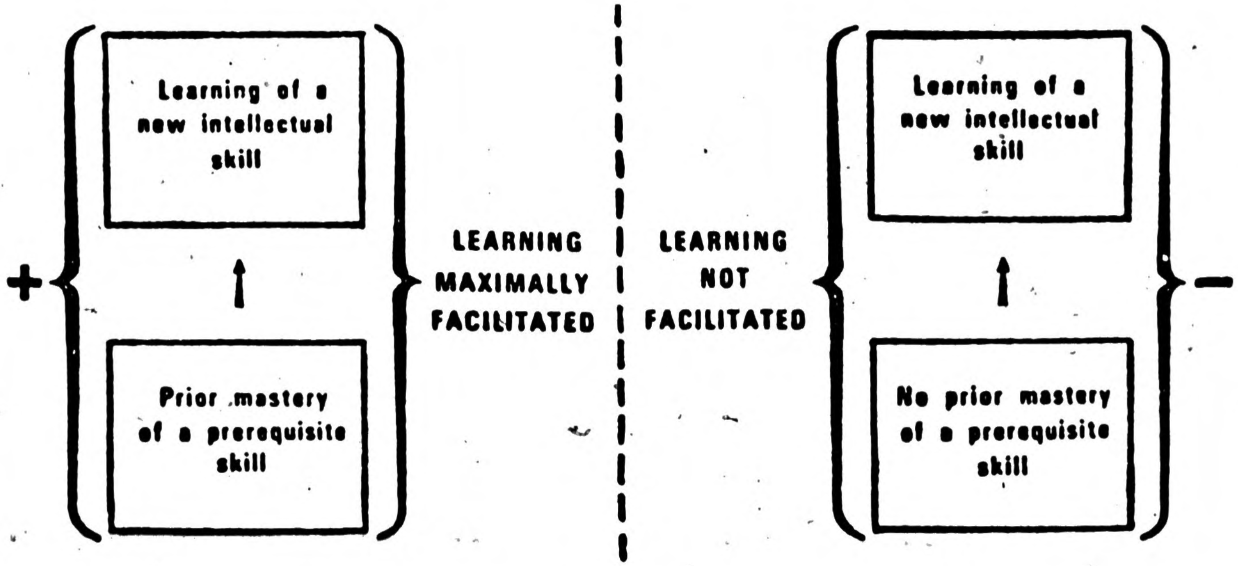

Figure 2

The Dependency of Learning on Prerequisites

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At its simplest level, the hierarchical paradigm holds that there are superordinate and prerequisite relationships in learning sequences. The learning of superordinate intellectual skills will be maximally facilitated if there is prior mastery of prequisite intellectual skills. Conversely, the learning of a superordinate intellectual skill will not be facilitated if there is a lack of prior mastery of a prerequisite skill. By placing superordinate and prerequisites into a valid sequence, a set, or hierarchy, of intellectual skills can be ordered (see Figure 3).

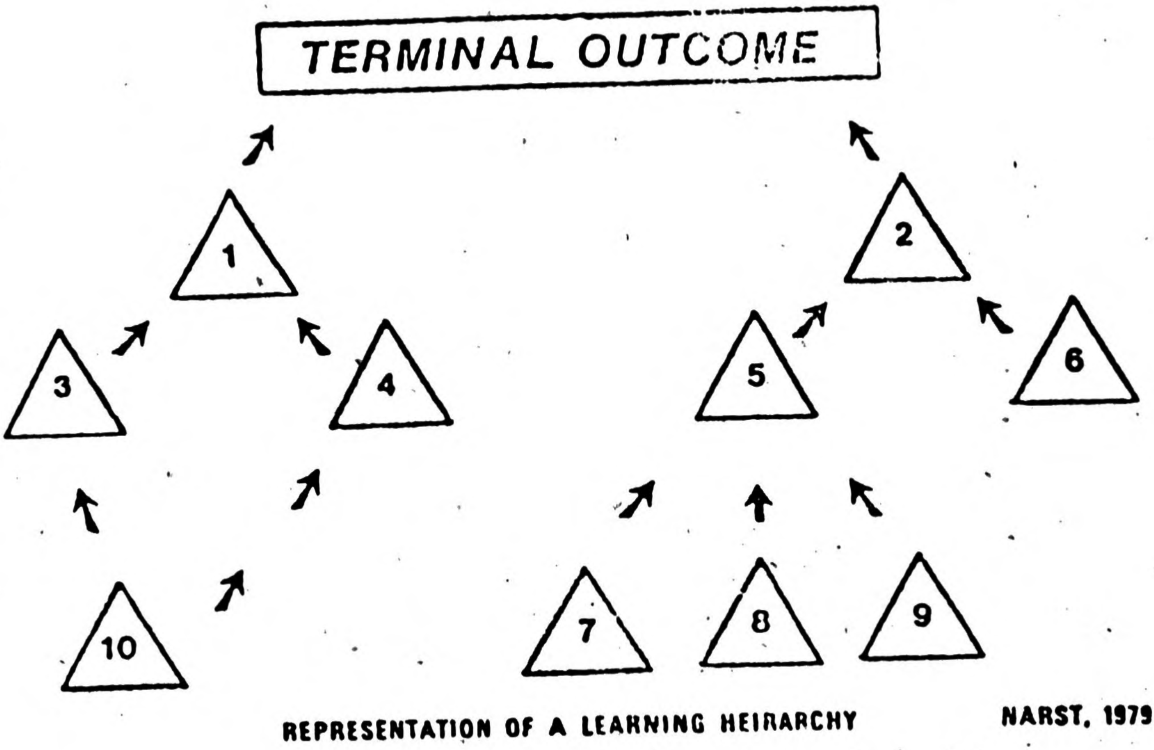

Figure 3

An Hypothesized Learning Hierarchy

Hierarchical Validation Procedures

Anyone who has attempted to construct a valid learning hierarchy needs not be convinced of the difficulty of the task. Unlike the construction of scope and sequence charts which identify curriculum topics and estimated instructional times and sequences (usually teacher— or text writer-validated), the construction of a learning hierarchy calls for the identification of learner-validated structures. Each objective in a hierarchy specifies an intellectual skill in the form of a specifically stated behavioral objective. The lines connecting specific objectives posit hypothesized learning dependencies. In a valid hierarchy, by necessity, most learners unable to demonstrate prerequisite skills should not be able to demonstrate a superordinate skill.

Once a terminal objective is identified, the construction of most hierarchies takes on the form of task analysis (cf. Miller, 1963). The terminal objective is usually in the form of a rule. The question is asked: "What would the learner have to do to be instructed in the rule?" Answers are determined and stated in the form of other behavioral statements which become hypothesized subordinates to the terminal objective. The same question is asked of each of these subordinates. This process is continued until the bottom level skills appear to be simple enough to be performed by the learner population.

What exists now is a hypothesized hierarchy. The hypothetical nature must be tested. Some writers (cf. Capie and Jones, 1971; Airasian and Burt, 1975) note that it is not even necessary to order the statements into a hypothesized hierarchy before taking steps to validate the hierarchy.

The validation of a hierarchy can be a complex task. Hypothesized learning dependencies must be tested between each stated intellectual skill. In hierarchies consisting of large numbers of skills this demands numerous comparisons. The results of the testing may indicate that two or more prerequisites exist for a simple superordinate (Nos. 3 and 4 are each prerequisites to No. 1 in Figure 3). One skill might be found to be a prerequisite to more than one superordinate skill (cf. #10 to both #3 and #4). Or there might be no prerequisite-superordinate arrangement identified (as #5 and #6).

There have been a number of alternative procedures developed for testing the statistical dependency of cells within hierarchies. Each alternative has its proponents and its detractors. All techniques, however, use performance assessment of learners. This testing calls for the development of valid criterion-referenced assessments for each intellectual skill in a hierarchy. Since the intellectual skills represent response classes, the assessments probably should ask for learner responses to more than one situation. This step would also mitigate some measurement error problems such as a learner's guessing correctly or making "dumb" errors. However, since individuals should be tested on each intellectual skill there must be a pragmatic upper limit to the number of items administered. Two items per skill seems to be a workable compromise although Emrick (1971) has postulated a means for actually deciding optimum number of items based on among other things, identifiable measurement errors of selected items.

Hierarchical validation procedures fall into one of two categories: Psychometric or Experimental.

Psychometric procedures. These procedures assume that a person who demonstrates mastery of a skill will also demonstrate mastery of prerequisites. It is furthermore held that if this relationship does not hold, it is only because of chance error. To minimize error, samples of 100+ learners are tested with individual assessments. Records are kept of mastery and non-mastery by each learner on each intellectual skill. Using the results of large samples of learners, probable expectations of prerequisites-superordinates are identified. Table 1 provides indication of some examples validation statistical procedures used in past hierarchical validation studies.

Table 1

Validation Statistics Used in Past Hierarchical Validation Studies

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- Proportion Positive Transfer
  - Gagne' & Paradise, 1961

- Adequacy, Consistency, Completeness Ratios
  - Cook & Walbesser, 1973
  - Walbesser, 1968
  - Walbesser & Eisenberg, 1972

- Necessity Ratio
  - Capie, 1970

- Phi Coefficient
  - Capie & Jones, 1971

- Guttman Coefficient of Reproducibility
  - Hofmann, 1977
  - Resnick & Wang, 1969

- Markov Decision Model
  - Wollmer & Bond, 1975

- Ordering Theory
  - Airasian & Bart, 1975

- C Statistic
  - White & Clark, 1973

Experimental validation procedures. Several writers (White, 1973; White and Gagne, 1974; Cotton, et al., 1977) provide opinions that experimental procedures may be more definitive than psychometric procedures for the development of hierarchies. In experimental validation it is important to demonstrate that the training of students to master a prerequisite skill results in the transfer of prerequisite learnings to superordinate tasks. Furthermore, attempts to train a learner in a superordinate skill will not succeed unless the student already has mastered the prerequisite skills. The difficulties of this experimental training technique are obvious, and it is not surprising that most hierarchies have been validated using psychometric validation procedures.

Hierarchical Learning and Development

In past writings Gagne has explored possible relationships between learning hierarchies and what is referred to as "development"—human changes in capability that are observed over very long time periods—months and years. In many earlier validation studies of hierarchies directed toward the creation of effective training programs, the time period was quite short. In fact, in initial studies focusing on the acquisition of mathematical skills, Gagne and his associates dealt with content that could be acquired by many learners in two weeks or less.

In 1968 Gagne wondered aloud whether the cumulative nature of the hierarchical paradigm could be descriptive of Piaget's conservation of liquid task (Piaget and Inhelder, 1964). This conservation task calls for learners to evaluate the equality of volume of liquids in two identical containers and later when the contents of one of the containers is poured into a taller or flatter container. The task represents only one of the Piaget conservation tasks but is certainly representative—in each case the learner must judge equalities and then mentally manipulate subordinate quantities (in this case the height, width and length of the container) to make predictions of conservation.

In this same article, Gagne postulated a hypothesized hierarchy that detailed prerequisite steps in the conservation task which rectangular containers are used. Figure 4 is a modified version of Gagne's (1968) hierarchy to which the authors have added action verbs, categorized the prerequisite behaviors into the types of intellectual skill, and made other slight modifications. Like Gagne's, this hierarchy is a hypothesized relationship—not, as yet, a validated hierarchy. The hierarchy is nonmathematical in content. The use of the verb "notes" in several prerequisite skills indicates that an investigator attempting to identify learner mastery would search for any indication of student acquisition. A learner might "note that if L is increased while W and H are held constant, volume of liquid would increase" if the learner indicated, for example, that more 'stuff' would be needed to fill the taller of two containers, whose W and L are the same.

