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ABSTRACT

The theme of the seventh yearbook of the Association for the Education of Teachers in Science (AETS) involves the relationship of psychology of teaching thinking and creativity as this activity is performed in a science education context. Eleven chapters follow a foreword by Jean Piaget and the reproduction of Part I of "The Central Purpose of American Education," a 1961 publication of the Educational Policies Commission of the National Education Association. Chapter titles and authors are: Learnable Aspects of Human Thinking (Robert M. Gagne); Teaching for Thinking and Creativity: A Piagetian View (Constance Kamii); Intellectual Development and Instruction: A Neo-Piagetian View (Robbie Case); A Theory of Teaching for Conceptual Understanding, Rational Thought, and Creativity (A. E. Lawson and C. A. Lawson); Teaching for the Development of Reasoning (Robert Karplus); Education for Rational Thinking: A Critique (D. P. Ausubel); Meaningful Reception Learning as a Basis for Rational Thinking (J. D. Novak); A Three-Stage Model for Teaching for Creative Thinking (E. P. Torrance); A Humanist's Perception of Thinking and Creativity; The Radical Behaviorist's View (J. S. Vargas and P. A. Moxley, Jr.); and Brain Asymmetry: The Possible Educational Implications (M. A. Mogus). (PB)

1980 AETS YEARBOOK

THE PSYCHOLOGY OF TEACHING FOR THINKING AND CREATIVITY

Edited by

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Association for the Education of
Teachers in Science

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ERIC/SMEAC and AETS are currently cooperating on an eighth publication. We invite your comments and suggestions on this series.

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FOREWORD

It is with great pleasure that I have received an invitation to write a brief introduction to the present volume for it brings together the ideas of a group of eminent psychologists and educators discussing a topic of primary importance: the development of rational and creative thought.

The Educational Policies Commission was indeed insightful in stating this as the central goal of American education. This goal is really to create individuals capable of intellectual and moral autonomy and capable of respecting this autonomy in others by applying the principle of reciprocity. The pedagogical problem created by such a goal is in effect the central issue addressed in the following chapters. It brings to the fore the question of active versus passive learning. Is it possible for a student to achieve intellectual and moral autonomy if he or she is not given an opportunity to achieve knowledge through free investigation and spontaneous effort?

I offer my warmest thanks to my colleague Professor Constance Kamii for so clearly and effectively presenting my point of view on this subject and for helping focus attention on its pedagogical implications. In brief, my position is that active free investigation as opposed to passive receptive learning is necessary to assimilate knowledge and form effective methods of study that will serve well for the rest of life. Instead of having memory take priority over reasoning power, or subjugating the mind to exercises imposed from outside, the active learner will learn to make reason function by himself and will learn to build and test his own ideas freely.

This Yearbook provides a rich diversity of opinion regarding the development of intelligence and creativity. This diversity is a strength of the Yearbook yet the careful reader should note the commonality that runs through a number of the chapters. That commonality is indeed the emphasis on the students' own active participation in the learning process, on their own experiences, on their formulation of hypotheses, and on the verification of these hypotheses through their own activities. It simply is not enough for the student to listen to lessons in the same manner as an adult listens to a lecture for reasoning to be created in the child and adolescent.

Jean Piaget

PREFACE

In The Central Purpose of American Education, 1961, the Educational Policies Commission stated that the central purpose of education was to develop in students a condition called freedom of the mind, i.e., the freedom to think and to choose. According to the Commission, the essence of the ability to think involves the rational processes of:

- recalling and imagining
- classifying and generalizing
- comparing and evaluating
- analyzing and synthesizing
- deducing and inferring

In their view these processes, which they called the rational powers, "enable one to apply logic and the available evidence to his ideas, attitudes, and actions, and to pursue better whatever goals he may have."

The science education community views development of these rational powers as an extremely worthy educational objective. Consequently in recent years there has been a considerable attempt to teach the investigative processes of the scientist along with the subject matter of the various scientific disciplines. This no doubt involves use of the Educational Policies Commission's rational powers. Nevertheless, a crucial link is missing--that is a viable psychological theory in which to understand the rational processes and to guide teachers in the design and delivery of instructional materials to effectively enable students to develop and successfully use those rational processes.

It is recognized that the Educational Policies Commission itself was guided by intuition rather than psychological theory in constructing its list of rational powers. Accordingly I have asked eminent psychologists and educators to participate in the development of a series of chapters that all address the same central questions concerning the development of the intellect and the design of instruction from the perspective of their respective psychological theories.

The present volume hopefully will stand as a document of singular importance in the development of a much needed theory of instruction. The Yearbook provides for the first time a single forum for the presentation of the prominent psychological views on the development of the intellect and how instruction can assist in this most significant development.

Each chapter provides the reader with a presentation of the author's psychological perspective of the development of rational thought and creativity and how instruction can aid in this development.

To insure that the reader can identify points of agreement and disagreement among authors as he reads the chapters, each author has been asked to respond to the following series of questions at some point during the presentation of his or her views:

1. Do you view the Educational Policies Commission's 10 rational powers as fundamentally important aspects of intellectual functioning? If so, why? If not, why not? If not, what aspects of intellectual functioning do you see as fundamental? (i.e., How do the rational powers fit or not fit within your conception of the development of the intellect?).

2. Can instruction be designed and carried out to promote the development of these rational powers (or the rational processes you view as fundamental)?

3. Does your theory provide a basis for the development of these rational powers (or the rational processes you view as fundamental) through instruction? If so, how? If not, what else is needed? (i.e., Does your theory dictate a specific instructional model to promote the development of these rational powers? If so, what is that model?).

4. Does your theory provide a basis for the sequencing of content in grades 1-12? If so, please explain what that sequence might be.

5. What teaching strategies, if any, do you view as important in the day-to-day activities of the classroom to encourage the development of the rational powers?

6. What psychological and/or educational research, if any, do you view as necessary to the development of sound instructional theory and practice?

Author selection was made with the intent of having prominent schools of present-day psychological theory represented. To a large part I was successful in this regard. The Piagetian, Ausubelian, Gagneian, and Skinnerian points of view are presented by Constance Kamii, by David Ausubel and Joe Novak, by Robert Gagne, and by Julie Vargas and Roy Moxley, respectively. The Humanistic psychologists' point of view championed perhaps most vocally by Carl Rogers is presented by David Aspy, the current director of the National Consortium for Humanizing Education. A chapter by E. Paul Torrance, a leader in the field of research into creativity, presents his views. Robbie Case presents what he terms a Neo-Piagetian view of intellectual development and its implications for rational power development. Case's theory represents a synthesis of much of Piagetian psychology with the recent work on memory development and models of information processing. The chapters by Robert Karplus, and by Anton Lawson and Chester Lawson also represent syntheses of ideas from a variety of current areas of psychological research. A final area of current interest in the psychological and educational literatures is the field of neurophysiology, specifically the recent research on split-brain humans. This research, which shows that the two brain hemispheres process information in very different ways, is reviewed by Mary Ann Mogus and its implications for teaching for creativity and rational thought development are explored.

As you read the chapters you will most certainly find points of agreement and disagreement among authors. One fundamental disagreement centers around the issue of whether or not generalizable rational and creative abilities can in fact be significantly enhanced through instruction. Ausubel takes the extreme position that little or nothing can be done to teach generalizable problem solving strategies since genetics plays by far the most prominent role in their presence or absence and transfer from one discipline to others does not occur. Thus he concludes that we should not spend our time in attempting to develop the use of general problem-solving abilities. Rather we should be contented to teach the content of separate disciplines. Further we should do it through expository methods leading to what he terms "reception" learning.

Other chapter authors, although not in agreement among themselves on many points, all take seriously enough the claim that generalizable problem-solving abilities can be taught to detail their respective psychological theories and implied educational practices to do so. No doubt, as Ausubel tells us, heredity-like experience places limits on creative achievement. Yet research and professional suggests that gains in creative and rational problem-solving attitudes and abilities are substantial enough to justify the increasing educational and industrial interest in their training. Edwards (1968)*, for example, reported the results of one extremely worthwhile creativity training program for employees of the Sylvania Electric Company. In his words the program resulted in "doubled profit, 2,100 new products; beat competition on two new products; increased patent applications five-fold; saved $22 million." Also companies such as Motorola claim hundreds of thousands of dollars in increased profits due to training programs in which employees learn problem-solving techniques such as "causal analysis."

The Novak chapter echos Ausubel's emphasis on reception learning. Novak, however, believes that, through the teaching of specific concepts embedded in specific disciplines, students will in fact develop rational and creative abilities. Novak concludes, as does Ausubel, that we should focus our efforts on the facilitation of "meaningful learning." Clearly no educator would argue with the position that learning should be meaningful, yet the Novak position seems to ignore an important segment of recent psychological theory and research dealing with problem-solving and creativity. Briefly put, the Novak position reduces all cognitive behavior of importance to the classroom teacher to "meaningful reception learning." This reduction may effect

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*Edwards, M. W. "A Survey of Problem-Solving Courses," Journal of Creative Behavior. 2: 33-51, 1968.

parsimony, however, in giving simplicity of explanation it may sacrifice completeness.

It is towards the sake of completeness that Gagne, Torrance, Lawson and Lawson, Karplus, Case, and Kamii speak of cognitive strategies, reasoning patterns, mental operations, and information processing techniques, and suggest means of facilitating their development. And it is to this end that author Aspy urges that teachers show empathy, genuineness and positive regard for student's ideas and problem-solving attempts and author Mogus urges teachers to allow students to utilize both right and left brain hemispheres in problem solving.

At this point it would be well to point out one other fundamental theoretical disagreement. All but one of the chapters, that being the radical behaviorist's chapter by Vargas and Moxley, present variations on a cognitive--as opposed to a behaviorist--theme of rational thought and creativity development. Readers no doubt recognize the important distinction between these two schools of thought. To the behaviorists all problem solving is ultimately reduced to trial-and-error and simple conditioned responses. To the cognitive psychologists on the other hand, problem solving involves conscious, deliberate, and purposeful mental activity. This difference is indeed most fundamental. Are human beings automatons reacting only to external, and after the fact, contingencies? Or are we guided by internal mental processes that allow insight, purpose and emotion and that seek the maintenance of an internal mental equilibrium?

The Vargas and Moxley chapter is surprising in this regard. They accept the basic S-R explanation of human behavior, yet they find themselves endorsing a science curriculum such as that of the Science Curriculum Improvement Study which was developed largely from the cognitive psychologist's point of view.

My hope is that the Yearbook's chapters will provide much food for thought, discussion and debate. Although a synthesis of the best of the presented ideas, and ideas perhaps not yet thought of, into an accepted theory of instruction must await the efforts of individual readers, allow me to make the following prediction. That theory of instruction, once accepted and put into effective use in our classrooms, will have as its central core the three-stage sequence of instruction suggested by Karplus, by Lawson and Lawson, and by Torrance.

Part I of The Central Purpose of American Education has been reprinted with permission of the National Education Association to provide the reader with a framework within which to consider each of the chapters in this yearbook.

PART I

EDUCATION IN THE AMERICAN SOCIETY

In any democracy education is closely bound to the wishes of the people, but the strength of this bond in America has been unique. The American people have traditionally regarded education as a means for improving themselves and their society. Whenever an objective has been judged desirable for the individual or the society, it has tended to be accepted as a valid concern of the school. The American commitment to the free society—to individual dignity, to personal liberty, to equality of opportunity—has set the frame in which the American school grew. The basic American value, respect for the individual, has led to one of the major charges which the American people have placed on their schools: to foster that development of individual capacities which will enable each human being to become the best person he is capable of becoming.

The schools have been designed also to serve society's needs. The political order depends on responsible participation of individual citizens; hence the schools have been concerned with good citizenship. The economic order depends on ability and willingness to work; hence the schools have taught vocational skills. The general morality depends on choices made by individuals; hence the schools have cultivated moral habits and upright character.

Educational authorities have tended to share and support these broad concepts of educational purposes. Two of the best-known definitions of purposes were formulated by educators in 1918 and 1938. The first definition, by the Commission on the Reorganization of Secondary Education, proposed for the school a set of seven cardinal objectives: health, command of fundamental processes, worthy home membership, vocational competence, effective citizenship, worthy use of leisure, and ethical character. The second definition, by the Educational Policies Commission, developed a number of objectives under four headings: self-realization, human relationship, economic efficiency, and civic responsibility.

The American school must be concerned with all these objectives if it is to serve all of American life. That these are desirable objectives is clear. Yet they place before the school a problem of immense scope, for neither the schools nor the pupils have the time or energy to engage in all the activities which will fully achieve all these goals. Choices among possible activities are inevitable and are constantly being made in and for every school. But there is no consensus regarding a basis for making these choices. The need, therefore, is for a principle which will enable the school to identify its necessary and appropriate contributions to individual development and the needs of society.

Furthermore, education does not cease when the pupil leaves the school. No school fully achieves any pupil's goals in the relatively short time he spends in the classroom. The school seeks rather to equip the pupil to achieve them for himself. Thus the search for a definition of the school's necessary contribution entails an understanding of the ways individuals and societies choose and achieve their goals. Because the school must serve both individuals and the society at large in achieving their goals, and because the principal goal of the American society remains freedom, the requirements of freedom set the frame within which the school can discover the central focus of its own efforts.

FREEDOM OF THE MIND

The freedom which exalts the individual, and by which the worth of the society is judged, has many dimensions. It means freedom from undue governmental restraints; it means equality in political participation. It means the right to earn and own property and decide its disposition. It means equal access to just processes of law. It means the right to worship according to one's conscience.

Institutional safeguards are a necessary condition for freedom. They are not, however, sufficient to make men free. Freedom requires that citizens act responsibly in all ways. It cannot be preserved in a society whose citizens do not value freedom. Thus belief in freedom is essential to maintenance of freedom. The basis of this belief cannot be laid by mere indoctrination in principles of freedom. The ability to recite the values of a free society does not guarantee commitment to those values. Active belief in those values depends on awareness of them and of their role in life. The person who best supports these values is one who has examined them, who understands their function in his life and in the society at large, and who accepts them as worthy of his own support. For such a person these values are consciously held and consciously approved.