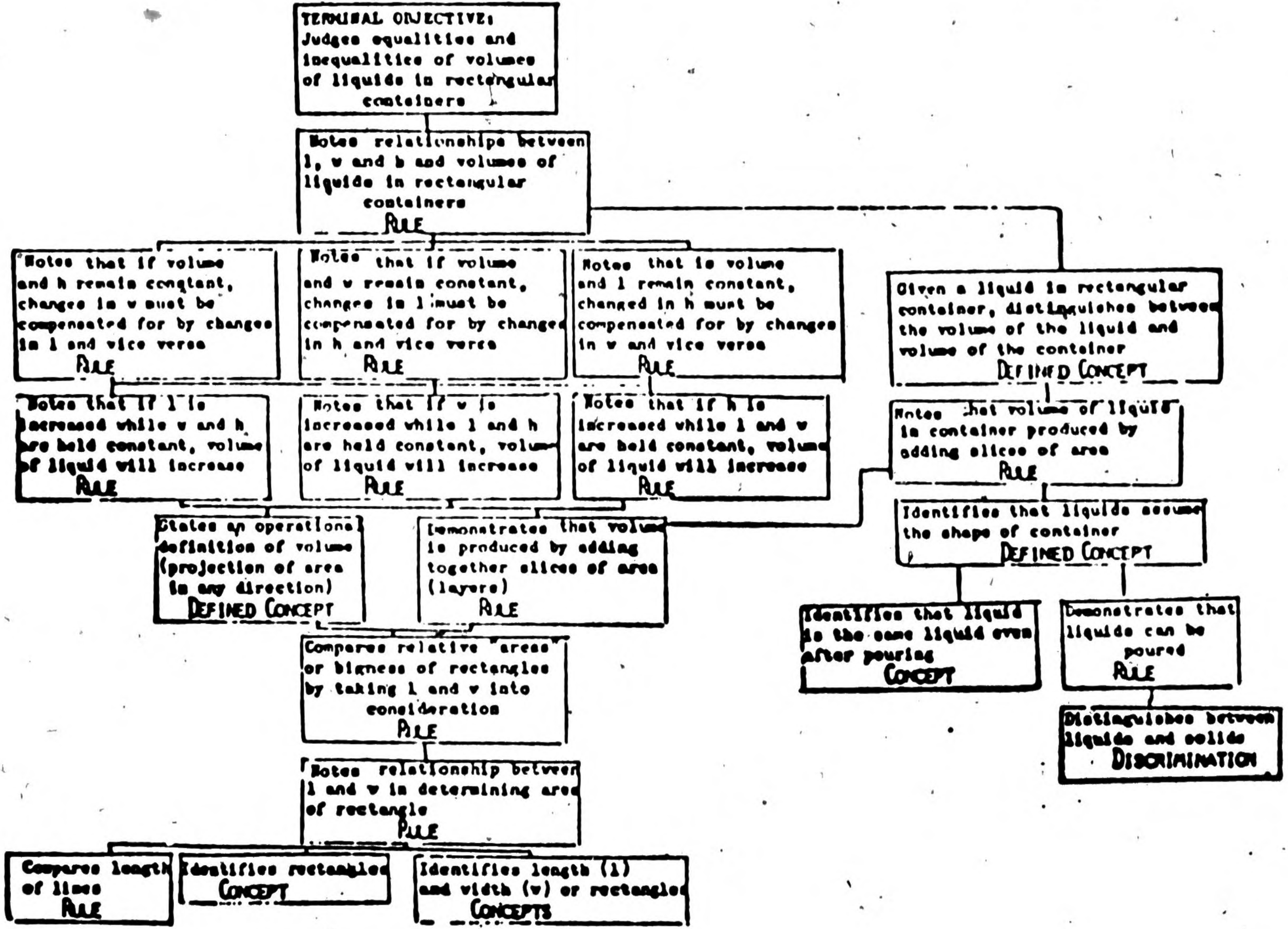

Figure 4

Hypothesized Hierarchy for Judging Equalities/Inequalities of Liquids in Rectangular Containers (after Gagne, 1968)

Gagne postulated that there are really two major subordinate paths in the hierarchy. The left path deals with estimated sizes of volumes as combinations of L, W and H as well as compensations for volume changes when one or two of the dimensions are held constant. On the right path are those intellectual skills focusing on the manipulations of liquids in containers.

In essence, Gagne makes the point that learning must be viewed as a factor in development. In contrasting the paradigm with developmental models, Gagne states:

> ....the cumulative learning model proposes that what is lacking in children who cannot match liquid volumes is not simply logical processes such as "conservation," "reversibility," or "seriation," but concrete knowledge of containers, volumes, areas, lengths, widths, and liquids (1968, p. 186).

Furthermore, Gagne notes that one of the reasons for the failure of compensatory training programs for non-conserving children is that instruction has been targeted at the terminal objectives of hierarchies rather than focusing on missing prerequisite skills.

It should be noted that the hierarchical paradigm was not developed as an antithesis to any other paradigm. However, the use of a hierarchy to examine human development does provide unique perspectives. If there were a validated hierarchy (and the one proposed in Figure 4 has not as yet been validated) for the conservation task it may well be that the successful learner could transfer the judgment of equalities and inequalities to cylindrical containers. Perhaps also the transfer of the learned rule could be made to other quantities like number, area, or length. Such successful transfers could provide a hierarchical definition of a developmental state like "concrete operations." The transfer also would verify the cumulative—not additive—nature of the paradigm.

Hierarchical Learning and Mastery Learning

To many people, the hierarchical paradigm is a reflection of a number of ideas espoused recently by Benjamin Bloom. Readers familiar with Bloom's work know that for the past decade Bloom has focused on the identification of key instructional variables in school learning. In doing so, Bloom amplified John Carroll's unique definition of learner "aptitude." Carroll (1963) suggested that perhaps aptitude is not a measure of whether or not a learner could master a subject but was instead a measure of the speed with which he could master the subject. Bloom expanded upon this, noting that given enough time, a significant majority (up to 95 percent) of all learners could master any subject.

With just a little imagination one can see the identification of hierarchical sequences of intellectual skills meshing with Bloom's

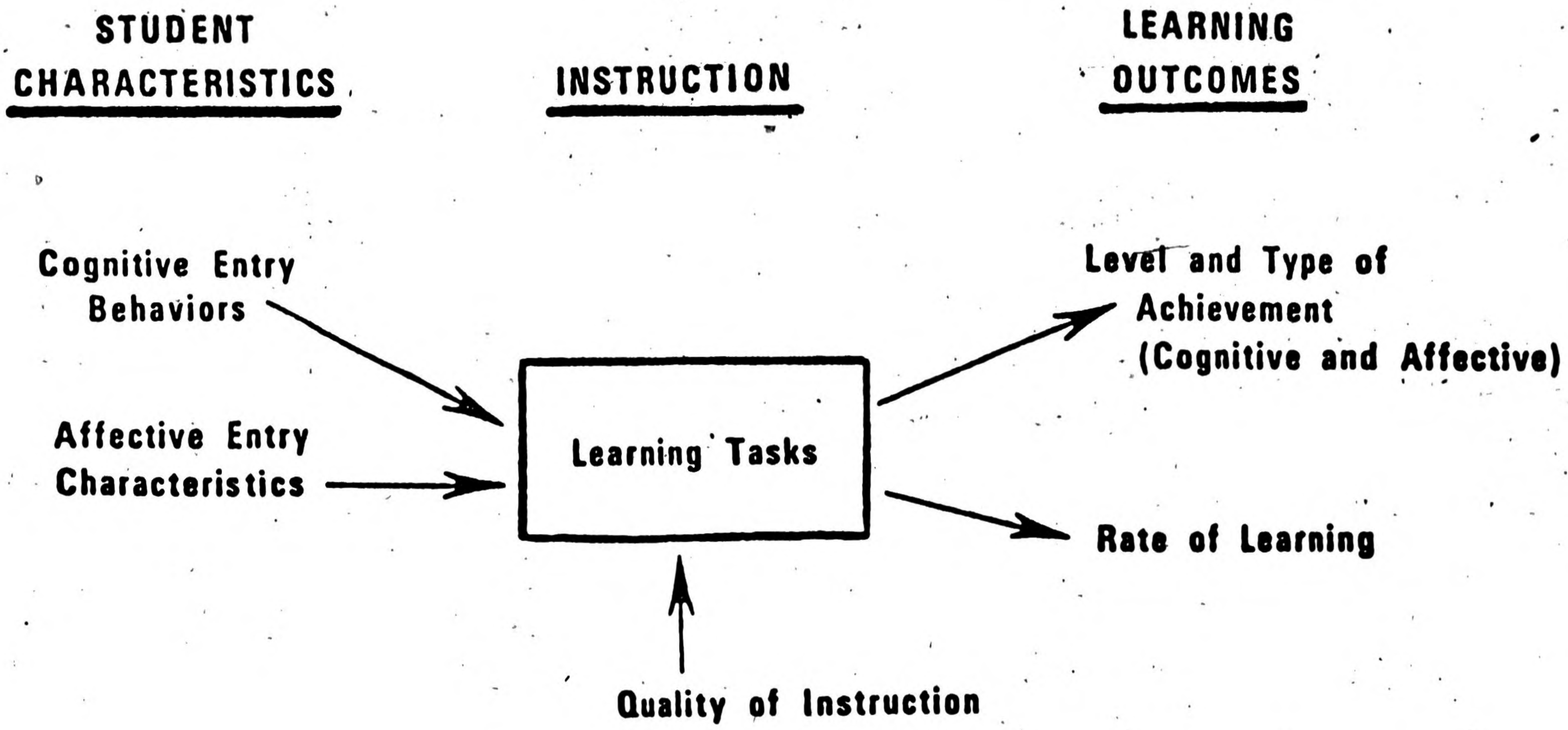

Figure 5
Variables in Bloom's Theory of School Learning

After Bloom, 1976

NARST 1979

premises. It is fascinating, however, to note that Gagne's work is not cited in Bloom's writings and also that Bloom's work is not cited by Gagne or other proponents of the hierarchical paradigm.

Bloom, in his most recent work (1976), provides a model for viewing school instruction. He notes that there are three interdependent variables central to his theory of school learning:

a. The extent to which the student has already learned basic prerequisites (Cognitive Entry Behaviors)

b. The extent to which the student is motivated to engage in learning (Affective Entry Characteristics)

c. The extent to which instruction is appropriate to the learner (The Quality of Instruction)

To Bloom, *Cognitive Entry Behaviors* are those prerequisite learnings that learner brings with him. Furthermore, Bloom provides some convincing evidence, collected in hundreds of studies, which indicated that up to 50 percent of the variance in student achievement can be attributed to a learner's Cognitive Entry Behaviors. In light of the basic premises of the hierarchical paradigm, this is not surprising.

Affective Entry Characteristics reflect the learner's perception of his successes and failures in similar learning experiences. This complex collection of learner interests and attitudes toward a subject (and self) is also a function of past experiences. Bloom notes that up to 25 percent of the variance in learner achievement can be accounted for by this characteristic.

Bloom's last variable, *Quality of Instruction*, provides an equally interesting focus. Bloom notes that there are four characteristics of Quality of Instruction: cues, active participation of the learner, reinforcement and feedback. Interestingly, Bloom's reported results indicate that up to 25 percent of the variance of learner achievement can be explained by instructional quality. This percentage appears quite small when compared with the variance explained by Cognitive Entry Behaviors. However, over time, instructional quality can be a significant determinant of learner outcomes, as we all know.

Bloom also notes that in combination these three variables can explain up to 80-90 percent of the variance in school learning. The hierarchical paradigm's insistence on prerequisite-superordinate relationships and on the existence of "external conditions" appear to us to reflect direct analogues of Cognitive Entry Behaviors and Instructional Quality. Interestingly, noticeably absent from Bloom's predictor variables is any indication of learner general intelligence. This parallels findings reported by Gagne et al. in the early hierarchy studies where individual differences in learning were found to be due less to general intelligence than to the learner's missing prerequisite skills. To us, these and other elements provide evidence of paradigm overlap and a possible indication of co-validity of each.

Finally

It appears logical to many educators that a series of interconnected hierarchies could form the backbone for curricula throughout all levels of education. The fact is, however, that there have been painfully few hierarchies validated, let alone curricula built based on the hierarchies. Some portions of the University of Maryland Mathematics Project reflect hierarchical efforts. In addition, Science—A Process Approach, especially in its initial NSF-support days, was developed based on hierarchical principles. However, these efforts are meager compared with total curriculum offerings of schools and colleges. Why the paucity of practical results of the paradigm?

One reason is the difficulty of hierarchical validation. A second reason is found in the component parts of a hierarchy. Learning hierarchies are connections of intellectual skills. Rational methods have not been developed to generate hierarchies for the learning of Motor Skills, Attitudes, Cognitive Strategies and Verbal Information. Needless to say, these latter four types of learning make up a sizable portion of all school curricula.

Obviously, these difficulties are large. However, the strengths of the hierarchy paradigm should continue to catalyze the continued study of the paradigm. In closing, let's look at two of the strengths.

Defined Learning Outcomes

It is certainly an understatement that many research studies in science education have suffered as a result of confusion about learning outcomes. Results reported in three different studies on the acquisition of "concepts" are blunted when one reads the reports and finds three different, and perhaps orthogonal, operational definition of "concept" used in the studies. Critics of Gagne's work may not always agree with his definitions of intellectual skills—"Discriminations," "concrete concepts," "defined concepts" or "rules"—but, nonetheless, the definitions are stated for all the world to see. Such a taxonomy could be a valuable tool for all of us involved in research to assure that we are exploring the same phenomena. Such a taxonomy could also permit us as science educators to agree perhaps on appropriate instrumentation to identify learner mastery, thus permitting a more valid focus on the nature and causes of the recently publicized "test score decline problem."

A Focus on Appropriate Sequences of Instruction

Critics of the hierarchical paradigm argue that the inordinate amount of structure within the paradigm is a detriment to the bright learner. However, these critics also seem to glean only selective parts of the paradigm. Yes, a hierarchy, when validated, does represent a sequenced set of intellectual skills. However, as noted earlier, this sequence is a probabilistic arrangement—it represents a probable expectation for a group of learners. A hierarchy does not identify the most efficient route for any one given learner. There are certainly possible variants in the hierarchy for individuals. The bright learner, because of past learning or innate capabilities may be able to skip over particular prerequisites. The hierarchical paradigm holds that when this happens the learner "has been able to acquire a higher-order skill by using a problem-solving approach that probably also utilizes some very important (and previously-learned) strategies" (Gagne, 1970, p. 241).