The conditions necessary for freedom include the social institutions which protect freedom and the personal commitment which gives it force. Both of these conditions rest on one condition within the individuals who compose a free society. This is freedom of the mind.

Freedom of the mind is a condition which each individual must develop for himself. In this sense, no man is born free. A free society has the obligation to create circumstances in which all individuals may have opportunity and encouragement to attain freedom of the mind. If this goal is to be achieved, its requirements must be specified.

To be free, a man must be capable of basing his choices and actions on understandings which he himself achieves and on values which he examines for himself. He must be aware of the bases on which he accepts propositions as true. He must understand the values by which he lives, the assumptions on which they rest, and the consequences to which they lead. He must recognize that others may have different values. He must be capable of analyzing the situation in which he finds himself and of developing solutions to the problems before him. He must be able to perceive and understand the events of his life and time and the forces that influence and shape those events. He must recognize and accept the practical limitations which time and circumstance place on his choices. The free man, in short, has a rational grasp of himself, his surroundings, and the relation between them.

He has the freedom to think and choose, and that freedom must have its roots in conditions both within and around the individual. Society's dual role is to guarantee the necessary environment and to develop the necessary individual strength. That individual strength springs from a thinking, aware mind, a mind that possesses the capacity to achieve aesthetic sensitivity and moral responsibility, an enlightened mind. These qualities occur in a wide diversity of patterns in different individuals. It is the contention of this essay that central to all of them, nurturing them and being nurtured by them, are the rational powers of man.

THE CENTRAL ROLE OF THE RATIONAL POWERS

The cultivated powers of the free mind have always been basic in achieving freedom. The powers of the free mind are many. In addition to the rational powers, there are those which relate to the aesthetic, the moral, and the religious. There is a unique, central role for the rational powers of an individual, however, for upon them depends his ability to achieve his personal goals and to fulfill his obligations to society.

These powers involve the processes of recalling and imagining, classifying and generalizing, comparing and evaluating, analyzing and synthesizing, and deducing and inferring. These processes enable one to apply logic and the available evidence to his ideas, attitudes, and actions, and to pursue better whatever goals he may have.

This is not to say that the rational powers are all of life or all of the mind, but they are the essence of the ability to think. A thinking person is aware that all persons, himself included, are both rational and nonrational, that each person perceives events through the screen of his own personality, and that he must take account of his personality in evaluating his perceptions. The rational processes, moreover, make intelligent choices possible. Through them a person can become aware of the bases of choice in his values and of the circumstances of choice in his environment. Thus they are broadly applicable in life, and they provide a solid basis for competence in all the areas with which the school has traditionally been concerned.

The traditionally accepted obligation of the school to teach the *fundamental processes*—an obligation stressed in the 1918 and 1938 statements of educational purposes—is obviously directed toward the development of the ability to think. Each of the school's other traditional objectives can be better achieved as pupils develop this ability and learn to apply it to all the problems that face them.

Health, for example, depends upon a reasoned awareness of the value of mental and physical fitness and of the means by which it may be developed and maintained. Fitness is not merely a function of living and acting; it requires that the individual understand the connection among health, nutrition, activity, and environment, and that he take action to improve his mental and physical condition.

Worthy home membership in the modern age demands substantial knowledge of the role that the home and community play in human development. The person who understands the bases of his own judgments recognizes the home as the source from which most individuals develop most of the standards and values they apply in their lives. He is intelligently aware of the role of emotion in his own life and in the lives of others. His knowledge of the importance of the home environment in the formation of personality enables him to make reasoned judgments about his domestic behavior.

More than ever before, and for an ever-increasing proportion of the population, *vocational competence* requires developed rational capacities. The march of technology and science in the modern society progressively eliminates the positions open to low-level talents. The man able to use only his hands is at a growing disadvantage as compared with the man who can also use his head. Today even the simplest use of hands is coming to require the simultaneous employment of the mind.

Effective citizenship is impossible without the ability to think. The good citizen, the one who contributes effectively and responsibly to the management of the public business in a free society, can fill his role only if he is aware of the values of his society. Moreover, the course of events in modern life is such that many of the factors which influence an individual's civic life are increasingly remote from him. His own firsthand experience is no longer an adequate basis for judgment. He must have in addition the intellectual means to study events, to relate his values to them, and to make wise decisions as to his own actions. He must also be skilled in the processes of communication and must understand both the potentialities and the limitations of communication among individuals and groups.

The *worthy use of leisure* is related to the individual's knowledge, understanding, and capacity to choose, from among all the activities to which his time can be devoted, those which contribute to the achievement of his purposes and to the satisfaction of his needs. On these bases, the individual can become aware of the external pressures which compete for his attention, moderate the influence of these pressures, and make wise choices for himself. His recreation, ranging from hobbies to sports to intellectual activity pursued for its own sake, can conform to his own concepts of constructive use of time.

The development of *ethical character* depends upon commitment to values; it depends also upon the ability to reason sensitively and responsibly with respect to those values in specific situations. Character is misunderstood if thought of as mere conformity to standards imposed by external authority. In a free society, ethics, morality, and character have meaning to the extent that they represent affirmative, thoughtful choices by individuals. The ability to make these choices depends on awareness of values and of their role in life. The home and the church begin to shape the child's values long before he goes to school. And a person who grows up in the American society inevitably acquires many values from his daily pattern of living. American children at the age of six, for example, usually have a firm commitment to the concept of fair play. This is a value which relates directly to such broad democratic concepts as justice and human worth and dignity. But the extension of this commitment to these broader democratic values will not occur unless the child becomes aware of its implications for his own behavior, and this awareness demands the ability to think.

A person who understands and appreciates his own values is most likely to act on them. He learns that his values are of great moment for himself, and he can look objectively and sympathetically at the values held by others. Thus, by critical thinking, he can deepen his respect for the importance of values and strengthen his sense of responsibility.

The man who seeks to understand himself understands also that other human beings have much in common with him. His understanding of the possibilities which exist within a human being strengthens his concept of the respect due every man. He recognizes the web which relates him to other men and perceives the necessity for responsible behavior. The person whose rational powers are not well developed can, at best, learn habitual responses and ways of conforming which may insure that he is not a detriment to his society. But, lacking the insight that he might have achieved, his capacity to contribute will inevitably be less than it might have become.

Development of the ability to reason can lead also to dedication to the values which inhere in rationality: commitment to honesty, accuracy, and personal reliability; respect for the intellect and for the intellectual life; devotion to the expansion of knowledge. A man who thinks can understand the importance of this ability. He is likely to value the rational potentials of mankind as essential to a worthy life.

Thus the rational powers are central to all the other qualities of the human spirit. These powers flourish in a humane and morally responsible context and contribute to the entire personality. The rational powers are to the entire human spirit as the hub is to the wheel.

These powers are indispensable to a full and worthy life. The person in whom—for whatever reason—they are not well developed is increasingly handicapped in modern society. He may be able to satisfy minimal social standards, but he will inevitably lack his full measure of dignity because his incapacity limits his stature to less than he might otherwise attain. Only to the extent that an individual can realize his potentials, especially the development of his ability to think, can he fully achieve for himself the dignity that goes with freedom.

A person with developed rational powers has the means to be aware of all facets of his existence. In this sense he can live to the fullest. He can escape captivity to his emotions and irrational states. He can enrich his emotional life and direct it toward ever higher standards of taste and enjoyment. He can enjoy the political and economic freedoms of the democratic society. He can free himself from the bondage of ignorance and unawareness. He can make of himself a free man.

THE CHANGES IN MAN'S UNDERSTANDING AND POWER

The foregoing analysis of human freedom and review of the central role of the rational powers in enabling a person to achieve his own goals demonstrate the critical importance of developing those powers. Their importance is also demonstrated by an analysis of the great changes in the world.

Many profound changes are occurring in the world today, but there is a fundamental force contributing to all of them. That force is the expanding role accorded in modern life to the rational powers of man. By using these powers to increase his knowledge, man is attempting to solve the riddles of life, space, and time which have long intrigued him. By using these powers to develop sources of new energy and means of communication, he is moving into interplanetary space. By using these powers to make a smaller world and larger weapons, he is creating new needs for international organization and understanding. By using these powers to alleviate disease and poverty, he is lowering death rates and expanding populations. By using these powers to create and use a new technology, he is achieving undreamed affluence, so that in some societies distribution has become a greater problem than production.

While man is using the powers of his mind to solve old riddles, he is creating new ones. Basic assumptions upon which mankind has long operated are being challenged or demolished. The age-old resignation to poverty and inferior status for the masses of humanity is being replaced by a drive for a life of dignity for all. Yet, just as man achieves a higher hope for all mankind, he sees also the opening of a grim age in which expansion of the power to create is matched by a perhaps greater enlargement of the power to destroy.

As man sees his power expand, he is coming to realize that the common sense which he accumulates from his own experience is not a sufficient guide to the understanding of the events in his own life or of the nature of the physical world. And, with combined uneasiness and exultation, he senses that his whole way of looking at life may be challenged in a time when men are returning from space.

Through the ages, man has accepted many kinds of propositions as truth, or at least as bases sufficient for action. Some propositions have been accepted on grounds of superstition; some on grounds of decree, dogma, or custom; some on humanistic, aesthetic, or religious grounds; some on common sense. Today, the role of knowledge derived from rational inquiry is growing. For this there are several reasons.

In the first place, knowledge so derived has proved to be man's most efficient weapon for achieving power over his environment. It prevails because it works.

More than effectiveness, however, is involved. There is high credibility in a proposition which can be arrived at or tested by persons other than those who advance it. Modesty, too, is inherent in rational inquiry, for it is an attempt to free explanations of phenomena and events from subjective preference and human authority, and to subject such explanations to validation through experience. Einstein's concept of the curvature of space cannot be demonstrated to the naked eye and may offend common sense; but persons who cannot apply the mathematics necessary to comprehend the concept can still accept it. They do this, not on Einstein's authority, but on their awareness that he used rational methods to achieve it and that those who possess the ability and facilities have tested its rational consistency and empirical validity.

In recent decades, man has greatly accelerated his systematic efforts to gain insight through rational inquiry. In the physical and biological sciences and in mathematics, where he has most successfully applied these methods, he has in a short time accumulated a vast fund of knowledge so reliable as to give him power he has never before had to understand, to predict, and to act. That is why attempts are constantly being made to apply these methods to additional areas of learning and human behavior.

The rapid increase in man's ability to understand and change the world and himself has resulted from increased application of his powers of thought. These powers have proved to be his most potent resource, and, as such, the likely key to his future.

THE CENTRAL PURPOSE OF THE SCHOOL

The rational powers of the human mind have always been basic in establishing and preserving freedom. In furthering personal and social effectiveness they are becoming more important than ever. They are central to individual dignity, human progress, and national survival.

The individual with developed rational powers can share deeply in the freedoms his society offers and can contribute most to the preservation of those freedoms. At the same time, he will have the best chance of understanding and contributing to the great events of his time. And the society which best develops the rational potentials of its people, along with their intuitive and aesthetic capabilities, will have the best chance of flourishing in the future. To help every person develop those powers is therefore a profoundly important objective and one which increases in importance with the passage of time. By pursuing this objective, the school can enhance spiritual and aesthetic values and the other cardinal purposes which it has traditionally served and must continue to serve.

The purpose which runs through and strengthens all other educational purposes—the common thread of education—is the development of the ability to think. This is the central purpose to which the school must be oriented if it is to accomplish either its traditional tasks or those newly accentuated by recent changes in the world. To say that it is central is not to say that it is the sole purpose or in all circumstances the most important purpose, but that it must be a pervasive concern in the work of the school. Many agencies contribute to achieving educational objectives, but this particular objective will not be generally attained unless the school focuses on it. In this context, therefore, the development of every student's rational powers must be recognized as centrally important.

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Anton E. Lawson, Editor

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LEARNABLE ASPECTS OF HUMAN THINKING

Robert M. Gagne
Florida State University

INTRODUCTION

As a goal for human development, an individual capability for original, "creative" thinking has often been affirmed (e.g., Barron, 1968; Koestler, 1964; Coler, 1963). The apparent consensus with respect to this idea, when stated in such general terms, serves to mask a large amount of disagreement about the basic definition of creative thinking, and even more concerning explanations of creativity (Rothenberg and Hausman, 1976). There is also frequent endorsement of the positive role which can be played by educational programs in fostering the capability of creative thinking (Bruner, 1960; Taylor and Barron, 1963; Torrance, 1963; Suchman, 1961). In this area, too, the agreement on a general goal cannot hide great divergence in ideas about how much and by what means students can attain powers of creative thinking (Rothenberg and Hausman, 1976; Crovitz, 1970; Ausubel, 1968).

An important document expressing optimism about the widespread attainability and teachability of powers of rational thought is the report entitled The Central Purpose of American Education, by the Educational Policies Commission of the National Education Association of the United States (1961). This influential report relates the general goal of "freedom to think" to mental development that can be fostered by the formal education of the school. While acknowledging the importance of the content areas comprising the cardinal principles of the Commission on the Reorganization of Secondary Education (1918), the report attributes a central role in the development of human thinking to a set of *rational powers,* or thinking processes. The development of these powers is conceived to be the central purpose of schooling, and the report offers examples of how teaching may be oriented to this purpose.

Scientists and science educators in particular are frequently concerned that provisions for scientific reasoning, invention, and creative thinking be reflected in school curricula. Virtually every one of the nationally organized science programs developed during the decade of the '60s includes in its stated purposes the idea that students will be led to "think like scientists." Presumably, such a phrase was employed to reflect the intention of encouraging attitudes of objectivity, respect for empirical evidence, avoidance of over-generalized conclusions, and the like. In part also, thinking like a scientist was taken to mean critical thinking, logical reasoning, and appropriate use of analogy. Armed with such prerequisite capabilities, it was hoped that some students would become the creative scientists of the next generation, while most others would at least possess "scientific literacy."