In short, hierarchies are not meant to slow down bright learners. Hierarchies should provide bases for finding more efficient paths for the majority of learners. Valid hierarchies should provide the diagnostician or the teacher with higher probabilities in their identification of where individuals or groups of learners fit in a hierarchy. This step in itself certainly should increase the possibility for the design of more personalized instruction.

Neither does the use of a validated hierarchy dictate a teacher's style of instruction. Nothing precludes the teacher from starting on any spot in a hierarchy and moving his students "up" or "down." Shulman (1970) argued that the direction of movement in a hierarchy distinguishes expository from discovery learning. In discovery learning, the learner is placed in a problem situation where he is unable to explain a phenomenon. Through exploration (presumably dealing with the acquisition of prerequisites), he eventually discovers the solution. Shulman, furthermore identifies a teacher's starting with prerequisites and working "up" as that strategy followed in most expository classes. Again, the hierarchical paradigm does not insist on any specific sequence for instruction, only the acceptance that there are necessary prerequisites to the mastery of any superordinate skill. If this condition is met, effective learning should take place regardless of the instructional sequence selected. Perhaps this condition is one reason for our failure to identify differences in the effectiveness of different instructional types in past studies.

In summary, the hierarchical paradigm presents a unique vantage point from which to view school learning. The vantage point certainly permits opportunities for all of us in science education to construct, review and modify science instruction for learners at all levels.

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THE DEVELOPMENTAL LEARNING PARADIGM

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What Is Intelligence?

Consider the problem presented in Figure 1. The task of the problem solver is to complete the matrix of figures by selecting the correct figure from the eight given in Figure 1.

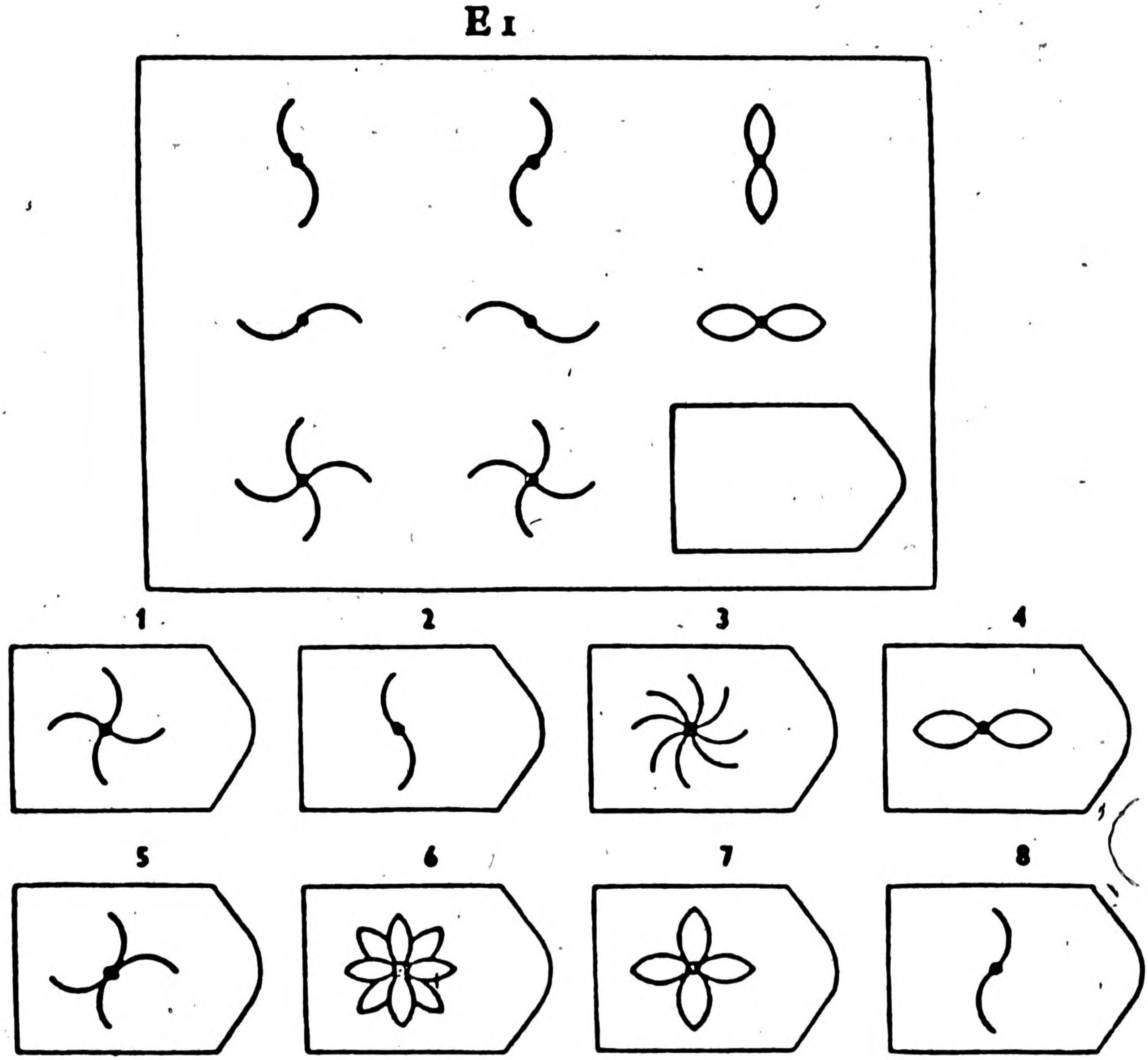

Figure 1

Item E_1 from the Raven Standard Progressive Matrices Test, Raven (1958).

Before looking at the answer choices, examine the left-hand column of the matrix. Notice that the bottom figure is simply a composite of the top and middle figures. Does this pattern also hold true for the second column? A quick inspection reveals that it does. Now examine the top row of the matrix. Notice that the right-hand figure is a combination of the left-hand and middle figures. Does this pattern hold true for the second row? Again we can see that it does. Thus the missing figure is most likely a combination of either the first two figures in column three or a combination of the first two figures in row three. Either combination will do and, in fact, both are the same. Thus the correct answer is most certainly figure seven.

The reasoning strategy just described could be termed additive superimposition (following Hunt, 1974) since initial figures are mentally added by superimposing them to produce new figures. Now consider Figure 2.

Again the task of the problem solver is to select the correct figure to complete the matrix. Will the superimposition strategy work again? Clearly no. The correct answer is figure five. But if additive superimposition will not work, what strategies will?

Certainly there are more ways than one to solve the problem, yet consider this strategy. Notice that each figure consists of three parts: a base, a pair of sides, and a top. Now if we consider just the base we see that it varies in being either present or absent. In all cases when present it is straight. Also in each complete row and column there are two figures with bases and one without. If we extrapolate this pattern to row three or column three which contain the missing figure we can readily conclude that the missing figure must have a base. This follows since row three and column three already contain one figure with a base and one without.

Now consider the sides. In each complete row and column the sides are one of three types: either one convex-one concave, both straight, or both concave. Again if we extrapolate this pattern to the row and column with the missing figure we can conclude that the missing figure must have one convex and one concave side. This follows in that the figures present have either two straight sides or two concave sides.

All we need to do now to complete the figure is select the correct top. Notice that in the complete rows and columns the tops are either pointed or flat. In fact there are two pointed and one flat top in each complete row and column. In the row and column with the missing figure we already have one flat and one pointed top so the missing figure must have a pointed top. Thus the missing figure must be number five.

Such a problem-solving procedure involves identifiable reasoning strategies. First there is clearly the need to divide the individual figures into component parts—an isolation of the variables as it were.

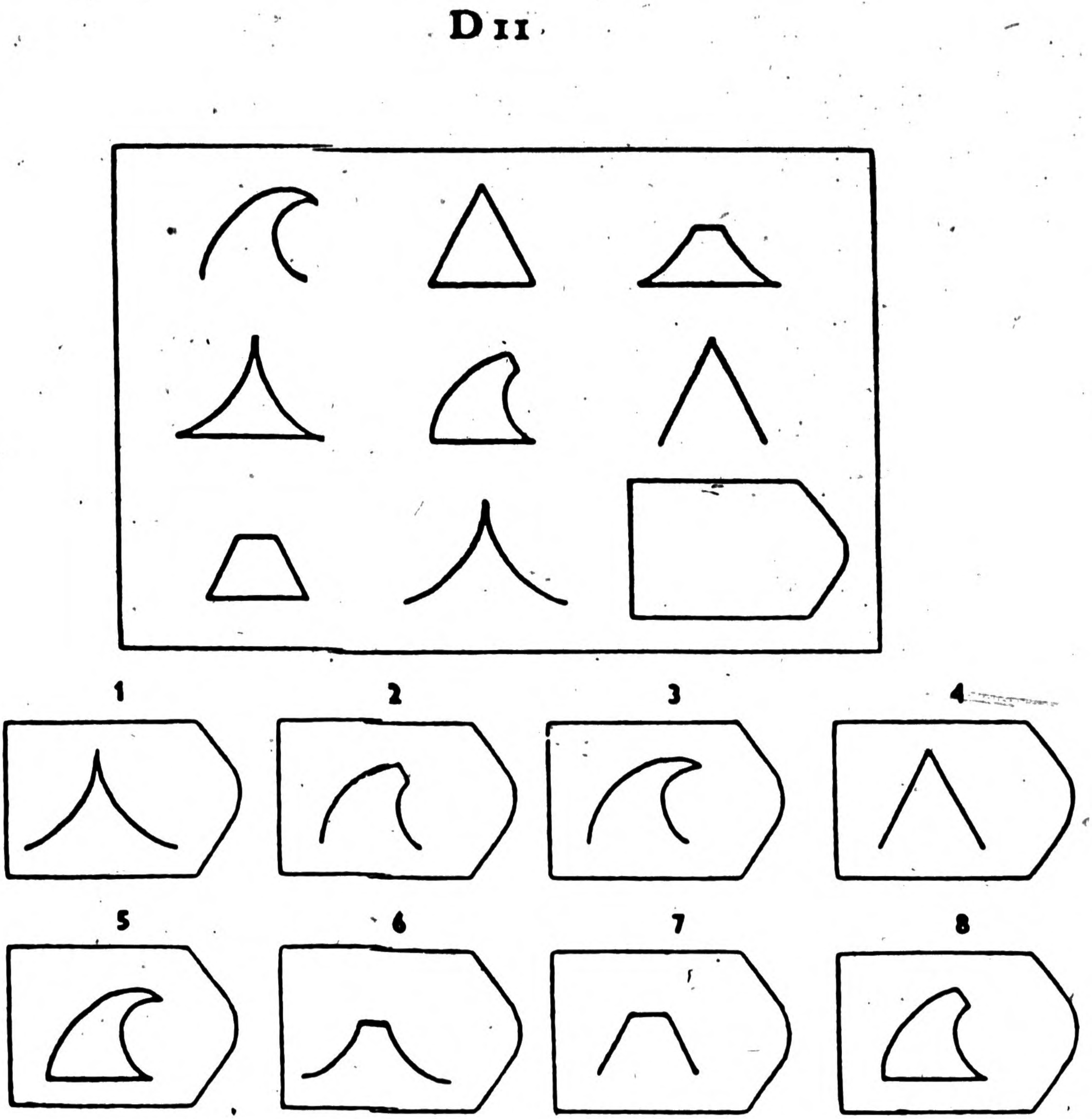

Figure 2

Item D_{11} from the Raven Standard Progressive Matrices Test, Raven (1958).

Next there is the need to separate these variables in order to consider each one by itself in a systematic search for the pattern followed by each. In short the isolation, separation and systematic analysis of variables or features will lead to the correct solution. The more perceptual and less analytical additive superimposition strategy which worked before will not work on this more complex problem.

As many of you may know, the two problems just discussed are part of a series of problems collectively known as the Raven Progressive Matrices Test. Raven, its designer, spoke of the test as a measure of a person's "innate educative ability" (1940). It is considered by Spearman himself to be an appropriate measure of his "g" or general intelligence factor (Spearman and Wynn-Jones, 1951). Other psychologists such as Jensen (1972), Vernon (1947) and Vincent (1952) consider the Raven test to be the best, the purest, measure of "g" available.

Thus to the psychometrician, the Raven test could be used, and indeed is used, to test innate intelligence. For example, a sample of children at a specific age would be tested and the number of correct items each child selects would be used to classify them as bright, average, or dull. A less complex, but similar test, would be constructed for younger children and administered for the same purpose. More complex but again similar "advanced" tests would be constructed and administered to find out who among older children or adults is bright, average or dull.