These ideas form a background for this chapter. What I intend to do in approaching the topic of the learnable aspects of human thinking is, first, to review some of the major contemporary evidence and theory. Valuable formulations of the problem, and evidence pertaining to them, have been contributed in recent years by science educators and by psychologists. Drawing upon these sources, I shall attempt to provide an account of human thinking which is in the tradition of modern cognitive psychology, employing the general conception of information-processing as a theoretical basis. Seeking to identify the human capabilities that are involved in problem solving and creative thinking, I shall consider what we know about their learnability, and what implications may be drawn for educational practice.

INTELLECTUAL COMPONENTS OF SCIENTIFIC THINKING

If the problem of how to teach thinking is to be faced, it is evidently necessary as a first step to identify the intellectual capabilities ("rational powers") that enter into such thinking, and to define their characteristics as well as may currently be possible. Although progress has been made in recent years in this problem area, we do not yet have the sort of basic list of these capabilities that engenders confidence.

As mentioned in the report on The Central Purpose of American Education (Educational Policies Commission, 1961), the rational powers include the processes of "recalling and imagining, classifying and generalizing, comparing and evaluating, analyzing and synthesizing, and deducing and inferring" (p. 5). A list of this sort cries out for the disciplined thinking that scientists know as operational definition. Were that to be undertaken, it would probably be apparent that some of these "powers" are involved in fairly routine kinds of human performances (e.g., "recalling"), whereas others are likely to occur as component steps in highly complex intellectual activities (e.g., "synthesizing"). Some of these powers, as well, might be found being applied to any specific situation by a high percentage of the human population, whereas others would be employed by only a small percentage of that population.

It is also not apparent that a list such as this is inclusive of the kinds of intellectual capabilities involved in scientific thinking. Are these indeed the processes involved in what the scientist identifies as problem definition, theory construction, hypothesis derivation, hypothesis testing, experiment design, data analysis, and conclusion drawing? It has often been pointed out that these "scientific operations" are not themselves descriptions of the thinking processes of scientists. What, then, are the intellectual processes involved in each of these phases of scientific investigation? Presumably, a proper approach to this question employs a well-known tool of contemporary cognitive psychology, which is called "task analysis" (Gagne, 1977), or "information-processing analysis." Basically, this is a matter of constructing flow-diagrams which analyze complex activities into simpler components, some of which are internal (cognitive) processes. Examples of the technique are described by Greeno (1976), Resnick and Glaser (1976), and Newell and Simon (1972).

A task analysis approach to each of the various operations that are considered to make up "scientific thinking" would be likely to identify a number of intellectual processes that have a variety of functions in scientific investigation. Some of these would doubtless be of very general applicability to human thought (such as memory storage, search, and retrieval), while others would pertain more specifically to the solving of problems (such as analyzing, planning, transforming, etc.). Notable, however, is the observation that task analysis would be likely to reveal a fair number of different intellectual processes, not a very small number. Human thinking is a complex matter, and cannot be reduced to one or two intellectual capabilities.

Suggested Intellectual Capabilities in Thinking

Writers and investigators who think about human thinking often begin with widely different basic assumptions. A commonly employed theoretical basis for investigations of thinking is that of Piaget (1970), and particularly the idea of formal operational reasoning described by Inhelder and Piaget (1958). This single-stranded notion of human rationality is exemplified by varieties of problems of a scientific nature, such as those requiring the conservation of volume or weight, using proportions, and controlling variables (Levine and Linn, 1977). Psychologists have employed many kinds of problems in their attempts to investigate human thinking (Davis, 1973; Johnson, 1972). Sometimes the tasks used have been concrete and practical, and at other times highly abstract. In recent years, greatest progress appears to have been made within a cognitive or "information-processing" framework, as exemplified by the work of Newell and Simon (1972).

Formal Operations

Thinking ability is conceived by Inhelder and Piaget (1958) as a matter of attaining capabilities of reasoning including 16 logical operations which make up *formal operations*. This stage of development is attained in the early adolescent years, and commonly exhibited by age 14 or 15.

These investigators employed 15 different problem tasks for administration to children of various ages, in studying the changes from concrete operational thought to formal operational thought. An example of a problem task is the "bending rods" demonstration, in which six rods of varying length, width, cross-sectional shape, and material composition are shown, along with weights which can be hung from the rods. The children are asked to find out which rod bends the most, and to explain what makes one rod bend more than another. The formal operational level is considered to be exhibited, with this problem, when individuals are able to describe a proof involving holding "all other things equal." In other words, formal operational thinking includes the idea of control of variables, in seeking to isolate the influence of a particular variable.

Problems in Science

The work of Piaget and Inhelder has attracted much attention from science educators, who readily perceive the relation between the tasks used and those that occur as part of instruction in physical science. The study of science, insofar as it aims to reflect the activities of scientists, requires the use of formal operational logic. Understanding the derivation and the use of scientific principles would appear to demand a kind of abstract thinking that extends beyond the concrete operational stage, as conceived by Piaget (1970). Even a basic understanding of scientific concepts (e.g., mass) would seem to require abstract thought. Yet a quality of human performance of that sort, although obviously prerequisite, would appear still to be a far cry from "creative thinking" or even "thinking like a scientist."

Working usually within the framework of Piaget's conception of intellectual development, science educators have investigated a number of different problem tasks, and related student performance on these tasks to variables such as age, amount, and kind, of prior instruction. For example, such Piagetian tasks as conservation of weight, conservation of volume, and displacement volume have been employed to study children's thinking at the concrete operational level (Lawson and Nordland, 1976; Lawson and Renner, 1975; Karplus and Lavatelli, 1969). Some of the problems employed by Inhelder and Piaget (1958), including the bending rods task, the pendulum task, and the balance beam task have been used to assess the attainment of formal operational thought (Lawson and Wollman, 1976).

Other investigators have invented new tasks designed to reflect various levels of concrete operational, transitional, and formal operational thought. Summary descriptions of such tasks are contained in articles by Levine and Linn (1977) and by Lawson and Wollman (1976). Of particular note are tasks of proportional reasoning devised by Karplus, which have been employed in a number of investigations of science students of various ages (Karplus, Karplus and Wollman, 1974; Karplus and Peterson, 1970). With these tasks and with others, investigators have generally found low percentages (25-35%) of adolescent students, ages 14-17, capable of engaging in formal operational thought (Levine and Linn, 1977; Blasi and Hoeffel, 1974).

A few studies have attempted to go beyond the attainment of formal operations to encourage the development of creative thinking in science students (Davis, Raymond, MacRawls and Jordan, 1976; Hill, 1976; McCormack, 1971). While gains in achievement have sometimes resulted from these special teaching efforts, no general finding of increased "creativity" has been obtained. Creativity measures have included those described by Guilford and Merrifield (1960), and by Torrance (1966). It is not an unusual finding in such studies (e.g., Davis, Raymond, MacRawls and Jordan, 1976) that instruction which emphasizes fluency of thought leads to improved test scores on measures of the same kind (Maltzman, 1960). Establishing creative thinking as an enduring tendency or human trait presumably requires more elaborate provisions for the control of variables, as Johnson (1972) points out.

Psychological Conceptions of Thinking

Naturally enough, human thinking has a relatively long history of ivestigation in the field of psychology (cf., Davis, 1973; Johnson, 1972; Mandler and Mandler, 1964). Although the term *thinking* is usually conceived as having a rather broad meaning with reference to cognitive processes, *problem solving* is the term most preferred by psychologists who study this aspect of human functioning. As for *creative thinking*, most psychologists would probably agree with Newell, Shaw, and Simon (1962) that this class of activity has somewhat hazy boundaries. Problem solving, they say, is called *creative* to the extent that (1) the product has novelty and value; (2) the thinking is unconventional; (3) the thinking requires high motivation and persistence; and (4) the problem as posed was vague or ill-defined.

The processes considered to make a critical difference in problem solving are of various sorts. In the past, they have often been associated with the more general theories of certain "schools" of psychology, or at least with certain prototype experiments. A recent critical review of problem solving investigations is given by Mayer (1977). His description of critical processes includes the following:

1. *The dominance of responses* or "habit families," as brought about by a previous reinforcement history, is the conception of problem solving favored by the *associationist* tradition (Duncan, 1967).

2. Thinking as *hypothesis testing* is exemplified in experimental studies of concept using, of which a prominent example is described by Bruner, Goodnow, and Austin (1956). These investigators emphasize *strategies of hypothesis selection* as critical processes in thinking.

3. The idea of *reorganizing the elements* of the problem structure is emphasized in the writings of Gestalt psychologists. The reorganizing process can often be stimulated by means of a verbal "hint" providing *direction*. Examples of this conception are found in the work of Maier (1930) and Katona (1940).

4. Thinking is sometimes conceived as *assimilation to a schema*, i.e., to a meaningful organization within the learner's memory. A schema may involve concrete components, imagery, or other forms of problem representation. Relevant modern studies are those of Mayer (1975) and Paige and Simon (1966).

5. An information-processing account of problem solving is the best-known contemporary conception, which incorporates a number of ideas of previous models of thinking. Essentially, this view proposes that problem solving involves a *sequence of mental operations*.

The theory of problem solving presented by Newell and Simon (1972; also, Simon, 1978) attempts to account for the interaction between the problem solver (called an *information-processing system*) and the problem task as presented (called the *task environment*). In dealing with the task, the problem solver represents the task environment as a *problem space*, which is his way of viewing the task environment. There are, of course, many kinds of problems, and accordingly many kinds of task environments. The structures that are possible in this problem space are limited by the structure of the task environment. And in turn, the possible problem-solving strategies that can be employed are determined by the structure of the problem space.

According to this theory, problem solving proceeds as the problem solver constructs an internal representation of the problem, and then searches his memory for an available strategy ("method") that bears a rational relation to attaining a problem solution. This strategy is applied, and comes to control the thinking behavior of the problem solver. If found to be unsuccessful, another strategy may be selected, or a different internal representation may be constructed (i.e., the problem may be formulated). An important aspect of the problem solving process consists of evaluation of the differences between a current state of affairs and the desired state, a procedure usually called *means-end analysis*.

The process of problem solving, as viewed by this information-processing theory, is influenced by such factors as (1) the problem-solver's capability in constructing an internal representation of the problem; (2) the availability of problem-solving strategies; (3) the availability in the problem-solver's memory of a store of general knowledge relevant to problem representation and to means-end analysis (Simon, 1978; Newell, Shaw and Simon, 1962).

A classification of problem types, viewed from the information-processing standpoint, and an initial overview of the human abilities involved in achieving solution of these types, has been made by Greeno (1978). A summary of some important points of this article is as follows:

1. Problems of inducing structure. The task presented by these problems is to induce a total structure from parts which are given. Analogy problems (HAND: GLOVE::FOOT: SHOE) and series-extrapolation problems (A B R C D R - - -) are examples which have been studied extensively. Greeno considers these problems to involve processes of "understanding," analogous to the understanding of a sentence. The kinds of skills and knowledge required for solution are identified as (a) a process of "apprehending the relations" among the problem elements, and (b) "generating an integrated representation of the pattern." Evidently, this means that successful problem solution is influenced by skill in identifying pattern relations, and by knowledge of the elements of the pattern (which may be words or pictures).

2. Problems of transformation. In these problems, the task is to operate on a situation and transform it to a different situation,

the latter representing the goal. Generally, these are "change" or "move" problems, including the Tower of Hanoi, proofs of theorems, and water-jug problems (Luchins, 1942). Abilities for analyzing and planning, to carry out means-end analyses, are involved in these problems, according to Greeno. The selection of strategies for planning is of considerable importance as a human ability. Other factors of relevance are (a) skill in identifying features of the situation related to later outcomes, and (b) skill in using complex, integrated operations (as an example, arithmetic computation).

In many cases of transformation problems the inducing of structure is also required. The process of initial understanding of the problem is involved, as studied by Hayes and Simon (1974), Simon and Hayes (1976), using tasks differing in content but otherwise isomorphic to the Tower of Hanoi. The abilities identified by Greeno relating to this category of problem are the "understanding" previously mentioned, and the general knowledge available in the problem-solver's long-term memory.

3. Problems of arrangement. In problems of this sort, some components are presented, and the task is to find an arrangement that meets a stated criterion. A common example is an anagram (NCABO) and a somewhat more complex type is cryptarithmetic (Newell and Simon, 1972), as represented by the problem DONALD + GERALD = ROBERT. Card-arrangement problems (Katona, 1940) are other examples. According to Greeno's interpretation of the evidence, human abilities required for successful solution of such tasks include (a) fluency in generating trial partial solutions; (b) accessibility in the problem-solver's memory of solution patterns; (c) availability of rules that reduce the search possibilities (such as the rules of English phonology, as applied to anagrams); (d) specific strategies of task procedure (as in reordering the letters of an anagram in a consistent way).

4. Problems of transformation of arrangements. These are problems in which an arrangement of elements is given, and the task is to bring about a structural transformation of this arrangement. Examples are the matchstick problems of Katona (1940) and chess problems (Simon and Gilmartin, 1973). Such problems as these, Greeno says, partake of human abilities required for transformation problems, and also those for arrangement problems. In addition, studies have emphasized the possession of prerequisite skills such as the identification of patterns by chess masters (Chase and Simon, 1973; deGroot, 1966).

Besides the initiation of detailed task analyses which Greeno's work suggests, perhaps the most important general point being made by this article runs as follows. Not only are there many specific kinds of problems to challenge human thinking, there are also different types of problems, requiring different combinations of intellectual processes. In order to understand human thinking, one must analyze the particular kinds of processing involved in each type of problem. Sometimes these processes are of a very general sort, such as the storage and retrieval of general knowledge. In other instances they may be very specific, such as skill in identifying patterns of letters or chess pieces. The variety and specificity of problem types argues against understanding human problem solving in terms of a single conceptual scheme, such as the employment of forms of logic suggested by Piaget (1970), or the presence of a small set of general abilities of thinking.

HUMAN CAPABILITIES IN PROBLEM SOLVING

It is evident from the preceding selective summary of problem-solving research and theory that this field of investigation is still in a stage of exploration and ferment. Despite this fact, it may be possible to draw some general conclusions concerning human thinking which reflect current knowledge. My intention in this section is to do the following two things: (1) state the general conceptions of human capabilities which appear to be present in problem solving, or which have emerged as likely conclusions from research on this topic; and (2) indicate the likely possibilities of the learnable nature of these capabilities. This account is preliminary to a later consideration of alternative ways of conceiving of "learnable aspects of problem solving."

Varieties of Human Capabilities

Current theoretical writing on human problem solving is plagued by a profusion of terms. Terms such as mental operation, processes, understanding, analysis, representation, construction, method, strategy, and the like are common in the information-processing literature on human problem-solving. Sometimes different terms have identical meanings, whereas sometimes the meanings are overlapping, rather than identical. I strongly believe that psychological thinking, as well as writing, would be improved by agreement on some terms for *different kinds of human capabilities* (Gagne, 1977). In considering this issue from the standpoint of instruction and its effect on human learning, I have found it desirable to distinguish five kinds of human capabilities, as follows:

1. Intellectual skill. Stored in long-term memory are capabilities that make it possible for the individual to carry out procedures with symbols (as contrasted with procedures that employ bodily movement). Intellectual skill is a general name for such capabilities, which include identifying classes of stimuli (sometimes called *concepts*) and applying relations among concepts (usually called *rules*). Possessing an intellectual skill means "knowing how," as opposed to "knowing that." Examples are the various operations of mathematics, the principles of science, the rules of syntax.

2. Verbal information. Knowledge of the world, specific and general, organized in various ways, is also a human capability. This is "knowing that." In its simplest form, it is the names of objects. In complex form, it is organized bodies of knowledge. Information is called "verbal," not because it is necessarily stored that way exclusively (although some theorists think so), but because it is exhibited

as verbal statements (propositions). The distinction of verbal knowledge from intellectual skill is an important one. While obviously the two types of capability may be associated in memory, the human performances they make possible are quite different. In one case (intellectual skill) the individual can do something; in the other, he can only talk about it.

3. Cognitive strategy. Human individuals possess capabilities which enable them to exercise control over their own learning and thinking processes, and by so doing, modify the ways in which these processes function in any particular instance. This kind of capability was given prominence as *executive control processes* in the theory of Atkinson and Shiffrin (1968), and is a feature of virtually all information-processing theories of learning and memory. As *cognitive strategy*, it appears in the work of Bruner (e.g., Bruner, Goodnow, and Austin, 1956). Cognitive strategies are capabilities that may control such processes as attention, the encoding and retrieval of learned material, as well as ways of thinking (cf., Gagne, 1977).

The distinction between intellectual skill and cognitive strategy as two different forms of human capability is of particular importance. An intellectual skill enables the individual to perform mental operations that make direct and specific reference to aspects of his environment. For example, constructing a set of four by combining one with a set of three is a relatively simple intellectual skill learned by young children. The three "things" and the four "things" may be sticks, marbles, pictured objects, or even numerals representing objects; in any case, the possession of the intellectual skill is inferred from manipulations of things in the child's environment.

It is possible, however, to present the individual with a task that requires him to construct, or to choose, a way of solving a problem. This *way* is the cognitive strategy. For example, a matchstick problem of the sort studied by Katona (1940) challenges the individual to make a pattern of three squares rather than the four originally displayed by moving only three matchsticks. Several different *strategies* are possible. An effective strategy (for all puzzles of this sort) is to move the matchsticks so that as many as possible will form squares with four sides unshared, rather than three or two. It may be noted, however, that the inference of human capability which is sought in this case is not simply that the individual can construct squares with matchsticks, or that he can distinguish four sides from three or two. These, of course, are intellectual skills which are assumed to be well learned. Instead, the task is presented to the individual in a manner which will reveal whether he can *select* and *use* a way of proceeding with this type of problem, i.e., select and use a cognitive strategy. The latter capability is controlling the *internal processes of thought*, even though the effects of this control are evidenced externally in the individual's environment. Not surprisingly, these effects also involve the use of previously learned intellectual skills; but this fact need not hinder the detection of the cognitive strategy which is being employed in solving the problem.

4. Attitude. The capability called *attitude* is a learned state that modulates the individual's choices of personal action toward some person, thing, or event. Obviously, one may acquire a positive attitude toward problem solving in general, as well as toward particular kinds kinds of problem tasks. At this point, little more need be said about attitudes.

5. Motor skill. This kind of skill is listed here simply to complete the set of five major varieties of human capabilities. Problem solving may, of course, require the use of motor skills in the attainment of a solution.

Why are these distinctions important to a discussion of problem solving? The reason is that, among the welter of terms used by various writers on human thinking, potential confusion is vastly reduced if the reader understands whether the reference is to intellectual skill, to verbal information, or to cognitive strategy. (Confusion over references to attitudes and motor skills is less likely, although not of zero probability.) Distinctions among the three "cognitive" kinds of human capability are important in a conceptual sense for the following reasons:

1. Each capability has a different theoretical function in information processing.

2. The overt human behavior (performance) made possible by each capability is different.

3. The conditions necessary for the learning of each type of capability are different.

The third of these three reasons may be seen as following from the first two. It is of particular relevance to the question of the learnability of human competence in problem solving, as will be shown later.

Involvement of Three Capabilities in Thinking

The studies and theoretical writings previously mentioned show clearly that intellectual skills, verbal information, and cognitive strategies are involved as human capabilities in the process of thinking (in the sense of problem solving). Some of the main points are mentioned in the following paragraphs.

Intellectual Skills

The involvement of intellectual skills in the performance of both concrete and formal operational tasks suggested by the work of Piaget has been shown many times. A number of studies, for example, have demonstrated that the prior learning of specific intellectual skills exhibits positive transfer to conservation tasks (Henry, 1978; Bucher and Schneider, 1973; Sheppard, 1973; Gelman, 1969; Wallach, Wall, and

Anderson, 1967), as well as to other problem-solving tasks (Bem, 1970, 1967; Lowery and Allen, 1969). Similar findings have been obtained when the focus of interest is scientific reasoning, or formal operations (Wollman and Lawson, 1978; Lawson and Wollman, 1976; Linn and Thier, 1975; Ring and Novak, 1971; Englemann, 1967).

Often, the cited studies have started out to discover what conditions may be employed to facilitate what is conceived (in Piaget's terms) as a transition from pre-operational to concrete operational thought, or from concrete operational thought to formal operations. The usual finding has been that the desired post-instructional performance depends on the acquisition of *prerequisite intellectual skills*. For example, children are shown to be able to conserve number by learning the number concepts involved in counting; adolescents are shown to be able to use proportional reasoning after learning rules of representing ratios of rod-lengths in symbolic form. In almost all cases, too, findings have shown that the generalizability of the capability thus learned is limited to the intellectual skill being taught. In general, the evidence shows that tasks of scientific reasoning can be learned by acquisition of the specific intellectual skills involved in them. When such learning occurs, transfer of learning is apparently limited to similar tasks. Such evidence calls into question the idea that a human ability as general as "formal reasoning" is the major factor responsible for the observed differences in human performance, in the manner suggested by Inhelder and Piaget (1958). In contrast, however, the evidence that intellectual skills (concepts, rules) are involved in tasks of scientific reasoning is substantial. It may be noted that this emphasis on "content" is seen by Johnson-Laird and Wason (1977) as implied in the recent writings of Piaget (1977).

Intellectual skills have usually been accorded a prominent role in problem solving, according to the various theoretical writings of psychologists. Associationist views provided for little else (except trial-and-error) than "responses," which can generally be interpreted in modern terminology as concepts or rules. Gestalt psychologists assumed the presence of "elements" to be reorganized, and in this case, too, the elements were concepts and rules. The idea of the "schema" in problem solving implies an organized memory structure which includes intellectual skills (cf., Greeno, 1976).

Information-processing views of problem solving emphasize intellectual skills as components of problem-solving, as the work of Newell and Simon (1972) and the writings of Greeno (1978) and Mayer (1977) suggest. For example, solutions to analogy problems have been shown to depend not only upon knowledge of words (one kind of verbal information), but also upon ability to use rules of English phonology (Mayzner and Tresselt, 1966). Solutions to cryptarithmetic problems clearly depend upon the possession of prerequisite skills of addition of multi-place numbers. In any of the investigations of problem solving belonging to this tradition, it would appear impossible to find even one that indicates solution by any sort of "sheer reasoning" alone. Intellectual skills, usually those learned prior to the presentation of the problem, are directly involved in the activity of problem solving.

Verbal Information

There appear to be no clearly identifiable studies of the influence of accessible verbal information on the performance and transfer of problems in scientific reasoning, such as those used by Inhelder and Piaget (1958). It is true that some studies have investigated variations in the verbal statements used to present the problem (this would be the "task environment," as defined by Newell and Simon, 1972). The question of human capability of interest here, however, is the extent to which problem solving is facilitated by the kind and amount of verbal information available in the individual's memory. For example, can the older student more readily conserve volume because he has available more factual knowledge about liquids, about cylinders, about the pouring of liquid, and so on? Is the student who makes reasonable hypotheses about the bending of rods helped in doing so by the organized verbal information he has stored about varieties of rods, varieties of metals, varieties of shapes, and instances of bending?

Although the examples may seem unusual, these are not idle questions. After all, the correlation of student performance on tasks involving thinking or reasoning with their performance in using verbal information (e.g., a vocabulary test) is likely to be fully as high as the correlation of thinking performance with age (cf., Yamamoto, 1964). The learning of an increasing store of meaningful propositions is considered by Ausubel, Novak and Hanesian (1978, p. 238) to be of critical importance to intellectual development. The integral role of semantic networks in thinking is a part of most accounts of information processing (Greeno, 1976; Norman, Gentner, and Stevens, 1976).

Problem-solving investigators of the information-processing view frequently emphasize the role of "general knowledge" in successful problem solution. The representation of the problem in problem space frequently can be shown to depend upon specific knowledge available to the individual. Verbal information is of course directly involved in word-anagram problems, since knowledge of words is inherently part of the problem. Many other kinds of problems, however, appear to be aided by verbal knowledge. For example, knowledge about the functions of the objects presented has been shown to affect performance in Maier's (1930) problems of pendulum and hatrack (Saugstad and Raaheim, 1960; Saugstad, 1955).

Besides verbal information's function in the initial understanding of the problem (Simon and Hayes, 1976), it is conceived to have a critical role in learning transfer in the form of "organized networks of propositions." The generalization of problem solving abilities presumably occurs to the extent that the <u>context</u> of problem tasks contains similar or identical cues. The context (task environment) in which one problem is solved contains a number of items of verbal information, including even information about the environment of the problem-solver which happened to obtain on that occasion. Cues made available by the retrieval from memory of this context of information presumably have considerable influence on the application of problem-solving strategies and skills to new problems occurring in new task environments.

Cognitive Strategies

There would seem to be little doubt that cognitive strategies are prominently involved in human problem solving. Examples of these strategies are the "forms of logic" described by Piaget (1970) and by Inhelder and Piaget (1958). A great many studies have indicated, either directly or indirectly, that different kinds of "logic" strategies are available to children at different age levels. Reviews of selected sets of these studies have been provided by Bryant (1974), by Case (1975), and by Levine and Linn (1977).

It is of some importance in conducting studies of scientific reasoning, and in interpreting such studies, to maintain the distinction between cognitive strategies and intellectual skills. As an example, in the study conducted by Lawson and Wollman (1976), two kinds of instruction were given to the subjects during a training session involving the task of bending rods. The youngsters were asked to classify the types of rods, and also to identify the factors affecting bending. Clearly, these are prerequisite *intellectual skills*. Proceeding from this point, the subjects made tests of rod bending using various weights, and were then asked questions designed to suggest "keeping all factors the same." Thus, this second function of instructions was to suggest (or to activate) a *cognitive strategy*. Acting together in training on a number of problem tasks, these factors were shown to produce gains in scientific reasoning as indicated by performance on later tasks chosen to represent similar levels of formal operational reasoning.

The role of cognitive strategies (identified by various names) is abundantly evident in the various tasks studied by psychologists (Mayer, 1977) as well as in information-processing theory. Newell and Simon (1972) refer to cognitive strategies as "methods," and clearly conceive them as being available to the problem solver from his memory store. Means-end analysis is a particularly common and valuable strategy employed in the solution of many kinds of problems (Greeno, 1978). Wickelgren (1974) describes a number of strategies useful in solving problems of a mathematical sort, including "classifying action sequences," "state evaluation and hill climbing," "defining subgoals," "deriving contradictions," and others. Strategies to be employed by children in solving detective-story mysteries have been identified by Olton and Crutchfield (1969).

Perhaps the most important point to be noted about cognitive strategies, in viewing the field of human problem solving as a whole, is their great variety and abundance. As factors in the achievement of problem solution, cognitive strategies range from extremely simple methods like "break the problem into parts" to relatively complex strategies like "means-end analysis," or the identification of "macro-actions" (Wickelgren, 1974). Within the broad field of strategies, or methods of attack, it would appear that the particular strategies involved in conservation tasks (e.g., ignoring perceptual similarities), as well as in tasks requiring certain forms of logic, constitute only a small set of the strategies that are potentially available to the problem-solver, whether child or adult.

PROBLEM-SOLVING CAPABILITIES AND LEARNING

In the previous section, I have been concerned to summarize and interpret the evidence which indicates the involvement of three kinds of capabilities in human thinking of the problem-solving variety: intellectual skills (concepts, rules), verbal information ("knowledge"), and cognitive strategies. It should now be possible to discuss the question of the learnability of these forms of human capability.