But there is another way to consider intelligence. That is the way of the developmentalist. To the developmentalist intelligence does not refer to some innate ability but refers to how far along in the development of certain intellectual abilities one has progressed. Thus, rather than constructing a number of tests of different complexity, the same test could be used at varying age levels. Administration of the test in this fashion would reveal that as children become older, they become more intelligent. The developmentalists' view of intelligence represents as much of a revolutionary shift in paradigms from that of the psychometricians' as did the Copernican shift from a geocentric to a heliocentric solar system. Taking the developmentalists' view of intelligence to heart, our job as educators would be to provide instruction that optimizes the rate of growth of this intelligence and see to it that none of our students failed to complete the developmental process. More specifically, our job is to help students develop reasoning strategies such as those needed to solve Raven's Progressive Matrices items, i.e.—to become more intelligent. This, in a nutshell, is the Developmental Learning Paradigm.

Predictably this view raises a number of critical and, to date, unresolved issues. For example, how do reasoning strategies develop? What kinds of reasoning strategies are there? Does their development occur in the same sequence and same manner for everyone? Is there a fundamental set of reasoning strategies which operates in the mind of the adult problem solver? How does the presence or absence of these strategies influence school learning in the traditional sense? Can school learning influence their development? To at least partially answer some of the questions, let us begin with a closer look at the ideas of development and learning.

What Is Development?

The traditional view of intellectual development (in which I include Gagne's cumulative learning model) holds that it is the sum total of bit-by-bit learning experiences which the learner has acquired over the course of a variety of provoked encounters. To the developmentalist, such as Piaget, a quite different picture is seen as closer to the truth. Rather development is the acquisition and integration of mental operations which result not from a series of provoked and isolated learning experiences but from a spontaneous (self-directed) process in which the individual actively takes part in the solution of self-chosen problems which arise in the course of his behaving in and trying to understand a complex environment. The individual is an explorer, a problem finder, a problem solver. His encounters with experience raise questions. Once questions are raised, his innate need to find answers pushes him to continue his exploration and thinking until answers are found. He is not a passive recipient of external information. Not only does the individual gain knowledge through this process, he also gains in his ability to gain knowledge, i.e.—his ability to solve problems. He develops knowledge generating strategies which consist of sequences of mental operations (e.g., adding, measuring, classifying, seriating, isolating and controlling variables).

Allow me to provide an example of this type of self-directed exploratory behavior and an example of what can happen if it is interrupted by well-intentioned but excessive external guidance. The example seems to me to capture the essence of the central educational issue raised by the developmentalist view.

My two-year-old son Bobby has a set of eight small "nesting" boxes which vary in size so that they fit one within the other in a serial order from small to large. They can be nested or placed upside down largest first, next largest next, and so on until each is stacked upon the other to make a tower. Now making such a tower is an extremely difficult task for a two-year-old. Bobby can usually pick the largest box first and perhaps the next largest but most certainly, if left to his own, he will err before completing the tower. He appears to recognize the correct solution but he lacks the ability to arrive at it by himself.

When we play with the boxes, I normally build the tower so he can see the result. Then he knocks the tower down, grabs the boxes, and attempts to built it himself. Of course, it is an assumption on my part that he actually is attempting to build the entire tower. His actual motives may in fact be quite different. Nevertheless, his spontaneous effort goes on and on. He does not tire easily although he has never actually constructed the entire tower.

One day while he was playing with the boxes I decided to find out if a concerted effort at teaching him the correct way to build the tower would be successful. When he first grabbed the largest box I let him continue but, instead of letting him proceed when he grabbed an incorrect box, I intervened. "No, Bobby, that's not the correct box. This is the correct one." And so on. I continued this intervention for about ten minutes until we successfully built the tower. To my surprise, within only these few short minutes we had worked out a successful technique to unerringly build the tower. He would grab a box, then look at me for approval or disapproval. If I approved, he would add it to the first. If I disapproved, he would grab another box and so on.

Unfortunately such a prescription had two rather serious side effects. First, it eliminated all of his spontaneous effort to build the tower. He would not add a box without looking to me for approval. His behavior had changed from spontaneous to dependent in the course of only a few minutes. And, second, without me for continual guidance he was not able to build the tower again. Seeing my own child transformed in this instance from a curious, ambitious, and energetic builder to a dependent, cautious, seeker of approval taught me never to try my heavy-handed teaching methods again.

If adults usurp the child's spontaneous and self-directed efforts by imposing nonassimilatable procedures or by answering not-asked questions, the child may be able to rotely solve problems or parrot words, but he will neither be able to solve novel problems nor be able to understand how those empty words relate to the world he knows.

The key educational issue raised by this discussion is clearly one of active, spontaneous, self-directed learning versus passive, outer-directed, "reception" learning. The developmentalist position is that the active spontaneous self-directed approach is essential if the development of intelligence is the aim. To understand why this is so, let us look more closely at the process by which children spontaneously learn about their world and develop intellectually.

How Does Intelligence Develop?

As the discussion of the Raven Progressive Matrices Test pointed out, intelligence can be viewed as the ability to solve problems through the use of reasoning strategies. Reasoning strategies operate in problem solving as part of one basic process which has as its aim the organization of experience into meaningful systems of objects, events, and situations in order that the problem solver can behave accordingly, survive, and prosper. A consideration of the development of intelligence then leads directly to this basic problem-solving process which, according to Piagetian theory, involves the dual processes of assimilation and accommodation. Although a fine-grained analysis of Piaget's model of assimilation and accommodation reveals shortcomings (cf., Flavell, 1977, Chapter 7; Thomas, 1977) on a more global scale, it serves as a valuable general framework for viewing the relationship between the developing subject and his environment.

Assimilation essentially means perceiving or conceiving of external objects and events in terms of one's own presently available knowledge (i.e., fitting new information into existing mental structures).

Accommodation, on the other hand, refers to the noticing and taking account of the various properties of external objects and events that are different from those you already know of in such a way that mental structures change (i.e., altering existing mental structures so that new information will fit).

I prefer to conceive of the self-regulation process in terms of the diagram shown in Figure 3. The box on the lower left-hand corner represents an encounter with some new, hence undifferentiated object or event. The mind draws on its present store of mental structures (box at upper left) to assimilate the new phenomena. The interaction of the new phenomena plus the mental structure evokes a thought—a mental pattern. In the past this mental pattern has been linked to behavior, thus the presence of the mental pattern produces an expectation of what the subject will experience next if the previous behavior is repeated (represented by the lower center box). When the previous behavior is actually carried out, the expectation can then be compared with the actual result of the behavior (the box at the right).

If the expectation and the result are one and the same, then the new object or event will have been directly assimilated to previous mental structures and no modification of these structures will occur. However, if the expectation and the actual result are not the same, then the subject finds himself with a new object or event and no behavior with which to assimilate it. He has a problem. Mental disequilibrium results. What happens now depends upon available strategies. A search through other mental structures for possible solutions or a closer inspection of the phenomenon itself for an analysis of its properties may result. This latter route leads to the eventual differentiation of the phenomenon and the eventual accommodation of mental structures.*

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*This description of the self-regulation process differs somewhat from Piaget's description. To Piaget, assimilation and accommodation are two sides of the same coin—always occurring together. One or the other simply dominates, depending upon the situation. The result is a type of a "Lamarkian" acquisition of mental structures from an internalization of actions. This view seems to me to be inadequate just as Lamark's theory of evolution was found inadequate in light of Darwin's later thinking. The present conception of the self-regulation process does not suffer from this problem. Rather it is analogous to a Darwinian model of mental structure building in which mental structures arise as a consequence of a spontaneous combinatorial activity of the brain and are selected for or against depending upon their ability or inability to successfully guide behavior to solve problems. For a more complete account see Lawson, 1967 (Chapter 1) and Lawson and Lawson, 1979.

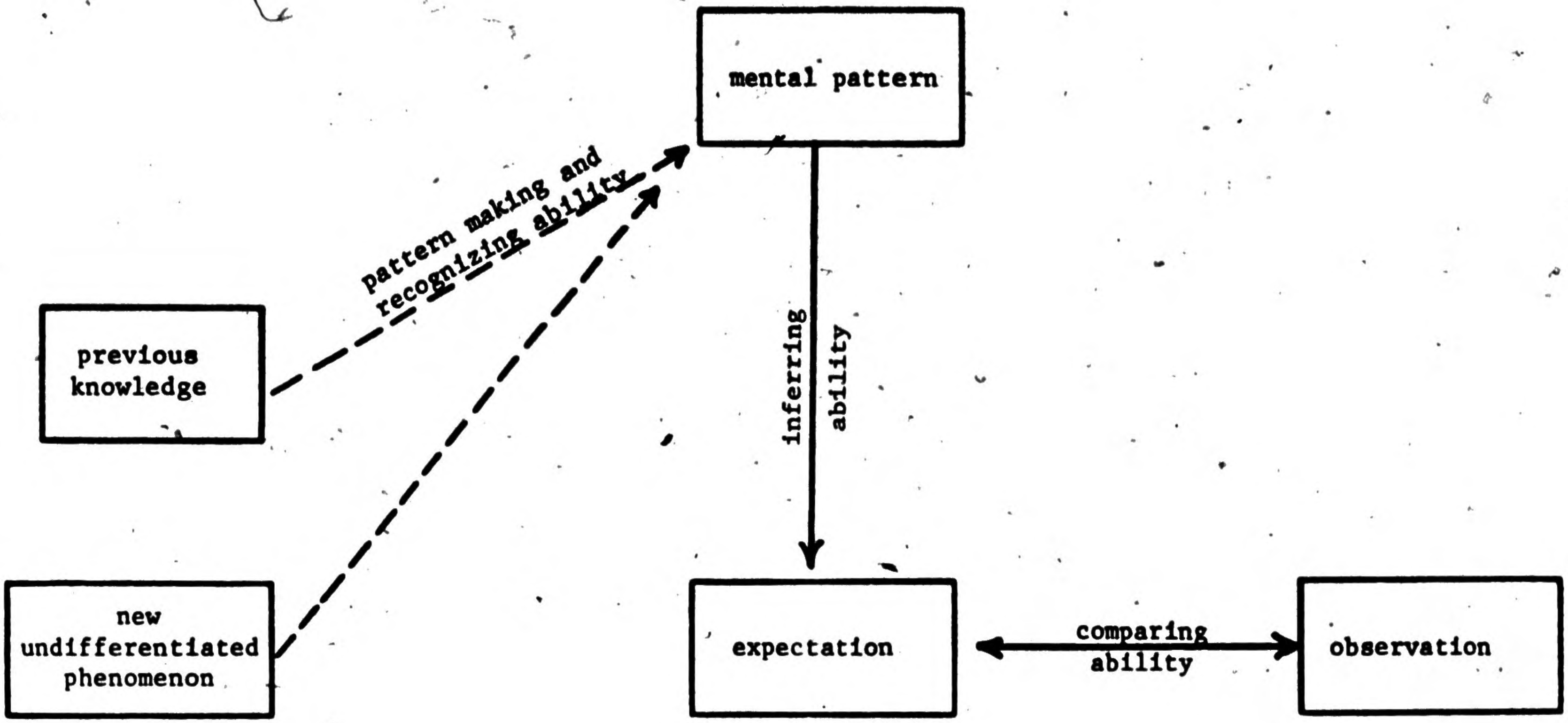

Figure 3

The basic phases and mental abilities of the self-regulation process. The primary innate mental abilities of pattern making-recognizing, inferring, and comparing operate from the very outset as part of the self-regulation process. Use of the process results in the acquisition of sensori-motor and conceptual knowledge. Use of the process also results in refinement and extension of the basic mental abilities themselves. This refinement and extension is reflected in the development of specific reasoning strategies.

As an example of the self-regulation process, consider a problem faced by my older son Matthew when he was about 14 months old. When playing with the toy shown in Figure 4 he would pick up the cylinder at the left and hunt for the correct hole to drop it into. Since he was initially unable to find the correct hole or orient the cylinder correctly to make it fit even if he did choose the correct hole, he was faced with a task which could not be resolved with his present mental structures. Self-regulation was needed. Nevertheless, without too much difficulty, I was able to physically assist him in fitting the cylinder into the correct hole. When he placed the cylinder above the correct hole I was able to push the object to orient it correctly so that it fit. When he let go it would drop out of sight and he was delighted—success!