Learning-Intellectual Skills and Verbal Information

Intellectual skills and verbal information are both clearly learnable. Together they constitute the largest part of the school curriculum in grades K-12. Emphasis is usually given to "basic skills" in the early grades, as children learn the concepts and rules of their language and of arithmetic. When proficiency is attained in reading, the learning of organized, meaningful verbal information is vastly facilitated. Thus, although the acquisition of intellectual skills is continued, the accumulation of stores of knowledge comes to be increasingly represented as a goal of schooling in the upper grades.

Not only is the learning of intellectual skills and verbal knowledge a highly apparent fact, it may also be said that a good deal is known about how such capabilities are learned (Gagne, 1977). The conditions necessary for learning of these capabilities are fairly well known, and these conditions can be employed with some degree of precision in the design of instruction (Gagne and Briggs, 1974). The problem-solving abilities of school students need not be hampered by a lack of acquired intellectual skills or verbal knowledge. If such turns out to be the case, as is sometimes suggested, the cause is most likely to be a failure to recognize that *human problem solving requires prerequisite skills and knowledge*. Ability to solve problems cannot be learned in some abstract, isolated fashion. A similar statement applies to creative thinking, which, as we have seen, differs from problem solving only in degree along certain dimensions. Learning in both cases must make use of *content-relevant* elements, which are intellectual skills and verbal information.

The Acquisition of Cognitive Strategies

In contrast to the definitive knowledge available concerning information and skills, systematic conceptions of how cognitive strategies are acquired and used are much harder to come by. There are puzzling aspects to cognitive strategies which have not yet yielded to research and theory. On the one hand, particular cognitive strategies often appear to be very simple mental operations, readily acquired. For example, a simple instruction to children to "plan each step in terms of its relation to the goal" can bring about a remarkable change in problem-solving performance (Pellegrino and Schadler, reported in Resnick and Glaser, 1976). On the other hand, the spontaneous employment of just the right strategy at just the right time is what seems to represent the primary source of difficulty in problem solving, responsible for low success rates (cf., Blasi and Hoeffel, 1974; Karplus and Peterson, 1970).

Set in Problem Solving

The use of a particular strategy in problem-solving often appears to be dependent upon the establishment of a *set*. As employed in writings on problem-solving, a set is a mental state that may be activated by some stimulus and that persists in "working memory" (Bower, 1975) during the time the problem is being worked on (Newell, Shaw, and Simon, 1962). The set may be initiated as a result of stimuli provided by the problem solver himself, or by a stimulus provided in his external environment. In the latter instance, it may be said that the set is "suggested," or "activated," by instructions. The effect of the set is to activate a cognitive strategy that persists during the time the processes of problem solving are being employed. For example, a set in the working memory may be used by the problem solver to "keep in mind" a strategy such as "define the subgoals."

Cognitive strategies of many types, pertaining to such processes as attending, encoding, and retrieving, have been activated by the simple means of giving verbal instructions, which presumably have the effect of activating relevant sets. A procedure of this sort has been shown to be effective with young children, as well as with older children and adults (Gagne, 1977). Critical summaries of research in this field have been presented by Brown (1975) and by Flavell (1977). Some of the kinds of set-induced strategies which may be relevant to problem solving are discussed by Flavell (1976).

In problem-solving studies, examples of the effects of sets induced by instructions are many. The verbal hints given to Maier's (1930) subjects in "hatrack" and "pendulum" problems were said to supply "direction" and were capable of greatly increasing the probability of solution. In his study using matchstick problems, Katona (1940) found two different sets to be effective, as activated by instructions either (a) to open as many gaps as possible in the matchstick pattern, or (b) to decrease the number of sticks serving as sides of squares. The various strategies described by Wickelgren (1974) are obviously capable of being established by verbal suggestion to the problem solver, assuming that he has previously acquired their meaning as strategies ("state-evaluation," "identifying subgoals," etc.). As a generally applicable strategy, Crovitz (1970) describes the use of lists of relations between elements of the problem, as a means of discovering the crucial relationship which represents the solution. Simon (1975) describes a number of quite different strategies that can be used to solve the Tower of Hanoi problem, each of which might be activated by a set suggested by verbal instruction.

It is not unreasonable to speculate that "training" in problem-solving strategies may in some instances be simply a matter of establishing a set. That is to say, experimental conditions having the intention of effective learning may instead only activate a set, which fails to persist after the particular problem is solved. In their initial study of productive thinking, it is notable that Crutchfield and Covington (1965) observed that some of the strategies involved in solving detective mysteries appeared to be activated by brief exposure to problems, rather than being acquired as learned capabilities. The problem solving of even young children has been shown to be markedly affected by external suggestions, usually of a verbal sort (Bem, 1970, 1967; Huttenlocher and Strauss, 1968). Mehler and Bever (1967) found that an externally-induced set brought about conservation of number in a high proportion of a group to children of age two and a half. A recent review by Gelman (1978) cites a number of studies indicating that brief verbal instructions can bring about successful solutions of cognitive problems by young children.

The impression gained from the evidence regarding cognitive strategies in problem solving runs somewhat as follows. Specific problems, besides calling upon the problem solver's knowledge and skills, typically require one or more cognitive strategies for their solution. Strategies may be relatively simple and concrete (like mental rehearsal) or they may be quite complex and abstract (like seeking contradictions). Assuming they are known to the problem solver as procedures ("methods"), strategies can often be put into effect by activating a set. This may be done, and usually is, by the presentation of external verbal instructions. Alternatively, the problem solver may provide the cues from his own memory which activate the set. As a state in working memory, the set functions to maintain the "direction of thought" of the problem solver during the time he is actively at work on the problem. That is to say, the set brings into play a cognitive strategy which is a method considered (by the problem solver) to be relevant to the solution of the problem. Should the method fail, another set-induced strategy may be adopted, until solution is achieved. Once the problem is solved, the non-persistent nature of the set implies that it will disappear from working memory.

The evidence from problem-solving studies makes it seem most likely that there are many, many different cognitive strategies. Those implied by the "forms of logic" would appear to be only a small portion of the total number. It is, of course, a key feature of Piaget's theory (1970) that the particular strategies represented by these logical operations constitute the fundamental elements of intellectual development. An alternative view does not necessarily deny the significance of logical operations as cognitive strategies in human thinking; rather, it looks upon these particular strategies as a somewhat special but small group among the many possible. Success in specific conservation tasks can be improved, it seems likely, by direct instruction having the purpose of activating a set-induced strategy relevant to the problem. Children asked to conserve number, for example, may be instructed to count the objects presented; those confronted with liquid-volume conservation tasks may be instructed to ignore the heights of the particular liquid containers employed. Similarly, success in *specific* problems of proportional reasoning and controlling variables can most probably be induced by set-activating instructions relevant to the problems presented. Notable in this connection is the prominence of verbal instructions such as those describing a "fair test" in the training employed in Lawson and Wollman's (1976) study which resulted in the finding of "specific transfer" of procedures of controlling variables in fifth-grade students. Commenting on studies of problem solving in science programs, Levine and Linn (1977) conclude that once children are "alerted" to the ideas of controlling variables, they can apply these ideas in a number of particular situations.

The idea that problem solving performance is markedly influenced by set-induced strategies is subject to two important constraints. First, it may be noted that the strategy activated by a set is *specific*, not general. For a particular problem, adopting the method of working backwards may be the right strategy; for another problem, identifying contradictions may be the relevant method. As an example, despite its relation to more general Gestalt principles, "opening gaps" is a strategy highly specific to particular matchstick problems. Thus, conceiving of problem solving as critically dependent upon relevant cognitive strategies does not in itself answer the question of how to improve students' rational powers, when these are defined in a general sense. Particular strategies may readily be induced for particular problems. There remains the problem of how such strategies can be applied generally and in an adaptively selective fashion by the human individual, faced with a great variety of problems during his lifetime.

A second limiting condition surely applies to the employment of strategies in human problem solving. The procedure that constitutes the strategy must itself be understood, in order for it to be activated by a set. If the verbal direction is "try counting," or "plan each move in terms of the final goal," or "work backwards," or whatever, it is clear that the problem solver must know the meaning of these verbal statements. That is to say, he must be able to make application of the component concepts and rules which make up the procedure of the strategy. Sometimes, of course, these skills are very simple ones, and can be assumed as having been previously learned. In the case of children, however, the prerequisite skills and verbal information involved in a particular strategy may have to be learned before one can expect the latter to be maintained by a set.

CONTRASTING VIEWS OF HUMAN THINKING

An information-processing view of human thinking appears to me to imply that certain kinds of human capabilities, stored in human memory, are retrieved and brought to bear upon a problem as conceived by the problem solver. These capabilities include intellectual skills, verbal information, and cognitive strategies. The first and second of these types are clearly learnable, and, as necessary conditions for thinking, deserve the emphasis they receive in formal education. The third, cognitive strategies, include learnable procedural components, but are most clearly controlled by non-persistent mental states called sets.

Activation of a set which maintains a particular strategy is readily accomplished. Typically, it is done by brief verbal instructions; or it may be induced by the problem solver himself, from cues accessible in his memory. It is possible that what often appears as the learning of strategies is really the activation of sets. Research studies should surely be designed to control the variable of set, when learning is the focus of interest.

The Ability View of Thinking

It would appear that a commonly accepted, but usually implicit, view of human capabilities in thinking runs somewhat as follows. Individuals learn certain verbal information, and a good many intellectual skills, which enable them to perform many kinds of tasks. Many of these performances are "routines," having a "memorized" character. They can be described as "algorithms."

Thinking, however, is a kind of activity which requires that the individual bring to bear still another kind of disposition, often called an *ability*. In the ability-measurement tradition, "creative ability" is a complex that includes such component abilities as "divergent thinking," "originality," "convergent production," "comprehending relations," and many others (cf., Barron, 1968; Guilford, 1965; Guilford and Merrifield, 1960). In the Piagetian tradition, concrete-operational and formal-operational reasoning may be conceived as two *abilities* which become available to the individual at different ages.

However they may be described, it is these abilities which make thinking possible, and which determine success attained by problem solvers in tasks of scientific reasoning, problem solving, and creative thinking. Usually, abilities are conceived as being maturationally determined, although they require interaction with environmental factors for their proper development. Abilities, in this view, are considered to be very general in their applicability to a great variety of problem-solving tasks. Success in problem solving is viewed as resulting primarily from the application of relevant abilities (originality, divergent thinking, formal operational reasoning) to a problem situation, regardless of its specific features. Thus, among those who employ this conception, there is agreement concerning the generalizability of thinking abilities, although there may be differences in views about their learnability.

An Alternative View of Thinking

It appears to me that the information-processing view of cognition makes possible, and indeed favors, a conception of human thinking which is at variance with the "ability" view just described. It utilizes a set of ideas that I consider worthy of further attention in pursuit of research on human problem solving, and indeed in their suggestion of a model which is relevant to educational practice.

Such a conception begins by addressing the question of what kinds of human capabilities are *not* learnable. These are usually called *capacities*. Sensory and motor capacities (like visual acuity and strength of grip) come to mind as examples of human functions that are not influenced by learning. Cognitive capacities, presumably, are such things as speed of concept recognition, capacity (size) of short-term memory, speed of code translation, number of entities differentiable in memory, and others of this sort (cf., Hunt, 1976). Some basic set must surely be identifiable of human capacities, the limits of which are not subject to change through learning.

Abilities as measured by typical ability tests, however, are a mixed bag. Sometimes they do partake of innately determined capacities, but they rarely attempt to measure them directly. Most often, ability tests are mixtures of human performances that are partly intellectual skills and partly verbal information. In addition, cognitive strategies are prominently involved, as shown by the fact that scores on almost any ability test can be improved by giving the examinees pre-instructions that describe a specific strategy of "how to do it." There is, therefore, no mystery as to why ability tests exhibit moderate degrees of correlation with problem-solving behavior. They correlate to the extent that the tasks involve the same information, the same or closely similar intellectual skills, and sometimes the same cognitive strategies.

Learning to be a good thinker, in my view, means first learning the prerequisites, which are intellectual skills and verbal information. Intellectual skills are essential prerequisites because they are actually involved in the "production" of the problem solution. To solve a problem of proving a theorem about the length of the hypotenuse of a right triangle, one must already have the skills of constructing right triangles, identifying their parts, and understanding squares. To solve matchstick problems, one must know the prerequisite intellectual skills of identifying spatial "gaps," or of selecting "double function" matchsticks.

Verbal information is also a valuable and learnable prerequisite to human thinking, but for reasons that are somewhat different. The knowledge available to the problem solver makes it possible for him to "define the problem," or, as Newell and Simon (1972) put it, to "represent the problem space." Additionally, the store of knowledge available to the individual may be seen to be an important determiner of transfer of learning. How readily does the problem solver transfer his knowledge to new situations? This generalizability may be determined, not by what "ability stage" he has reached, but rather by the kind and amount of organized verbal knowledge in his memory. It is conceivable that transfer occurs because the new situation, with its problem, can be related to a complex of knowledge by way of identical elements, class inclusion, analogies, and related means.

The learnable factors in human thinking described thus far may be *specific*. They may be as specific as the rules of syntax and mathematics; and as specific as the knowledge about particular objects and events in the world may be. The third kind of human capability involved in human thinking enters into the process, I believe, in an equally specific way. There must be a great many kinds of cognitive strategies, each of which may determine a "method" to be used by the problem solver. Cognitive strategies are not general in their nature (as in "originality"), but specific (as in "make a note of the outcome of each step before proceeding to the next"). Furthermore, as contributors to the solution of specific problems, they are readily established as sets, either by the presentation of simple instructions or by self-initiation of the problem solver. This means that in studies that purport to "train" them, cognitive strategies are not usually learned, in the typical meaning of that word. They are simply activated. (Some of the intellectual skills that make up their procedures may be learned, but this point has already been made.)