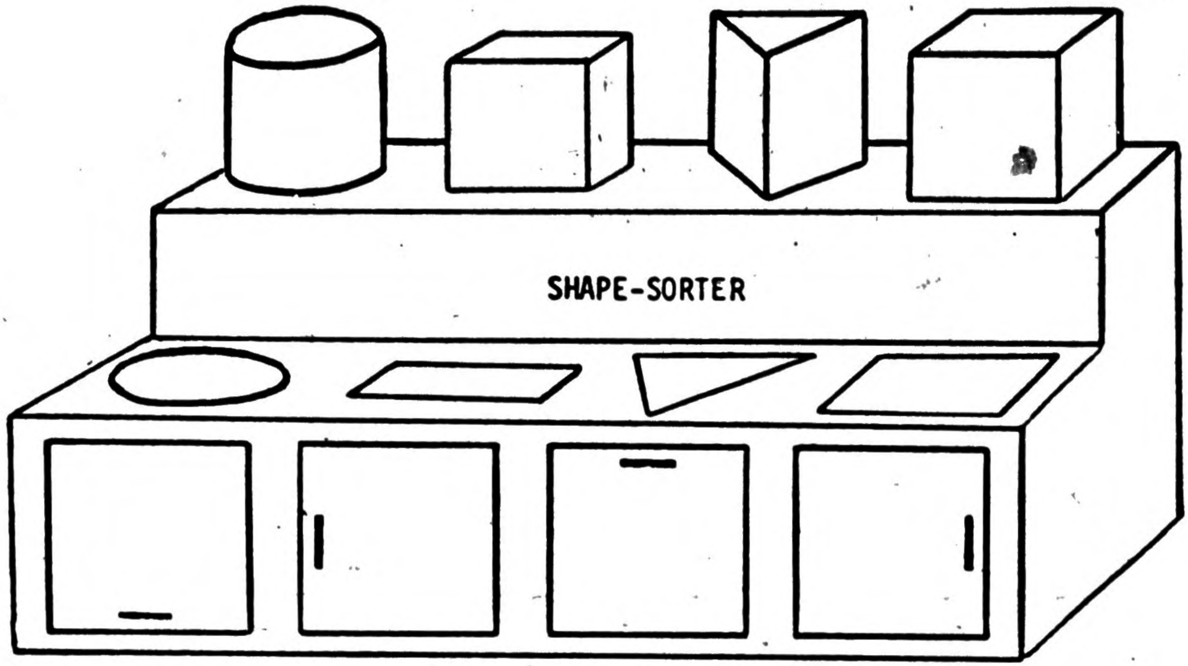

Figure 4

The Fisher Price Shape-Sorter

But when he then picked up the rectangular solid next to the cylinder, which hole do you think he tried to put it in? The one below the rectangular solid? Wrong. He did not even consider the hole even though to us it clearly is the correct choice. Instead he would try to put it into the round hole. Presumably this is because it was that behavior, the act of placing an object above the round hole and then letting go, that previously led to success. In other words, he would attempt to assimilate the new situation to the previously successful behavior. In general, successful behavior will always be repeated until contradicted. Now, of course, when the rectangular object was placed over the round hole it would not fit so the behavior was contradicted. But only after numerous contradictions was Matthew willing to try another hole. I tried showing him which holes the various objects would actually go into, but this showing was to no avail. He had to behave himself. In other words, Matthew learned from his behaviors. Only after repeated behaviors did he find the correct holes. It was the coordination of behaviors which ultimately led to the accommodation of his mental structures and new more complex behaviors.

At a level closer to your teaching experience consider the self-regulation needed by a bright-eyed, conscientious college sophomore named Karen. When shown one wide and one narrow plastic cylinder of equal height with equally spaced marks along their heights, she predicted that water which filled the wide one up to the fourth mark would rise higher if poured into the narrow cylinder. So far so good. Now when the four units of water in the wide cylinder were actually poured into the narrow one they rose to the sixth mark. Seeing this she predicted that water which rose to six in the wide would rise to eight in the narrow. As she put it, this is because it was two higher before so it would still be two higher. Now of course we recognize a problem here but Karen did not. Not yet anyway. But when Karen actually saw the water rise to nine when poured into the narrow one instead of eight, as she predicted, the problem surfaced. Her additive strategy simply did not work. The result was mental disequilibrium and a conscious search for a new strategy.

My experience in trying to teach Karen to use a proportional strategy to solve the problem as well as her inability to use proportions in other appropriate situations (for example, instead of using proportional reasoning to triple a recipe, she would cook a single recipe three times!) clearly demonstrated the magnitude of the problem. Both Piagetian theory and my experience argue that this learning is not isolated and easily remedied. Rather it is intimately tied to a whole host of ideas (e.g., probability, correlations, control of variables) which are a part of a general way of processing information known as formal thought. At this level the required self-regulation takes considerable time and effort on Karen's part. As in Matthew's case, this will take repeated attempts at solving problems until her inappropriate strategies are relinquished and more appropriate strategies are adopted.

Thus the self-regulation process results in new knowledge of the external world. But, as we can see, the process may also result in an increased ability to generate knowledge through the development of explicit guides to problem solving called reasoning strategies—what others have called heuristics, cognitive strategies, reasoning patterns and the like.

I choose to define a reasoning strategy as a plan, plot, or device for bringing order, for generating orderly relationships out of experience, in other words for solving problems and generating new knowledge. Seriating, for example, certainly involves a plan or device to generate order out of experience as does sorting. Classifying, that is forming classes and subclasses of objects, events, and/or situations, is also such a plan or device. Measuring is another such device.

Having a reasoning strategy corresponds to "knowing how" as opposed to "knowing that." In the sciences we recognize this distinction as one of scientific process versus scientific product. Various scientific processes such as measuring, classifying, predicting, formulating and testing hypotheses, analyzing data and so on are guided by the use of a variety of reasoning strategies and are used to generate knowledge. The knowledge which is generated is a product of that process itself. The generated knowledge is what we store as concepts and conceptual systems, e.g.—the principles, laws, models, theories of science.

Presumably use of these "procedural" reasoning strategies is guided by mental structures as in the case for specific "product" concepts. However, the mental structures guiding the use of reasoning strategies differ from those of specific concepts and conceptual systems in that they are potentially applicable to problems within all conceptual systems. These strategies are acquired through repeated attempts at self-regulation and at the high levels of development through what Piaget and Inhelder (1976) have referred to as reflective abstraction. Reflective abstraction is a general term for the subject's thinking back upon what he has done correctly and/or done incorrectly during a number of problem-solving attempts and his abstracting of successful procedures and/or key relationships so that they can be repeated and sought in future attempts. Thus the development of intelligence involves (1) encountering problems, (2) generating successful strategies for solving these problems, (3) accumulating problem solutions (i.e., concepts and conceptual systems) and (4) reflecting back upon the strategies used to generate solutions and abstracting them from their contexts so that they can be used in new contexts to more readily solve new problems (i.e., be used as anticipatory schemes).

Let us now consider the basic reasoning strategies which develop in this fashion and how they function in the mature problem solver. Development of these reasoning strategies then will serve as an overall goal for the educative process.

What Kinds of Reasoning Strategies Exist?

The ability to self-regulate is, of course, assumed to be present from the very onset of life. It is a functional invariant of cognitive development. Notice that three basic mental abilities operate within this process. They are the mind's ability to create and recognize perceptual and conceptual patterns (pattern making and recognizing ability), its ability to link these patterns to expectations (inferring ability), and its ability to compare these expectations to actual outcomes of behavior (comparing ability). It is the extension and refinement of these abilities that results in the development of explicit and general guides to problem solving, i.e., reasoning strategies.

Reasoning strategies are basically of two types. Those involved in seriating, classifying, measuring and so on have as their primary aim the adequate description of experience, hence I choose to call this first type descriptive reasoning strategies. Problem solving based upon the use of such strategies is primarily an empirico-inductive process. In the Piagetian tradition these descriptive strategies are presumed to be based upon the use of a set of concrete mental operations. The second type of strategy is more complex. This type has as prerequisites for generation and use these descriptive strategies and the conceptual isolation and control of variables. Complex strategies include proportional reasoning, correlational reasoning, and probabilistic reasoning. Inhelder and Piaget (1958) refer to these complex reasoning strategies as "formal operational schemata." These strategies function as part of a hypothetico-deductive problem-solving procedure; hence, I choose to call these hypothetico-deductive reasoning strategies.

Hypothetico-deductive strategies operate in the cognitively mature individual as part of an overall process of thinking which has as its aim the linking of events in terms of cause-effect relationships. The linking of events in terms of causality is basic to explanation. Thus reasoning strategies in general are plans, plots or devices for the organization of experience in terms of empirical description and hypothetical explanation.

Although all normal persons presumably have the potential to develop use of reasoning strategies, recent data indicate that only about 25-50 percent of the late adolescent and adult population in this country have well-developed use of the more complex hypothetico-deductive strategies (for a review see Chiappetta, 1976).

How Do Reasoning Strategies Function in Cognitively Mature Thinking?

Figure 5 represents a model of the way in which I hypothesize that the fundamentally important descriptive and hypothetico-deductive reasoning strategies operate in conjunction with previous knowledge and the three basic mental abilities in the cognitively mature individual to solve problems and create new knowledge through the self-regulation process. Thus the model is one of "hypothetico-deductive thought."

As shown, descriptive reasoning strategies such as classification, seriation and correspondence operate to differentiate the parts of the new phenomenon. They are needed to order objects and properties and to isolate important variables. The mind's pattern making and recognizing ability (commonly referred to as creativity—perhaps a function of the right hemisphere) allows the generation of patterns, e.g., ideas, hypotheses, postulates, premises, and so on to tentatively organize the new phenomenon. This often involves the borrowing of a pattern from one's present store of concepts and conceptual systems as was the case when Mendel borrowed algebraic patterns to organize data from the crosses of pea plants and when Coulomb borrowed Newtonian laws of planetary attraction to organize data from the interaction of electrically charged objects.

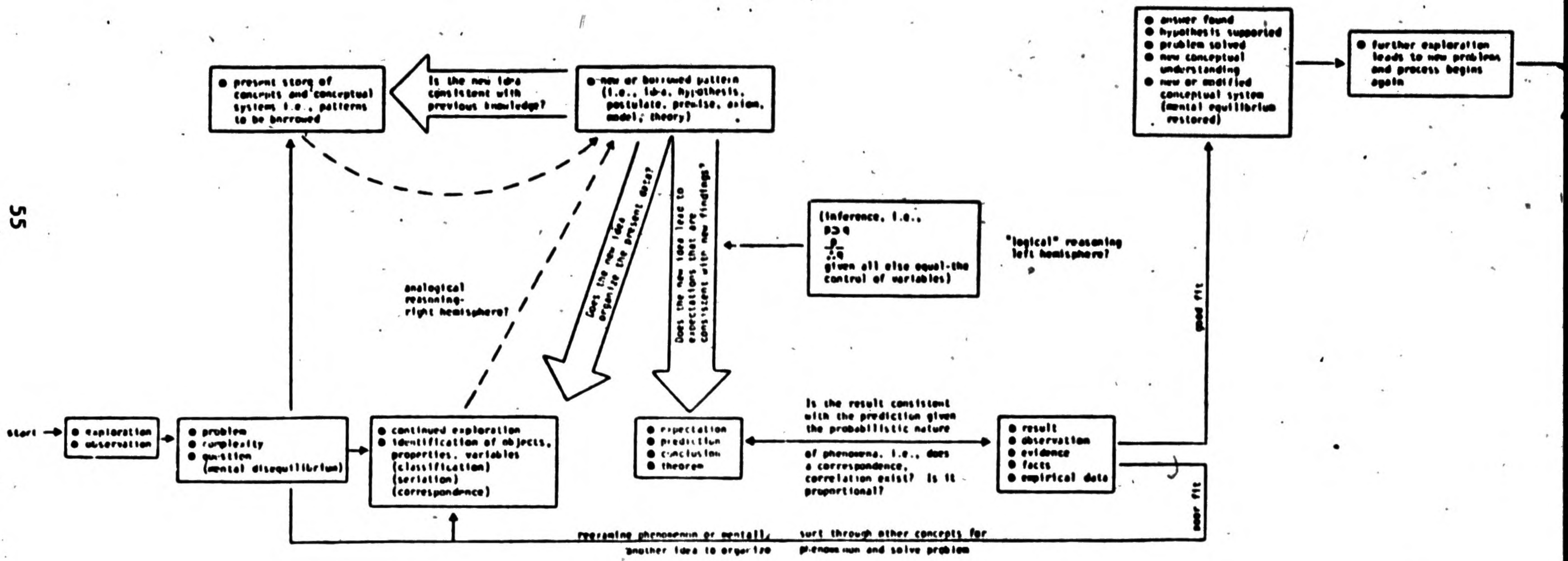

Figure 5

The basic phases, mental abilities, and reasoning strategies used in the self-regulation process by a cognitively mature hypothetico-deductive problem solver. See text for explanation.

Once the new pattern has been generated, it must be tested. This occurs in one or more of three ways. Obviously the first question that must be asked is, does the new idea actually solve the present problem? In addition, one must ask, does the new idea fit with previously learned concepts and conceptual systems? If the answer to this second question is no, either the idea itself will have to be changed or some accommodation of previously learned concepts and conceptual systems is likely to occur. A third way in which the new idea can be tested is through the deduction of its logical consequences and the comparing of these consequences with actual experimental results. In that this test will be conducted in the "real" world and one can never be sure of having controlled all variables involved in the situation, the deductions take the form of a weak modus ponens and modus tollens (cf., Bunge, 1967). Nevertheless the derivation of predicted consequences, logical conclusions, theorems, etc. requires an understanding of the need to control variables and an understanding of the probabilistic nature of phenomena. The analyses of data at this point often require what have been termed proportional and/or correlational reasoning (Adi, Karplus, Lawson, and Pulos, 1978; Karplus and Peterson, 1970).

If the problem solver does indeed find that his new idea, hypothesis, model, etc. satisfies one or more of these tests, the result is new conceptual understanding and a new plane of mental equilibrium. If, however, any or all of these tests leads to contradictory findings, the process must either (1) be repeated with the reexamination of the phenomenon and/or the generation of a new hypothesis or (2) the individual must find out what went wrong with the tests or (3) the individual may simply conclude the problem is not solvable (at least by him/her) and he/she will go on to something else.

Figure 5 then is viewed as a model of a mature adult thought. It represents the goal of the educational process in that creativity, reasoning and conceptual understanding are all implied. In the next section I will turn to a discussion of how the presence or absence of reasoning strategies influences what can be learned.

How Does Intellectual Development Influence School Learning?

According to Piaget to know something is to act upon it. "To know is to modify, to transform the object, and to understand the process of this transformation, and as a consequence to understand the way the object is constructed" (Piaget, 1964, p. 176). To be able to act, modify, transform either physically or conceptually implies the presence of some operative mental structure guiding those actions. Thus to "know" requires the presence of operative structures (what I have termed reasoning strategies). For example, when does someone know the concept of "number"? The developmental answer would be that he/she knows it when he/she conserves it, e.g. when he/she recognizes that number of checkers stays the same even though their arrangement may change. This implies the presence of the mental operations of thinking back to the start-reversing the action of rearranging, of counting, of (not) adding to, of (not) taking away. Likewise when does someone "know" a concept such as "ecosystem"? Again I believe the answer is that he/she "knows" it when he/she conserves it. That is, when he/she recognizes that an ecosystem transformed by being stripped of its first, second, and higher order consumers is still an ecosystem. He/she recognizes the key property of ecosystems--their ability to recycle materials. Again, operations are implied. As Piaget (1965, p. 2) has stated, "Every notion, whether it be scientific or merely a matter of common sense, presupposes a set of principles of conservation, either explicit or implicit." The point is that a person's operative structures (i.e., his/her level of intellectual development) determine what can or cannot be meaningfully known (i.e., acted upon either physically or mentally).

Suppose, for example, as a biology teacher you wish to have your students learn principles of Mendelian genetics. As Walker, Mertens, and Hendrix (1979) correctly point out, understanding principles of genetics requires use of a number of hypothetico-deductive or formal reasoning strategies. First an understanding of the nature of theoretical models and their relationship to empirical data is required (theoretical reasoning). The generation of zygote possibilities given certain frequencies of genes is required. This involves an aspect of formal thought referred to as combinatorial reasoning. The application of combinatorial reasoning results in the generation of certain ratios of gene combinations which in reality represent probability estimates that certain phenotypes will occur. Thus theoretical reasoning, combinatorial reasoning, and probabilistic reasoning, all aspects of formal thought, are involved in "understanding" and using Mendelian genetics.

This analysis suggests to the developmentalist that a topic such as genetics would cause a severe comprehension problem for students with little or no facility with these aspects of formal thought. Such students of course may be quite capable of the verbal parroting of key words and phrases (e.g., gene, dominant, recessive, crossing over) but this verbal knowledge would be no part of their useful bag of knowledge. Presumably such ideas simply cannot be assimilated because the cognitive operations required for assimilation are either missing or poorly developed. This is why educators, who take a developmental perspective to teaching, object to the introduction of theoretical concepts such as these to students who are not developmentally "ready" (e.g., Lawson and Karplus, 1977; Herron, 1978; Renner, 1976).

The young child or developmentally delayed adolescent certainly does not lack in imagination. Thus he/she may be quite capable of imagining tiny particles and calling them genes, if the teacher wishes, but with little or no awareness of (1) the theoretical system of which they are a part and in fact from which they derive their meaning and (2) the empirical data which lead to the postulation of these "tiny particles" in the first place. To the person with no understanding of the nature of theoretical systems and their relationship to empirical data (i.e., theoretical reasoning), the idea of the gene and other theoretical concepts must seem to have been derived as if by magic or perhaps by decree of some omniscient scientist.

The issue of appropriate selection and sequence of concepts then becomes extremely important. Space does not permit a detailed discussion of this topic but, in general, concrete concepts or concrete manifestations of formal concepts should precede the introduction of theoretical concepts and concepts that place severe demands on students' reasoning abilities. The Science Curriculum Improvement Study's (SCIS) elementary school science program is a good case in point. In the early grades the idea of object, property, serial order, habitat and other similarly concrete concepts are introduced. In the middle elementary grades more complex concepts such as system-subsystem variable, food chain, food web are introduced. Still later the concepts of energy source, energy receiver, energy chain, producer, consumer, and community are introduced. Finally at the sixth grade level, when some students are beginning to develop some expertise in formal reasoning, the more formal concepts of electricity, scientific theory, and ecosystem are introduced. The intent is to match the kind of tasks and concepts students are asked to comprehend in class with the kind of tasks and concepts they are attempting to master in their spontaneous attempts to order and explain their out-of-school world.

A general principle of instruction then is that the demands that the subject matter places on students' reasoning must be analyzed. Only material that is "appropriate" to the developmental level of the learner should be introduced.

How Can School Learning Influence Intellectual Development?

But what does the term "appropriate" really mean in the preceding sentence? Surely if the subject matter one selects places no new demands on students' ability to reason, then that subject matter would surely not facilitate reasoning development. To the developmental educator this result is untenable since, as stated, one of the major objectives of education is to help students develop their ability to reason. In this context an "appropriate" selection of subject matter means choosing concepts and activities that will challenge but not overwhelm students' reasoning abilities. Let us consider this idea further.

According to the present thesis, reasoning strategies develop when the child or adolescent engages in spontaneous attempts to bring coherence to his/her world by seeking answers to self-chosen questions, i.e., through self-regulation. As Piaget (1974) put it:

> ...the child may on occasion be interested in seriating for the sake of seriating, in classifying for the sake of classifying, but, in general, it is when events or phenomena must be explained and goals attained through an organization of causes that operations will be used the most (p. 17).

This position has led educational psychologists such as Constance Kami (1979) to state that the Elementary Science Study (ESS) program in which students are given a great deal of freedom to explore natural phenomena and seek solutions to self-chosen problems is the most developmentally oriented science program on the market. This may be the case. However, the discovery approach, to which the ESS program adheres, at least in part, has I believe been justly criticized for its relative lack of breadth of content coverage (e.g., Ausubel, 1963). The SCIS learning cycle approach seems capable of effecting a viable compromise solution to the problem of letting students spontaneously inquire, raise questions and seek solutions, while at the same time introducing a coherent and significant number of meaningful concepts.

The SCIS learning cycle approach employs three repetitive phases of instruction. During the first phase, called exploration, students encounter new objects, or events, and learn through their own actions and reactions. They explore phenomena and/or ideas new to them with minimal guidance or expectation of specific accomplishment. This phase of the learning cycle is comparable to the initial phase of the self-regulation process in that the new experience should raise questions or complexities that cannot be immediately assimilated in terms of past ways of thinking.

The second phase of the learning cycle, called invention or sometimes concept introduction, normally starts with the teacher's introduction of a new term or principle that highlights key aspects of the phenomena and enables the learners to begin to organize their thinking about the exploration experiences. The concept is normally introduced by the teacher, but importantly it can also be introduced by students themselves if the experiences were well chosen and the students were actively involved. This phase corresponds to the second phase of the self-regulation process in which the student spontaneously generates an hypothesis to tentatively solve his problem. The introduction of a concept, a way of ordering the experiences, provides the student with an initial insight into how various aspects of the phenomena are related and can be assimilated. In a sense this is the key pattern that we want our students to discover but that we introduce ourselves because we realize that classrooms are seldom filled with Charles Darwins or Albert Einsteins.

For some students this initial suggestion by the teacher may be immediately relatable to current thinking and appropriate accommodation will result. But for most students this will not occur. The teacher's suggestions do not facilitate a mental coordination of the phenomena, the introduced concept, and past ways of thinking. This is why the third phase of the cycle, discovery or concept application, is so important. In the discovery phase, further experiences are provided by the teacher which involve the same concept or concepts but within new contexts. Thus important conceptual features stay the same but the context varies. With the students' repeated attempts at mentally coordinating the various aspects of their experiences with their own thinking they will gradually be able to abstract the key features and effect the appropriate mental accommodation. This last phase is roughly analogous to the third and final stage of the self-regulatory process. Thus the learning cycle includes three of the four factors Piaget posits as necessary for intellectual development (i.e., experience, social transmission, and self-regulation). Only maturation, which of course is a biological phenomenon, is lacking.

Whether or not using such a teaching approach does in fact have any positive influence on intellectual development is still very much an open question. It would seem that for any approach to be effective it would have to involve activities in which the learners were in fact called upon to solve problems which required use of the reasoning strategies in question. In addition, it would seem that the approach would have to have provisions in it which required students to reflect on their problem solving attempts to gradually abstract the correct procedures. At any rate recording any measurable cognitive development as a consequence of any specific teaching approach is fraught with numerous methodological problems such that the issue is unlikely to be resolved in the immediate future.

If one takes the less ambiguous task of teaching more specific reasoning strategies, such as the isolation and control of variables, proportional reasoning, probabilistic reasoning and so on, it seems quite clear that positive advances can be effected. In my opinion, however, these advances will only be transitory, unless students return to an environment (both in and out-of-school) in which it is necessary to apply the newly acquired strategies. Such an environment presumably is one in which questions are raised, tentative solutions are advanced and evidence is actively sought and debated for their test.

In Conclusion

The developmental view holds that intellectual development proceeds by a series of self-regulations which provide the possibility for an accompanying series of reflective abstractions. Self-regulations arise in the course of encounters with specific experiences which contradict present ways of thinking. Reflective abstractions produce pieces of the puzzle which other reflective abstractions eventually put together to construct coherent and stable systems of reasoning, one on top of the other. Each step along the way maturation of the nervous system does nothing more or less than open up the possibility for further development. Thus thinking lies at the very heart of development. Thinking about what you do and discover, about what people say, and about what happens to you and you do not understand. Always thinking, at first trying to understand why—what is the cause?, until coherent answers, systems of answers, and methods of finding answers are constructed. Regrettably, for some students, their out-of-school environment may discourage this kind of questioning and reflective behavior. For them intellectual development will not reach its full potential. It is for such students that we must do our best as teachers to help them initiate thinking and develop intellectually.

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THE IMPACT OF PARADIGM-BASED RESEARCH UPON CLASSROOM PRACTICE

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Introduction: The Experiment

This is a significant moment in the 80-year history of research in science teaching. With a team of thousands,* we have just conducted our first experiment of national proportions. And at this moment, we are in the process of interpreting the results of that experiment which has taken 20 years to complete.

What was this experiment? Two decades ago, many of you in this room began an unprecedented effort, supported by the National Science Foundation, to develop new science programs that would meet a national need for future scientists. You decided to build those science programs around the most promising theories or models of learning and child or adolescent development to be found. Such theories or models will be called paradigms** here, and so paradigm-based research will simply refer to research based on one or more promising, or dominant, theories or models.

As the new science programs and their accompanying teacher training programs were completed during the 1960s and 1970s, we waited and watched for the results of this first nation-wide experiment.

What was the impact of these NSF-funded, paradigm-based science programs on American school classrooms? The National Science Foundation commissioned three complementary studies to assess the status of pre-college science in the United States.*** The reports became available early last year.

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*This team included scientists, educational psychologists, science educators and teachers.

**Thomas Kuhn describes paradigms as achievements which share two characteristics: "they are sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity, and simultaneously, sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve." This use of the term suggests that some accepted examples of actual scientifice practice, which include law, theory, application and instrumentation together, provide models from which spring particular coherent traditions of scientific research (p. 10).

***The status of mathematics and social science education were also assessed in this three-part study.

Now on the evening of the second decade of our experiment, we are synthesizing the results from these three reports. And with the excitement that all scientists share as they interpret the results of their first experiment, we—as a profession—are discovering the impact of the paradigms we used.

It is in this sense that I said it is a significant moment in our history, for we have "come of age" as a community of scientists, through our total commitment to a paradigm-based experiment of heroic proportions.

At such an important point in our history, I thought it would be worthwhile for us to look at ourselves at arm's length, or through the eyes of an outside observer. I have chosen Thomas Kuhn to be that observer. Why?

Through his essay, The Structure of Scientific Revolutions, Kuhn(1968) describes the way scientists use paradigms in their daily work. Searching for parallels between the normal process of science and our own activity has been quite instructive. I think it leads to a slightly revised view of how paradigms actually impact classrooms, and how we may control that impact.

In this presentation, I will try to show what I think can be gained by assuming that Kuhn's description of normal science applies to us, and how such an interpretation could lead to some very different expectations and actions in the future.