What kind of education does it take, then, to become a productive thinker, a successful problem solver? A part of the answer is, it takes learning of stores of knowledge about the world (verbal information) and the understanding and mastery of intellectual skills ("knowing how" to represent the world and manipulate it symbolically). As for cognitive strategies, simply acquiring and storing a set of these is not sufficient to assure better thinking on new, previously unencountered problems. The individual must not only have acquired a variety of strategies, he must also be able to *select* the particular ones that match his particular problems. Insofar as this adaptive capability is learnable, it must be based upon a *variety of experience* in problem solving. The key word here is experience, which of course increases with age. For those who continue to be active learners (and not simply attendees) during school years, experience in continuing to meet and solve problems of a variety of sorts will leave a residue of accessible strategies, and also an adaptability which favors the use of the right strategy for the right problem.

The kind of educational practice implied by this analysis bears a resemblance to that advocated by Bruner (1960, 1971), Kestin (1970), Ausubel (1968), and many others. Procedures of instruction aimed at encouraging the development of good thinking will provide frequent opportunities for practice in the display of ingenuity, inventiveness, and creative enterprise. They will do this, however, within an instructional framework of skills and knowledge that provide the essential prerequisites for human thinking, the content of the thought itself, and also the semantic context that makes possible the generalizing of problem-solving capabilities.

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TEACHING FOR THINKING AND CREATIVITY:
A PIAGETIAN POINT OF VIEW*

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INTRODUCTION

Do I view the Educational Policies Commission's "10 rational powers" as "fundamentally important aspects of intellectual functioning"? Although these are important aspects of intellectual functioning in adults, I do not believe that they are the most fundamental processes to identify when considering thinking and creativity in science education.

I cannot go along with the "10 rational powers" as fundamental for two reasons. The first is that thinking cannot be divorced from knowledge, and knowledge involves the mind as a whole. To be of any value to educators, "fundamentally important aspects of intellectual functioning" must be conceptualized as a coherent whole. The five pairs of processes ("recalling and imagining," "classifying and generalizing," "comparing and evaluating," "analyzing and synthesizing," and "deducing and inferring") are juxtaposed aspects of thinking, and their interrelationships must be shown in relation to knowledge.

The second reason is that the "10 rational powers" reflect a lack of awareness that children think very differently from adults, and that in childhood they develop processes that are more fundamental than the "10 rational powers." I would like to take "recalling," the first item of the list, as an example to show what I mean. According to Piaget, ability to "read" what is observable in external reality depends on operations, which will be discussed shortly, and the totality of knowledge that one brings to a situation. When observable facts are beyond the child's comprehension, he reads them at his level by assimilating them into everything he knows, thereby deforming them considerably. Since recall is memory of what we read from reality, the accuracy of our memory is greatly influenced by what we apprehended in the first place.

Here is an example from the many empirical studies reported in Piaget and Inhelder (1968), a volume on the relationship between memory and the development of operations. In this study, Voyat presented the child with two U-shaped glass tubes filled with colored water as shown

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in Figure 1. (The tubes were glued onto cardboard and presented vertically to the child.) He first told the child that he would show him something briefly and then ask for a description and a drawing of it from memory. After showing the tubes to the child for 45 seconds, Voyat asked for a description and a drawing. The five levels found among the drawings of 60 children between the ages of 4 and 15 are shown in Figure 2. The first level is characterized by the absence of differentiation between the container and the liquid contained. IA and IB show only the container, while IC shows only the liquid. At level II, there is differentiation between the container and content, but the four levels of liquid are all the same. At level III, on the other hand, both tubes have unequal levels. Level IV is characterized by a clear differentiation between the two tubes, but there are various errors such as the absence of the stopper in IVC. Level V, finally, corresponds accurately to the objects in external reality that all the children had looked at.

In Table 1, we can see a relationship between children's ages and the precision and accuracy of their drawings. Four- and five-year-olds are mainly at level I, whereas older children are at levels IV and V. The skeptic may argue that these levels do not indicate the accuracy of children's observation but their ability to draw, which improves with age, but multiple choice among 12 drawings gave the same results. Although recognition is usually easier than recall, it did not change the children's levels in this particular task.

Table 1

Relationship between Age and Level of Immediate Recall

Age \ Level	I	II	III	IV	V
4-5	12 (54%)	6 (27%)	2 (9%)	2 (9%)	0 (0%)
6-7	4 (22%)	4 (22%)	1 (5%)	8 (44%)	1 (5%)
8-15	0 (0%)	1 (5%)	1 (5%)	9 (45%)	9 (45%)
Total	16 (26%)	11 (18%)	4 (6%)	19 (31%)	10 (16%)

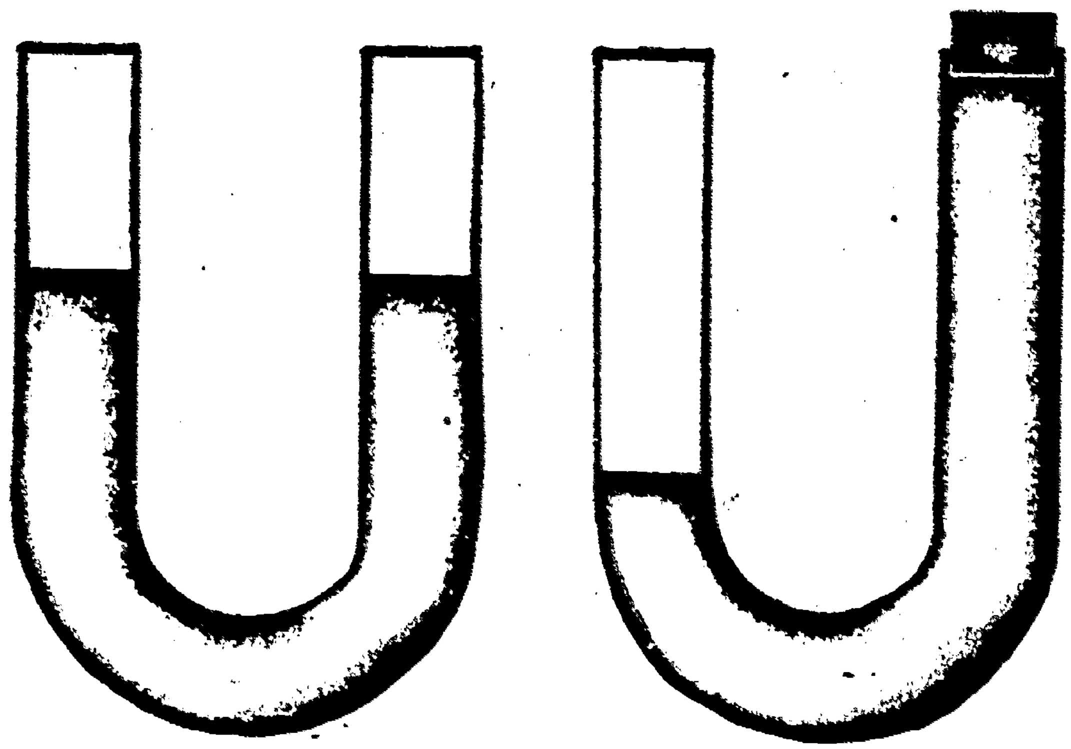


Figure 1
The Glass Tubes Filled with Colored Liquid Used in the Memory Task

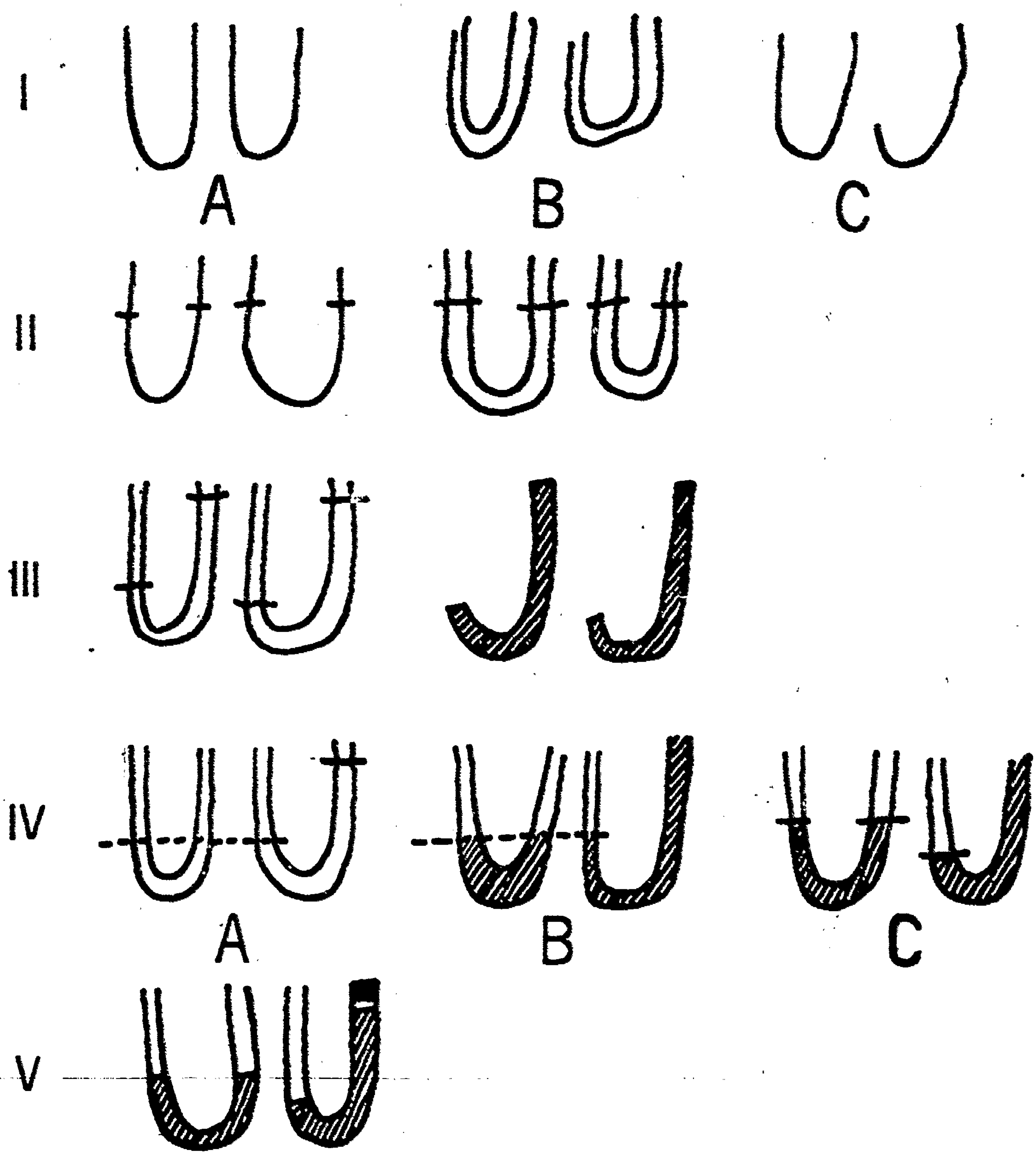


Figure 2
Children's Drawings in Immediate Recall

I hope the reader will be able to see after reading the section on operations which appears later in this chapter that it is operations that enable children to read from reality that the tube to the left has equal levels and no stopper, while the tube to the right has unequal levels, a stopper, and the same amount of liquid as the other tube.

Piaget speaks of each one of the "10 rational powers" but in a vastly different way. His conceptualization of these processes is much more adequate than the juxtaposed list of the Educational Policies Commission. The following discussion will begin with the epistemological background of Piaget's theory (a) to show the relationship between the "rational powers" and knowledge and (b) to take Piaget's theory as an example of how a scientific theory evolved in trying to explain where knowledge comes from. Scientific theories evolve by constantly reinterpreting old empirical "facts" (i.e., knowledge in this particular example). (Although Piaget's theory is a biological theory of knowledge, the biological part is omitted from this chapter because of limitation in space. The reader is referred to Piaget (1967) for further details.) The chapter will then focus on constructivism, with an emphasis on operations and the evolution of science. After this theoretical discussion, the paper will conclude with some principles of teaching that can be derived from Piaget's theory.

Before turning to epistemology, however, I would like to point out that scientific thinking is not limited to rational thought. It also involves passion, intuition, intellectual leaps, conviction, confidence, and ability to exchange views with others as well as the courage to have ideas that are different from other people's. Without some irreverence for authority and tradition, and without the drive to prove or disprove a theory, or to attain a difficult goal, there would be no science or engineering, and not much thinking or creativity. A psychological theory of thinking and creativity in science education must, therefore, not be limited to cognition. However, as I am not even sure what creativity is, this chapter will deal mostly with thinking.

EMPIRICISM, RATIONALISM, AND PIAGET'S THEORY

Piaget is often believed to be a developmental psychologist, but psychology is only a small part of his work. He is actually an epistemologist, and studied the development of thought in children because he was convinced that this was the best scientific method of answering old epistemological questions such as "How do we acquire knowledge?" and "How can we be sure that what we think we know is true?"

Since these fundamental questions of knowledge are involved in scientific knowledge and science education, philosophers' answers to these questions will be reviewed briefly. Philosophers have debated for centuries about how human beings attain truth, or knowledge. Two main currents--the empiricist and rationalist currents--developed in answer to this question.

Empiricists (such as Locke, Berkeley, and Hume) argued in essence that knowledge has its source outside the individual, and that it is internalized through the senses. They further argued that the individual at birth is like a clean slate on which experiences are "written" as he grows up. As Locke expressed in 1690,

> The senses at first let in particular ideas, and furnish the yet empty cabinet, and the mind by degrees growing familiar with some of them, they are lodged in the memory . . . (1947, p. 22).

Rationalists such as Descartes, Spinoza, and Kant did not deny the importance of sensory experience, but they insisted that reason is more powerful than sensory experience because it enables us to know with certainty many truths which sensory observation can never ascertain. For example, we know that every event has a cause, in spite of the fact that we obviously can not examine every event in the entire past and future of the universe. Rationalists also pointed out that since our senses often deceive us in perceptual illusions, sensory experience cannot be trusted to give us reliable knowledge. The rigor, precision, and certainty of mathematics, a purely deductive system, remains the rationalist's prime example in support of the power of reason. When they had to explain the origin of this power of reason, rationalists ended up saying that certain knowledge or concepts are innate and that they unfold as a function of maturation.