In Part One, I will describe the structure of scientific revolutions and how the paradigms of scientists give substance, meaning and energy to such revolutions. This brief description is primarily for the benefit of those few who have not yet read Kuhn's essay.

Against this background, in Part Two I will describe five studies which look for evidence that paradigm-based research has had an impact on American classrooms. I will try to show how the authors' ideas might be interpreted differently, in some cases, through Thomas Kuhn's lens.

Finally, in Part Three I will try to show how Kuhn's description of the structure of scientific revolutions allows us to interpret the "classroom impact" of paradigm-based research in a new way; and in closing I will speculate about the likelihood of our own scientific revolution.

Part One: Science, Paradigms, and Revolutions

Let me begin then by talking about the nature of science, the use of paradigms and the nature of scientific revolutions. Kuhn describes a view of scientists which is familiar, and may be our own image: people who have chosen problem solving as a way of life, and who are curious about the universe. How do scientists use paradigms in the normal process of science? Kuhn's description portrays scientists who are engaged in "...a strenuous and devoted attempt to force nature into...conceptual boxes..." (1968, p. 5).

Perhaps the following paragraph describes that process best:

> In the development of any science, the first received paradigm is usually felt to account quite successfully for most of the observations and experiments easily accessible to that science's practitioners. Further development, therefore, ordinarily calls for the construction of elaborate equipment, the development of an esoteric vocabulary and skills, and a refinement of concepts that increasingly lessens their resemblance to their usual common-sense prototypes. That professionalization leads, on the one hand, to an immense restriction of the scientist's vision and to a considerable resistance to paradigm change. The science has become increasingly rigid. On the other hand, within those areas to which the paradigm directs the attention of the group, normal science leads to a detail of information and to a precision of the observation-theory match that could be achieved in no other way. Furthermore, the detail and precision-of-match have a value that transcends their not always very high intrinsic interest. Without the special apparatus that is constructed mainly for anticipated functions, the results that lead ultimately to novelty could not occur. And even when the apparatus exists, novelty ordinarily emerges only for the man who, knowing with precision what he should expect, is able to recognize that something has gone wrong. Anomaly appears only against the background provided by the paradigm. The more precise and far-reaching that paradigm is, the more sensitive an indicator it provides of anomaly and hence of an occasion for paradigm change. In the normal mode of discovery, even resistance to change has a use that will be explored more fully....By ensuring that the paradigm will not be too easily surrendered, resistance guarantees that scientists will not be lightly distracted and that the anomalies that lead to paradigm change will penetrate existing knowledge to the core (1968, pp. 64-65).

How is it then that paradigms change? Shifts in allegiance are frequently slow, and one by one scientists are won over as the evidence to support the new theory accumulates. This growing evidence may actually be the work of other scientists who are tempted into trying to place pieces of the puzzle into new spaces opened up by the in-coming paradigm.

However, acceptance of the new paradigm is never total.

> Darwin, in a particularly perceptive passage at the end of his Origin of Species, wrote: "Although I am fully convinced of the truth of the views given in this volume..., I by no means expect to convince experienced naturalists whose minds are stocked with a multitude of facts all

> viewed, during a long course of years, from a point of view directly opposite to mine....But I look with confidence to the future, —to young and rising naturalists, who will be able to view both sides of the question with impartiality" (Kuhn, p. 150).

How does this view of the scientist, the nature of normal science and the use of paradigms fit into our notion of a revolution? First, like the concept of a political revolution, Kuhn suggests that scientific revolutions can be described as having recognizable stages, with scientists and their paradigms playing key parts.

During the pre-revolutionary period, there is the awareness of an anomaly, some thing or some events do not seem to fit the paradigm. There is a growing discontent with the existing paradigm's capacity to explain. Frequently there are apparent failures in the instruments which are used to measure; they do not account for everything or they gather data which are unexplained by the current paradigm. Professional insecurity grows. Kuhn provides us with eloquent examples:

> Einstein...wrote only, "It was as if the ground had been pulled out from under one, with no firm foundation to be seen anywhere, upon which one could have built." And Wolfgang Pauli, in the months before Heisenberg's paper on matrix mechanics pointed the way to a new quantum theory, wrote to a friend, "At the moment physics is again terribly confused. In any case, it is too difficult for me, and I wish I had been a movie comedian or something of the sort and had never heard of physics" (1968, pp. 83-84).

All of these characteristics are a prelude to the search for a new paradigm, new rules and new instruments.

Then the change comes. In the second stage, the new paradigm emerges. Sometimes it happens in several places at once. Because many scientists are using the same data, same instruments, finding the same errors or anomalies and experiencing the same frustration, similar novel theories or models surface at approximately the same time in different labs and different countries. Thus, there is competition for verification, or what Kuhn calls probabilistic verification:

> Verification is like natural selection; it picks out the most viable among the actual alternatives.... But paradigm debates are not really about relative problem-solving ability, though for good reasons they are usually couched in those terms. Instead, the issue is which paradigm should in the future guide research on problems many of which neither competitor can yet claim to resolve completely. A decision between alternate ways of practicing science is called for, and in the circumstances, that decision must be based less on past achievement than on future promise (pp. 145, 156-157).

Finally, there is the post-revolutionary period, which is more than a time for Nobel Prizes and toasting. Textbooks are rewritten, not just in light of the new theory, Kuhn tells us, but as though none of the pre-revolutionary frustration had ever occurred. This unintentional distortion of the actual process implies that scientists have striven all along for the particular objectives embodied in the newest paradigm.

During the post-revolutionary period other things happen. New instruments must be developed or old measurements modified so that existing facts can be reinterpreted in terms of the new paradigm. "The world looks different now" and a flood of new measurements are needed to interpret this new view. If you watched the film, "Einstein's Universe," this past week, you will recall the vivid examples of this post-revolutionary research. It illustrated how scientists' work continues to explore the predictions and applications of the new paradigm.

Here then, we have Kuhn's description of how normal science operates as a process; how scientists behave, building boxes to restrict their focus and instruments to measure what they see, all the while knowing these temporary boxes must be pushed to their limits in search of anomalies, so that they may ultimately be sacrificed for a new paradigm. We see that periods of frustration and crisis precede breakthroughs, and scientific revolutions, with their stages, demand flexibility and change in the behavior of scientists.

Part Two: Five Views of Impact

In what ways does Kuhn's notion of normal science characterize our own behavior as problem-solvers or researchers? As we consider five recently published views of the impact of paradigm-based research on classrooms, I invite you to speculate about the parallel between Kuhn's "normal science" and our own research.

Geraldine Joncich Clifford, an educational historian, was asked to write about the history of the impact of research on teaching. Her analysis appears as Chapter 1 of the Second Handbook of Research on Teaching (1973).

Given the absence of quantitative data in 1973 to serve as evidence of direct impact of research on schools, Clifford visualized a variety of sources of indirect evidence. You will be most interested, I think, in her discussion of the evidence for and against impact in science education.

What is the nature of the evidence of impact? Clifford uses two kinds of evidence. Certainly the most abundant are reports by persons who were on the scene at the time. She quotes many of you. It was pleasant finding so many of your views represented; but in years to come young readers may have difficulty with her "evidence," only because your conclusions have been stated without the corroborating kind of evidence that is common knowledge among us.

But Clifford has also conducted her own personal search for primary evidence, and in her first-hand gathering of data one captures the essence of what she calls the cultural diffusion of research impact.

First, there is the curriculum itself. Because the curriculum of the 1960s contains the most massive evidence of attempts to implement paradigm-based research, and because later I will be discussing this most thoroughly documented case of impact, I will not dwell on Clifford's analysis. However, it is important to point out that she gives appropriate prominence and space to this example and correctly links the NSF-supported curricula (e.g., PSSC Physics, CHEM Study and BSCS Biology, to name only a few) with their appropriate paradigms about learning and intellectual development (e.g., Bruner, Gagne, Piaget and others) on which they were based.

Second, evidence of the impact of paradigm-based research is seen in the NSF-funded training programs and workshops for teachers, science consultants and school administrators, illustrating the belief that the new research-based curricula demanded retraining for new awareness and teaching methods.

Science methods textbooks are a third source of indirect evidence where impact might be found. In "a random, nonsystem-sampling ... of books published in the last 20 years in the broad language-arts teaching area" Clifford found textbooks appallingly silent in their references to research. Her sample also included at least one textbook in elementary science: "There were also indicators of limited impact in science education which should be thought sympathetic to research. A textbook in elementary science ... was frankly a compendium of the author's judgments of good practices, good examples, and agree-upon aims; although one of the two bases given for a science curriculum was children's growth and development (the other was the needs of society), no research was cited from developmental studies..." (1973, p. 18).

Just for the record, I conducted my own "nonsystematic sampling" of elementary science methods textbooks: the first six textbooks a colleague (Charles Williams) pulled off his shelf. On examination, each of the books provided many pages describing the theories behind the methods being presented. You may wish to conduct your own survey.

I should point out that three of the six books were older than Clifford's report and three were more recent, but that was a happy accident of my nonsystematic sampling design.

Journals for teachers were a fourth area of Clifford's search for evidence of impact on teaching, and they fared no better under scrutiny than textbooks. In perusing the <u>Physics Teacher</u>, to name one American journal, and the <u>Journal of Biological Education</u>, to include one British publication, Clifford found a potpourri of news, articles and reports, with little evidence of any interest in research. "'Practical' teachers' magazines (including journals from all areas of the curriculum), ... are a veritable wasteland for research" (1973, p. 19).

Here I must cite one major reference to illustrate an exception to Clifford's evidence: the new NSTA (National Science Teachers Association) publication, What Research Says to the Science Teacher, Volume 1, 1978.

By now you may wonder why I have included a description of Clifford's 48-page history, since many of her findings published in 1973 have been countered by more recent evidence.

First, it is a paper of major significance and depth, one that has been and will be widely read by a diverse audience. Therefore, we should be aware of Clifford's analysis of the impact of research on (science) education. It is also important for us to recognize our own progress within the past five years since Clifford's report.

Another reason for referring to Clifford's article has to do with the way she sees cultural diffusion, American schools and society:

> As its principal agents for socializing youth into its core values, schools have remained among society's most circumscribed instrumentalities.... If American society was conservative in expecting schools to teach if not 'release' its youth, if its moralism was old-fashioned in its views of authority, discipline, competition and hard work, research seeking for impact somehow had to come to terms with that society (1973, pp. 31-32).

This view of Clifford's points out an important difference between the conditions that affect the research of scientists and ourselves. The mission of schools is open to public review; yet the classroom is the educational researcher's laboratory.

How does Kuhn's notion of the process of normal science pertain to this fact? Scientists, according to Kuhn, are guaranteed or need isolation as researchers and a profession. They are protected from the public, from having to defend their hypotheses to a lay public.

We are all keenly aware of this difference. The following example illustrates the case. Many of you may recall seeing a panel of scientists on television two weeks ago as we watched Voyager I approach Jupiter. Cameras bewildered and dazzled scientists and the American public with the beauty of Jovian rings, as one scientist laughingly noted that the pictures "shot-to-hell our theories." Can you recall an equivalent example from a television program portraying public school education where experimental theories were treated so generously? Research having to do with American schools tampers with the public's sense of ownership and choice.

To illustrate a second difference between the expectations of scientists, ourselves and "others" in the research process, Clifford found abundant evidence that schoolmen (and I assume women) wanted research to confirm their expectations, goals, and policies (1973, pp. 27-28).

This conflict of expectations is an inversion of intent, a reversal of the role of research. Kuhn describes the function of paradigms as setting expectations, causing people to look at things differently. But from Clifford we find evidence that the consumer often tries to control or set the expectations.

Next, let's briefly consider the views of Fred N. Kerlinger, as he expressed them in his presidential address at the American Education Research Association annual meeting in New York City two years ago. While we were at the NARST meeting in Cincinnati, Kerlinger talked about "The Influence of Research on Education Practice" (1977).

Kerlinger argued that basic research is underfunded and misunderstood in this country; we suffer from the misconception that basic- or paradigm-based research should "pay-off" and be "relevant."

> The purpose of scientific research is to understand and explain phenomena. A theory presents a systematic view of relations.... Science has no other purpose than theory. Many think research is or should be to improve the lot of mankind. Not so.... Most people assume educational research can solve educational problems and improve educational practices. This assumption is false.... Scientific research never has the purpose of solving human or social problems.... The researcher is or should be preoccupied with variables and their relations. He should never be required to think about or spell out educational implications of what he is doing or has done (1977, pp. 5-6).

Kerlinger has suggested, along with Clifford and others that the impact of (basic) research on educational practice is slow (Thorndike has suggested 50 years lag) and indirect. Presumably basic research has impact while applied research has pay-off; and these outcomes are determined by immediacy.

As an example of basic research, Kerlinger refers to the work of Piaget. Since all of us in this room are familiar with the simultaneous impact, pay-off and relevance of Piaget's theory to classroom practice, it represents an interesting case to explore the dichotomy between basic and applied research.