Piaget's theory was born out of his objection both to empiricism and to rationalism, and it is a synthesis of the two as shown in Figure 3. One way to clarify this synthesis is by comparing it (the outer oval) with the overlap between the two circles inside that represent empiricism and rationalism. The overlap refers to the fact that empiricists recognized the importance of reason, and rationalists recognized the importance of sensory input. The disagreement emerged when people had to decide on the relative importance of observation and reason to attain truth. Piaget's theory is different from this overlap in that it states that observation and reason are not just important in such a juxtaposed way, but that the two are mutually dependent, as one cannot take place without the other.

Even to recognize a yellow wooden object as a pencil, for example, we must have a classificatory scheme that enables us to think of the yellow wooden object as being different in some important way from other kinds of objects we know. (This statement is different from saying that to recognize a pencil as a pencil, we must have the "concept" of a pencil. The latter states that the pencil in external reality must correspond to a "concept" in our head. Piaget states that the positive "concept" can exist only in relation to the negative elements, namely "everything else.") If we did not put the pencil into relationship with our previous knowledge, the pencil would remain isolated in our mind and unrelated to everything else. To recognize the yellowness of the pencil, too, we must have a classificatory framework that enables us to distinguish "yellow" from other colors. It is thus only by putting things into relationships that we can "read" empirical facts from reality.

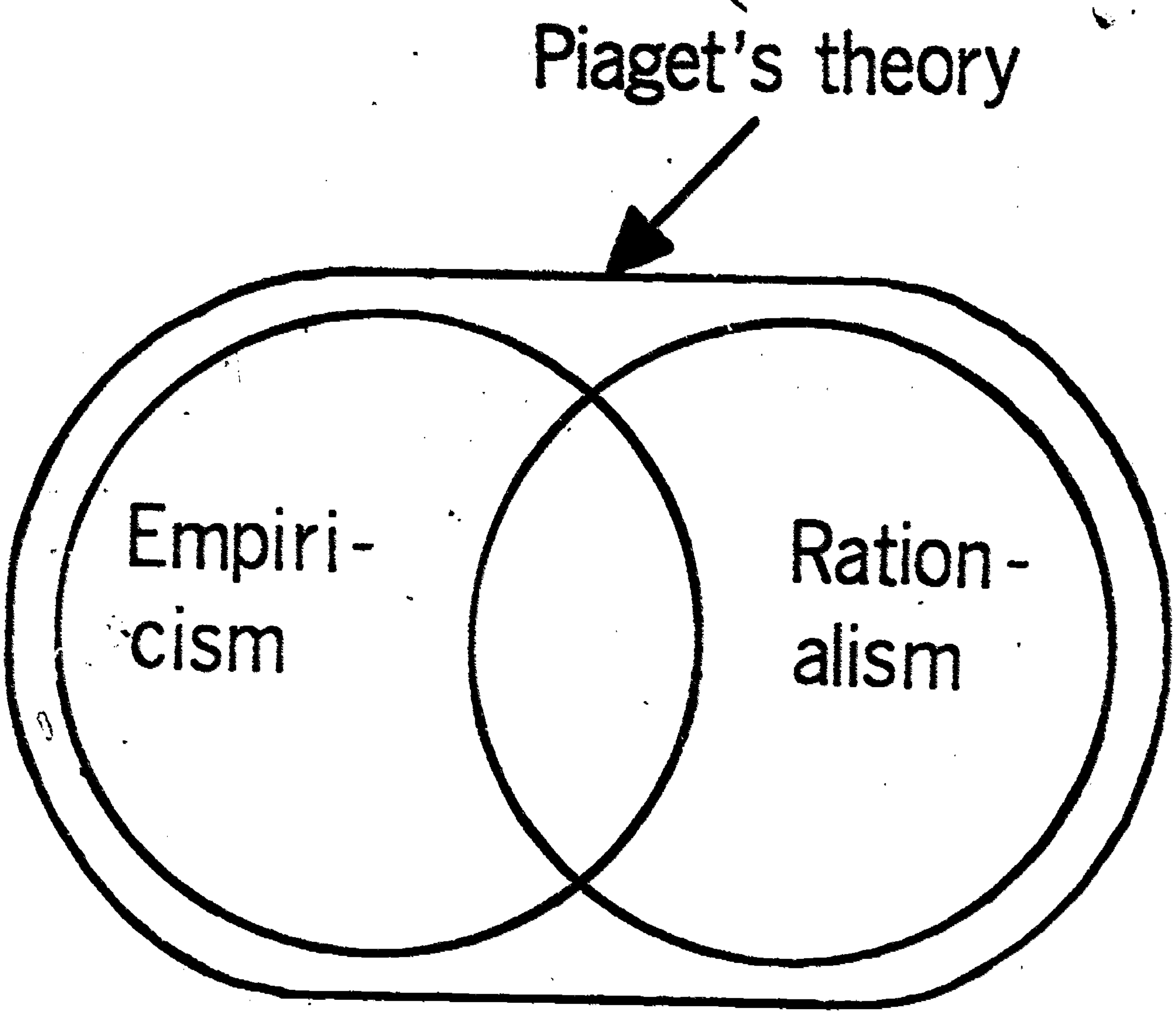


Figure 3
Piaget's Theory in Relation to
Empiricism and Rationalism

It will be shown later in this chapter that, conversely, reason could not develop without sensory information either because, without objects to put into relationships, the logico-mathematical framework could not develop.

Piaget thus felt that the empiricist view of the sensory nature of knowledge was inadequate. He also could not agree with the rationalist belief in the innate origin of reason. The originality of his work was that (a) he decided that epistemological questions had to be answered scientifically rather than by philosophical speculation; (b) he was convinced that the best scientific method of answering these questions was by studying the development of knowledge in children; (c) he formulated constructivism as a hypothesis; and (d) he invented ingenious methods of collecting data. These are all examples of creativity in science.

Psychologists and educators speak of teaching and learning without asking basic epistemological questions such as "Where does knowledge come from?" and "How does the child build it?" In the next section, I will discuss Piaget's answer to the first question. The second question will be addressed in the section that follows entitled "Constructivism."

PHYSICAL, LOGICO-MATHEMATICAL, AND SOCIAL KNOWLEDGE

In Piaget's theory, there are three types of knowledge--physical, logico-mathematical, and social (conventional) knowledge--that can be distinguished according to their ultimate sources and mode of structuring. It is important to keep in mind, however, that this trichotomy is only a theoretical distinction. In the psychological reality of the child, according to Piaget, the three types of knowledge exist together, indissociably, except in pure math and logic.

Let us first focus on physical and logico-mathematical knowledge. Physical knowledge is knowledge of objects that are "out there" and observable in external reality. Knowing the fact that a ball bounces when it is dropped on the floor, while a glass usually breaks, is an example of physical knowledge. The weight and color of an object are also examples of physical knowledge. The source of physical knowledge is thus mainly in the object, i.e., in the way the object provides the subject with opportunities for observation.

Logico-mathematical knowledge, on the other hand, consists of relationships which the subject creates and introduces among objects. An example of a relationship is the difference between a blue block and a yellow one. The relationship "different" exists neither in the blue block nor in the yellow one, nor anywhere else in external reality. It exists only in the head of the person who puts the objects into this relationship, and if the person could not create this relationship, the difference would not exist for him. The person can also put the two blocks into the relationship "same" (because the blocks are both blocks). The sameness here again exists neither in one block nor in the other, but in the head of the person who considers the objects as being the same. He can also put the blocks into the relationship "two," which does not exist *in* the objects.

The child's answer to the famous class-inclusion task shows the extent to which he can coordinate relationships of sameness and difference that *he* creates and introduces among the objects. In this task, the child is given six blue blocks and two yellow ones, for example, and is first asked, "What do we call these?" so that the examiner can proceed with whatever word came from the child's vocabulary. If the child says, "Blocks," he is asked to show *all* the blocks. The examiner then asks the child to show "*all* the blue blocks" and "*all* the yellow blocks." Only after thus ascertaining the child's understanding of these words does the adult ask the following class-inclusion question: Are there more blue blocks or more blocks?"

Four-year-olds typically answer, "More blue ones." The examiner thereupon asks, "Than what?" The four-year-old's typical answer is "Than yellow ones." In other words, the question the examiner asks is "Are there more blue blocks or more blocks?" but the one young children "hear" is "Are there more blue blocks or yellow ones?" Young children hear a question that is different from the one the adult asked because once they mentally cut the whole into two parts, the only thing they can think about is the two parts. For them, at that moment, the whole no longer exists. They can think about the whole, but not when they are thinking about the parts. In order to compare the whole with a part, the child has to do two opposite mental actions at the same time --cut the whole into two parts and put the parts back together into a whole. This is precisely what four-year-olds cannot do.

By eight years of age, most children's thought becomes mobile enough to be reversible. Reversibility refers to the ability to mentally do opposite actions simultaneously--in this case, separating the whole into two parts and reuniting the parts into a whole. In physical, material action, it is not possible to do two opposite things simultaneously. In our heads, however, this is possible to do when thought has become mobile enough to be reversible. It is only when the parts can be reunited in the mind that it is possible to "see" that there are more blocks than blue ones.

Social (conventional) knowledge, the third type, was implicitly but unmistakably delineated by Piaget (1932) without being designated by a name. Examples of social knowledge are the knowledge that there is no school on Saturdays and Sundays, that December 25 is Christmas Day, that a block is called "block," and that one sometimes shakes hands with another person. These truths have their ultimate source in the conventions worked out by people.

Social and physical knowledge are similar in that they are both knowledge of content and have their sources mainly in external reality. I say "mainly" because the two are constructed not directly from external reality but from within through a logico-mathematical framework in interaction with the environment. Without a logico-mathematical framework, the child would not be able to understand any convention just as he would not be able to recognize a yellow wooden object as a pencil. For example, to understand that certain words are considered "bad," the child has to distinguish between "bad words" and "words that are O.K." To understand that there is no school on Saturdays and Sundays, to cite another example, the child has to structure events into "days," dichotomize the days into "school days" and "days when there is no school," and coordinate this dichotomy with the cyclic order of seven different days.

The reader may have noticed that physical and social knowledge is mainly empirical knowledge. Logico-mathematical knowledge represents the rationalist tradition.

CONSTRUCTIVISM

From the first day of life, the child constructs his knowledge in an organized way with two frameworks—a logico-arithmetical framework and a spatio-temporal one. I will discuss in this section the child's construction of these frameworks to show the coherence of knowledge as a whole and its relationship to "operations," scientific concepts, and theories on the one hand, and to the "10 rational powers" on the other. The section will conclude with a discussion of how operations develop so that principles of teaching based on the child's natural development can be conceptualized.

The Logico-Arithmetical and Spatio-Temporal Frameworks

The logico-arithmetical framework has already been alluded to when I discussed the necessity of a classificatory scheme to recognize a yellow wooden object as a yellow pencil, and a school day as a school day. The term "logico-arithmetical" is used here rather than "logico-mathematical" because mathematics includes geometry, which belongs to the spatio-temporal realm. The logico-arithmetical framework is thus part of logico-mathematical knowledge and is independent of the spatial and temporal organization of objects and events. For example, there are more blocks than blue ones in the world, and more animals than cows, regardless of how these are arranged spatially on various continents of the globe. Time is likewise irrelevant to logic and, in fact, it interferes with logic. In the class-inclusion task, for example, it is when the child can think simultaneously of the large group and subgroups that he can give a logical answer. As long as he can think only successively of the parts and the whole, he continues to give the preoperational, prelogical answer. As long as he can think of the following five relationships only successively, the child can likewise not seriate ten sticks logically by coordinating all the relationships into one coherent system (i.e., $A<B<C<D<E<F<G<H<I$: $C<F$, $B<I$, $E<H$, $D<J$, and $A<G$). In adolescence and adulthood, the person who cannot think of many hypotheses simultaneously cannot test one after another systematically. Ability to think about many things simultaneously can thus be said to be essential for well coordinated, rational thinking.

Having argued that the logico-arithmetical framework is independent of space and time, I would now like to state that all objects and events exist in space and time. To know objects and events, therefore, we need not only a logico-arithmetical framework but also a spatial framework and a temporal one. Without a spatio-temporal framework, the regularity of events could not be read from reality and causality could never be understood. (Without a spatio-temporal framework, there would be no history or geography either.)