The fact that Piaget has no interest in "the American Question"* demonstrates his basic researcher behavior, while his recent involvement with the design and testing of children's books, applying his theory, demonstrates his behavioral interest in applied research.

We can think of other examples. Two years ago at the 1977 NARST meeting, we listened to Skinner discuss reinforcement theory. Clearly,

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*The American Question generally refers to those who ask how to use Piaget's theory to speed-up the development of students' logical thought. Please see the next footnote.

here is one who has spent a great deal of time pursuing basic research. Perhaps you will recall that near the end of his presentation Skinner enthusiastically described his most recent interest: the development of an educational program which involved the manipulation of light, sound and images during instructional tasks. Here then Skinner was acting as an applied researcher as he experimented with the application of theory.

These examples of Piaget and Skinner raise an important question. Is it helpful to the process of normal science to dichotomize research by labeling it basic or applied?

As I think about impact, it seems to me the impact of science is better served by viewing paradigm-based research as a continuum from the creation of paradigms to the exploration of meaningful applications, or as a cycle, as Kuhn's revolution implies.

Kerlinger has not suggested that paradigms exist without application to real or concrete events in the everyday world, but to dichotomize research as basic or applied may create false expectations, and actually be a distortion of reality.

What is misleading about the dichotomy is the implication of finality, that the paradigm from the moment of its creation is a more or less finished product, and like some factory produced product, the paradigm awaits a consumer market to buy it and use it "as is" in the daily research routines.

Entirely missing is any hint that part of the process of normal science occurs when other researchers attempt to fit existing data (measurements, events or relationships) into the new paradigm. I am talking about the major work that must be done by scientists during the period Kuhn has described as the post-revolutionary period, the "mopping up" work.

Absent from Kerlinger's basic-applied dichotomy and its implication of finality is any suggestion that the paradigm itself changes as other researchers test the limits of the new paradigm or its instruments, as they compare it with concrete realities. (Especially see Kuhn, 1968, pp. 32-33.)

How shall the next anomalies be uncovered; how shall the limits of predictability inherent in all paradigms be discovered? By our acceptance of the basic-applied dichotomy, we unwittingly attest to the finality or completeness of the paradigm, consent to limit our expectations, and contribute to a distortion of reality about the process of normal science, in my view.*

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*This view is the basis of my objection to Piaget's reference to the American Question. How can any national group test the limits of Piaget's paradigm without testing its reality in schools?

I shall return to this point when we talk about scientific revolutions in Part Three.

Now let us return to the three studies I referred to in the introduction, that set of studies commissioned by the National Science Foundation to assess the status of pre-college science, mathematics and social science education in the United States. The reports became available early in 1978.

In the first of these reports, the impact of "the first major investment of federal monies to improve curriculum and instruction" was assessed—not by conducting a new survey—but through a careful analysis of all of the literature (approximately 6000 documents) that appeared in journals, as unpublished documents, and as doctoral dissertations during two decades of NSF support, 1955-1975.

Stanley Helgeson, Patricia Blosser and Robert Howe summarize the trends and patterns that appeared in the preparation of science teachers, teaching practices, curriculum materials and needs assessments in science education, in a report, The Status of Pre-College Science, Mathematics and Social Science Education: 1955-1975, Volume I: Science Education (1977).

The result? The evidence was clear: based on both quantitative and qualitative data, there was massive evidence that these paradigm-based curricula had had an impact in classrooms. During the twenty-year period, one of every two or three science classrooms surveyed in the United States had used the new science programs which were based on theories of learning and child/adolescent development researched by Bruner, Gagne, Piaget and others (1977, pp. 16, 21-28). Class sizes were reduced from approximately 30 students in the 1950s to 24-25 students by the 1970s (1977, p. 32), presumably to enhance the inquiry hands-on approach to learning. Research showed "a consistent trend in the direction of better student performance with increased teacher ... participation (in NSF-sponsored institutes)" (1977, p. 103). Moreover, student achievement on nationally normed tests increased in science (ACT Natural Science scores) between 1964-1974, while overall student achievement had (ACT Comprehensive scores) decreased (1977, p. 174). State and national guidelines for science education reflected an increased concern for the nature of learning (1977, pp. 46-47) as did in-service education (1977, pp. 72-73); and 80 percent of those surveyed (N = 518) who taught elementary science methods courses claimed the NSF-supported programs had "a definite impact on the methods course" (1977, p. 95).

It was a period of good times for science education.

One is forced to conclude that these two decades of unparalleled activity and cooperation among scientists, educators and learning theorists, supported by the first major investment of federal monies to improve science curriculum and instruction, had an overwhelming impact in classrooms across the United States.

The inescapable conclusion from their report is that quality science education costs money. If it is important to have up-to-date science programs based on the best research available, guess what? You have to pay for them, even in a country where 7 percent of the gross national product is spent on education (Helgeson, et al., 1977, p. 110).

In the second study of the set, impact was assessed through a survey of current practices. In the report, Report of the 1977 National Survey of Science, Mathematics and Social Studies Education, Iris Weiss describes the results of a survey which sampled approximately 400 public school districts and included 4829 teachers, 1177 principals, 1893 district supervisors, 356 superintendents, and 173 state supervisors (1978, p. 16).

What is now happening in science classrooms across the United States? "...approximately two-thirds of science classes have lectures once a week or more; for approximately 25 percent of the classes...the occurrence is just about daily....(when) asked to indicate if lecture was used (note: not dominated) in their most recent lesson...approximately 70 percent answered affirmatively.... Class discussions occur on a daily basis in 50 percent of science classes..." (1978, pp. 101-105).

And what about hands-on or lab activity? "Just about daily" 13 percent of the teachers still provide this experience while 35 percent offered it "at least once a week," 21 percent "at least once a month," and 23 percent provide hands-on experience "less than once a month or never." Science teachers who have attended one or more NSF-sponsored activities are much more likely to use manipulative materials at least once a week than are teachers who have not attended (1978, pp. 103-108).

About half of the high school teachers have at some time attended an NSF institute, while 32 percent of the 7th-9th grade teachers, 12 percent of the 4-6 and 2 percent of K-3 elementary teachers have never attended such institutes (1978, p. 69).

District reports show that the use of one or more NSF programs has remained relatively stable: prior to 1976 and through 1977, 60-64 percent in high schools (7-12), and 26-31 percent in elementary schools (1978, p. 79).

Thus, in spite of fears that the impact of NSF programs was decreasing, Weiss's report suggests that the curricula and labs or hands-on activities are still having a sustained impact in classrooms.

The last of the three studies of impact was ethnographic. Case Studies in Science Education is a two-volume collection of field observations about science teaching and learning in classrooms across the United States. Eleven high schools and their feeder schools were chosen to represent the rural and urban; north, east, south and west; racially and economically diverse; innovative and traditional fiber of

American public schools during the school year 1976-1977, the 200th year in our country's history.

Robert Stake and Jack Easley, Jr., as co-directors of the project, summarize the findings: "Nationally we found that science education was being given low priority, yielding to increasing emphasis on basic skills .... general education aims for science instruction were not felt vital at any level. Seldom was science taught as scientific inquiry.... The textbook usually was seen as the authority on knowledge and the guide to learning.... Though relatively free to depart from district syllabus or community expectation, the teacher seldom exercised either freedom" (Preface, Vol. I, 1978).

This final commentary and view expressed by Stake and Easley is the most sobering of the three for it suggests a fading of impact, and perhaps even a discrepancy between what appears to be going on, as conveyed through the choice or use of NSF curricula, and what actually takes place in classrooms, as perceived by outside observers. Yet without ethnographic baseline data from a previous period, it is impossible to assess any change of impact.

These three NSF-commissioned studies of the status of science in American public schools contain more than can be digested in a few days time. If I have misrepresented them, I urge you to correct any false impressions I have given.

How do these reports of the impact of paradigm-based research on classrooms relate to Kuhn's view of the process of normal science? First, the reports are indirect evidence that paradigm-based research can be used to design curriculum materials and training methods for teachers, whether the reports are taken singly or together.

Second, these excellent studies demonstrate that we can measure, indirectly, some aspects of the impact of our research paradigms. Granted, our instruments are in their infancy; but we have an intuitive notion of the kinds of instruments and analyses that are needed to gather data and make finer measurements.

The troika-like design of this combined approach to data-gathering (the in-depth synthesis of 20 years of literature; the massive survey of current practices; and the large cluster of cross-referenced case studies) represents a landmark: the evaluation of the results from our 20-year experiment!

Part Three: What about the Revolution?

And now we turn to the last and most interesting of the questions posed. How can Kuhn's description of the structure of scientific revolutions be useful to us as we think about the impact of our research? Earlier I stated that I would try to show how Kuhn's model allows us to interpret our own history of research in science teaching in new ways that may alter our expectations and actions in the future, and open the possibility for us to influence the impact of research in classrooms.

As I see it, the major value of using Kuhn's model is that it allows us to see impact in a new light. We can see that impact occurs when the theory or paradigm fits reality—meaning when the theory helps people (for example, in schools) understand common phenomena or daily events better, when it helps them solve problems they could not solve before the theory. Consider the evidence: the success of our paradigms in the science programs during the past two decades. Why did they fit so well?

I would suggest that impact is related to the goodness-of-fit of the paradigm. The closer the theory fits reality, the greater its impact will be. The working hypothesis then might be that there is a positive correlation between the impact of a paradigm and its goodness-of-fit with reality. If a paradigm were a perfect match of reality as people know it, take schools for example, then the correlation between the paradigm's impact and its goodness-of-fit would be 1.00. I think Piaget's paradigm is a good example of a paradigm that fits a segment of reality, as we know it, pretty well.

If this hypothesis is actually the case, then to increase the impact of research, we need to improve the goodness-of-fit between the paradigm and the reality it attempts to explain. To accomplish this, paradigms must be pushed into the real world. That is precisely what we did in our two-decade experiment.

We cannot hold onto paradigms as though they had to be protected or preserved like some relic. Such preservation can only delay the essential reality-testing, and postpone the crises that characterize the pre-revolutionary period and foretell the evolution of a new better-fitting paradigm.

Scientists use paradigms as tools, to bring them closer to understanding nature's puzzles. When paradigms are used in this way, as boxes to be filled to capacity and tested to the breaking point, then normal science progresses.

Thus, instead of pampering paradigms, we must force them into the real world, the rough and tumble reality of classrooms. Only then can we see how well our paradigms explain or predict events that puzzle us.

To this end, we need to examine more closely our acceptance of the basic-applied dichotomy that is used to label research. We may find that this dichotomy has limited our expectations in research, by precluding our search for anomalies and our push to test the limits of our paradigms. Specifically, those who attempt to fit paradigms to real classroom situations may discount their own observations of discrepancy, simply because they expect the paradigms of the basic researchers to be complete and perfect.

By limiting our expectations, we unwittingly postpone the actual revision of theories or the need to discard "boxes" that no longer fit. Thus, in effect we contribute to the postponement of a search for better-fitting paradigms; and an important part of the interaction between data and theory—the revisionary process itself—can be thwarted.

Kerlinger has said that the impact of basic research is indirect and slow. Clifford drew the same conclusion and called this slow process cultural diffusion. But neither of these views goes far enough. They are passive in that they make no attempt to explain the mechanism which regulates impact, and imply that impact is beyond our control.

I suggest that the mechanism which regulates impact is the goodness-of-fit between the paradigm and the reality it attempts to describe. Further, I think it is possible that we control that mechanism to some extent either by delaying or accelerating the reality-testing of paradigms.*

And now finally, how does our progress in normal science compare with Kuhn's model of the structure of scientific revolutions? Are we exhibiting signs of a pre-revolutionary or post-revolutionary period?

As I view our progress, it appears that we are not yet experiencing a crisis, where "we wish we had become comedians" as Pauli wished. The anomalies which fail to fit the paradigms of Piaget, Gagne, Bruner, Skinner and others do not seem to be overwhelming yet.

It seems to me that we have not pushed any of these paradigms to their limits. Our instruments, instead, measure results that fit or are predicted by the paradigms. We have yet to test the capacities of the paradigms, and identify conditions wherein they fail to predict or solve problems.

Can we expect to see a revolution, the development of a grand theory which will synthesize or replace existing paradigms and leap far beyond our present horizons? Cronbach expressed a conservative view: "The trouble is ... that we cannot store up generalizations and constructs for ultimate assemble into a network" (Shaver, 1978). A more optimistic view was expressed by the physicist, Weisskopf: "The study of social relations between individuals of a given species—be it animals or men—is still in its infancy" (Shaver, 1978).

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*One consequence of this view is that we may need to re-evaluate the objectives and transactions expected in NSF-supported projects for diffusion or dissemination. Does dissemination imply "spreading the good word," for example, or "reality-testing the paradigms"? It not only makes a difference to school personnel, but clearly affects our expectations, transactions and what happens to the paradigm.

Clearly, the rate at which research advances is partly a function of talent but also a function of the amount of inquiry activity or normal science going on. While we have little control over talent, we can influence the amount of reality-testing we do. And therein, I would argue, lies the key to each paradigm's impact.

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