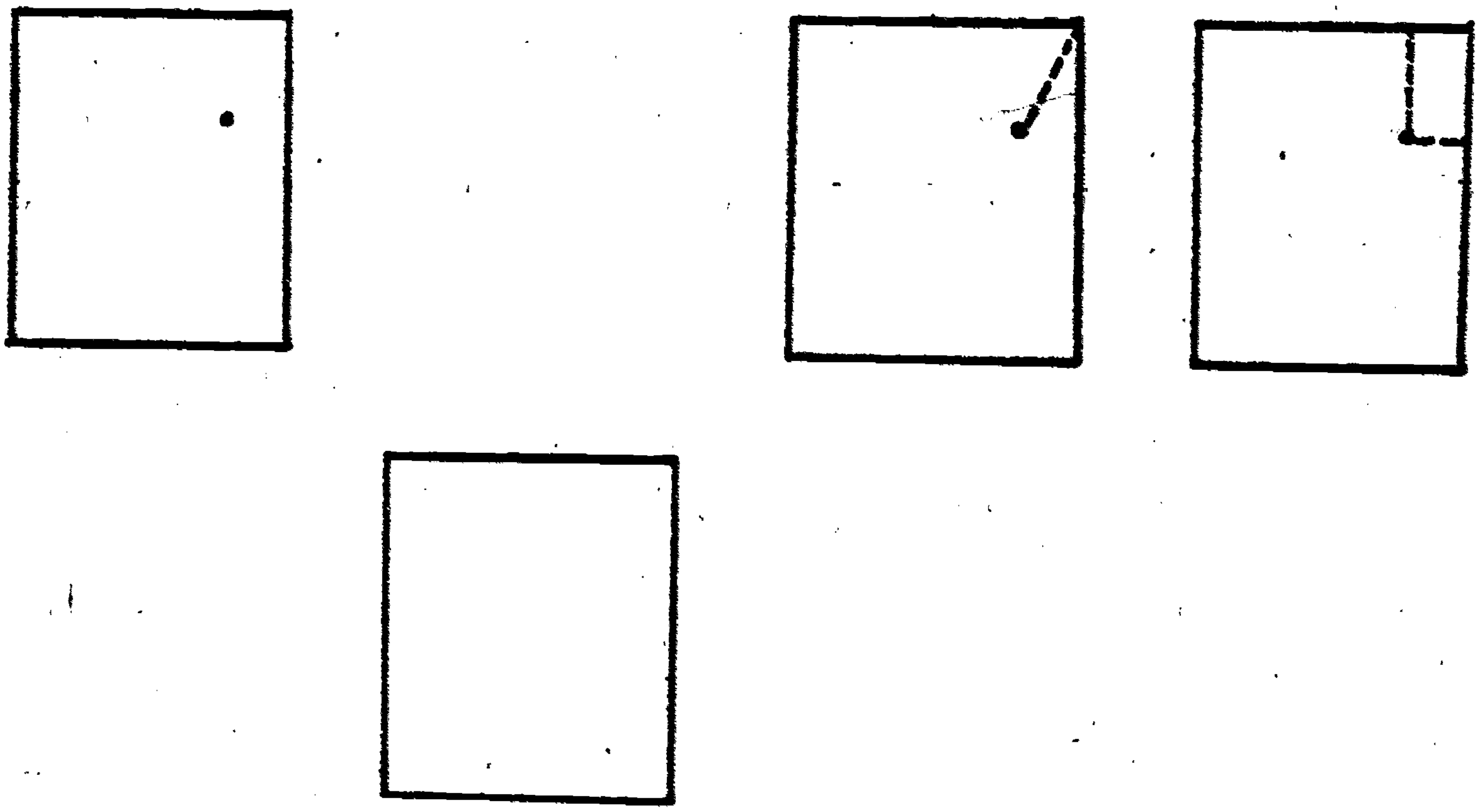
One of the unique contributions Piaget has made to epistemology is that he showed scientifically, by systematically collecting data, that these frameworks are neither innately in the child nor transmitted from the environment, but that each individual constructs them in interaction with the environment. Evidence of the construction of the logico-arithmetical framework can be found in The Early Growth of Logic in the Child (Inhelder and Piaget, 1959), The Growth of Logic from Childhood to Adolescence (Inhelder and Piaget, 1955), and The Child's Conception of Number (Piaget and Szeminska, 1941). The construction of the spatial framework can be seen in The Child's Conception of Space (Piaget and Inhelder, 1948), The Child's Conception of Geometry (Piaget, Inhelder, and Szeminska, 1948), and Mental Imagery in the Child (Piaget and Inhelder, 1966). In The Child's Conception of Time, Piaget (1946) showed that the temporal framework, too, is constructed by each child.

Let us look at how four-year-olds handle temporal relationships before constructing a coherent, deductive system of time. Piaget asked a typical four-year-old, "Who will be the older of you two when you grow up, you or your baby sister?" The answer was "I don't know." The rest of the conversation went as follows:

> Is your granny older than your mother? *No.* Are they the same age? *I think so.* Isn't she older than your mother? *Oh no.* Does your Granny grow older every year? *She stays the same.* And your mother? *She stays the same as well.* And you? *No, I get older.* And your little sister? *Yes!* (Piaget, 1946, p. 221.)

We can see in the above conversation that without a coherent system of time, the child is limited to empirical knowledge and cannot deduce that the difference in age between her sister and her will always remain the same. Neither can she deduce that her grandmother is older than her mother, and that the two get older just as children and babies do. These are examples of the differences between Piaget's view and the Educational Policies Commission's rational powers of "comparing," "deducing," and "inferring." Piaget's way of thinking about these processes is always in relation to knowledge as a whole. In addition, the processes are placed in the context of a scientific theory of development.

Space, too, is a framework constructed by the child. Let us look at a task that shows how the child's behavior changes as he constructs a coherent system of space. In this task (Piaget, Inhelder, and Szeminska, 1948, Chapter 7), the child was given two white sheets of paper, one with a dot as shown in Figure 4(a). He was also given a variety of instruments such as a pencil, ruler, stick, strips of paper, and bits of



(a) (b) (c)

Figure 4

Children's Ways of Locating a Point on a Rectangular Surface string, and was asked to make a point on the blank sheet so that it would look exactly like the other sheet. Four-year-olds (level I) drew the point by visual inspection of the position without measuring anything. At level II, children began to use the ruler but made only one diagonal measurement, usually from the closest corner as shown in Figure 4(b)! At level IIIB, around age nine, they finally became able to draw the point at the exact spot by making two measurements as can be seen in Figure 4(c). This behavior is a manifestation of the fact that the child has constructed a system of coordinates and knows that this system is necessary to locate the point on the second sheet. These examples illustrate how Piaget views the use of the rational powers of "comparing," "analyzing," and "evaluating."

Reflective Abstraction

The logico-arithmetical and spatio-temporal frameworks are created by the child by reflective abstraction (and equilibration). Piaget makes an important distinction between *reflective* and *empirical* (or simple) abstraction. In empirical abstraction, the child focuses on a certain physical property of the object and ignores the others. For example, when he abstracts the color of an object, he simply ignores the other properties such as weight and the material with which it is made. Reflective abstraction, in contrast, involves the creation of relationships between/among objects. Relationships, as stated earlier, do not have an existence in external reality. The term *constructive* abstraction might thus be better than reflective abstraction in that this term indicates that the abstraction is a veritable construction by the mind. Reflective abstraction is necessary for empirical abstraction to take place and, conversely, empirical abstraction is necessary for reflective abstraction to take place. For example, relationships are necessary to read the color of an object in external reality, and relationships could not be created without objects to put into relationships.

The simplest relationship is between two objects, and the child constructs logical relationships by coordinating the simple, small relationships that he created before. In classification, as we saw in the class-inclusion task, he coordinates the sameness and differences that he originally created between two objects. By reflective abstraction, he can go on to create hierarchical classes with many levels (e.g., "poodles," "dogs," "animals," and "living things"). The child can go on building relationships on relationships almost indefinitely. This is what is involved in higher mathematics.

The spatial framework, too, is constructed by reflective abstraction (and equilibration), beginning with such small relationships as that between the thumb and the mouth. The smaller, simpler relationships are then coordinated into larger, better structured ones, and the baby soon becomes able to deduce that he can go behind the sofa to retrieve the ball that disappeared by rolling from the front. Columbus, too, did not discover America by accident. He constructed a system of space and deduced that he should be able to go around the globe in the direction opposite to the one already known empirically.

When young children ask, "Is today tomorrow?" they are showing not only a problem of language but also the problem of not having a framework of time. The following conversation I had in a classroom of four- and five-year-olds in front of a birthday chart further shows the inconsistent criteria they use before constructing a deductive framework of time. The children told me that Child A had a birthday on the third of that month and Child B had one on the tenth. When I asked which child was the older, they replied, "Nobody, 'cause they are both four." I then asked who the oldest of the whole class was, and everybody agreed that it was Child X. When I asked who the next oldest was, they replied that it was Child Y. To the next question, "Who is the older, X or Y?" I got the answer: "Nobody, 'cause they are both the biggest."

By the time children are seven or eight, small, elementary relationships become coordinated into a number of coherent, closed structures. Among these are the hierarchical structure of classification, seriation, and number in the logico-arithmetical domain and systems of space and time in the spatio-temporal domain. Piaget speaks about mental activity within such systems by referring to "operations."

Operations

Piaget defines operations as actions which have become internalized, reversible, and coordinated into coherent structures. When Piaget speaks of actions in this context, he means both mental and physical actions, without a line of demarcation between the two. For example, when a child puts all the blue blocks together and all the yellow blocks together, his action is both mental and physical. He physically moves the blocks, but his action is guided by the relationships of "same" and "different" that he created. When the child can class-include, his physical actions can be said to be internalized because he can mentally create the larger class and subclasses without separating or reuniting the objects physically. These mental actions (operations) can also be said to be reversible and coordinated into a coherent, hierarchical structure. At the preoperational level, by contrast, the physical actions may be internalized but they are neither reversible nor coordinated into a coherent structure.

Seriation involves the coordination of differences, or the ordering of things according to their differences. In seriation, reversibility takes the form of being able to think of B, for example, as being simultaneously *bigger* than A and *smaller* than C. By the time children are seven or eight, they become able to mentally coordinate relationships such as $C < F$, $B < I$, $E < H$, $D < J$, and $A < G$ into one coherent structure, namely $A < B < C < D \ldots < J$.

In numerical reasoning, physical actions can be said to be internalized when, for example, the child does not have to put two sets together to think of an addition. These mental actions can be said to be reversible when the child knows that adding a number and subtracting it gives the same result as not adding anything at all. Since the coherence of arithmetic is well known, it will not be discussed here.

Spatial and temporal operations, too, consist of mental actions which have become reversible and coordinated into coherent structures. (For examples, see Piaget, Inhelder, and Szeminska, 1948.) When children have constructed these structures, they are said to have "operational" (or "operatory") systems of space and time.

Operations and Concepts

Operations are important in Piaget's theory not only in themselves but also as cognitive instruments for the structuring of knowledge of content. One example each of physical and social knowledge before the achievement of class inclusion are given below. They illustrate how Piaget's conception of "classifying" and "generalizing" clarifies the "10 rational powers" view.

The first example concerns why a wooden ball floats while a key and nail sink in water.

> DUF (7;6): "That ball?"--"*It stays on top. It's wood; it's light.*"--"And this key?"--*Goes down. It's iron; it's heavy.*"--"Which is heavier, the key or the ball?"--"*The ball.*"--"Why does the key sink?"--*Because it is heavy.*"-- "And then the nail?"--"*It's light but it sinks anyway. It's iron, and iron always goes under.*" (Inhelder and Piaget, 1955, p. 29.)

This child's thinking is full of contradictions. When his thinking becomes better structured, he will become aware of the contradictions and will begin to eliminate them. By thus eliminating every factor except the weight and size of the objects and putting them into relationship as shown in Figure 5, he will realize that, although the larger the object, the heavier it tends to be (the X's in this figure), *some* small objects are heavy and *some* large ones are light. With this realization, he is on his way to constructing the concept of specific gravity. Specific gravity is not observable and must be constructed by the child. Without the operations of class inclusion and seriation, as well as others, the child cannot possibly construct this concept.

Let us now take children's notions of a country, a town, and nationality as an example of the dependence of social knowledge on class inclusion. A spatial part-whole relationship is also involved in this example. Piaget (1951) found that until seven or eight years of age, children may assert that Geneva is part of Switzerland but think of the two as situated side by side as can be seen in the following interview:

> Claude M. 6;9: What is Switzerland? *It's a country.* And Geneva? *A town.* Where is Geneva? *In Switzerland* (The child draws the two circles side by side but the circle for Geneva is smaller.) *I'm drawing the circle for Geneva smaller because Geneva is smaller. Switzerland is very big.* Quite right, but where is Geneva? *In Switzerland.* Are you Swiss? *Yes.* And are you Genevese? *Oh no! I'm Swiss now* (p. 40).

	Small	Large
Heavy		X
Light	X	

Figure 5

The Class-Inclusion Structure
Involved in the Construction of Specific Gravity

The relationship between weight and size is presented as a double dichotomy to simplify the discussion. Since both variables must in reality be seriated, the relationship is much more complex than is implied by this figure.

The child knows the words "country," "town," and "in Switzerland," but below this surface is poorly structured social knowledge.

Concepts such as "specific gravity" and "country" are constructed by creating relationships in interaction with sensory input. In education, there is a strong tradition of assuming (a) that concepts are words and (b) that concepts can be transmitted socially through words. It is true that the concepts of specific gravity and nation were both created by man. There is, however, a fundamental difference between physical knowledge and social (conventional) knowledge. In physical knowledge, concepts such as "specific gravity" and "acceleration" are created by logico-mathematizing the material world, i.e., by transforming observable facts into coherent relationships. Specific gravity, therefore, cannot be changed simply by taking a vote. Nations, however, can be created or changed by agreement among people.

Conventions can be learned by social transmission. In fact, this is the only way children can find out about conventions. The physical knowledge and logico-mathematical bases of concepts in physical science, on the other hand, cannot be transmitted in a ready-made form. Each student must reconstruct them for himself; and the teacher's task in education is to provide students with opportunities that stimulate the constructive process. Words can help when the student is already at a high level of development. Too often, however, words are taught in ways that by-pass the students' thinking and encourage verbalism. The reader is referred to Kamii and Derman (1971) for a detailed account of what happens to children's logic when bits of adult knowledge about specific gravity are imposed on six-year-olds through the teaching of words.

Operations and Science

Operations are necessary not only to construct concepts but also to construct laws and theories. For example, the regularity of the sun's rising every morning and setting every evening could not be read from external reality without logico-arithmetical and spatio-temporal operations. Without operations, it would not even be possible to introduce a reference point in time to decide what constitutes a day. Operations are also necessary to read certain cyclic variations between the lengthening of the day and the shortening of the night, and the relationship between these variations and those in the position of the sun's appearance and disappearance. Even the geocentric theory thus involved relationships on relationships.

For centuries before Copernicus's publication of On the Revolution of the Celestial Spheres in 1543, astronomers were bothered by the inaccuracy of the predictions made with the geocentric theory. All they did, however, was introduce corrections, until the geocentric theory became hopelessly complex and incoherent. By taking the same empirical facts and putting them into a vastly different set of relationships, Copernicus invented the heliocentric theory. Operations were of course necessary for the creation of new relationships, but something else was necessary for such an original, revolutionary, and powerful reconceptualization. I do not know what this "something else" is. It is something like "creativity" and "the ability to see things in a different way," but these terms do not say or explain anything.

Science itself is an example of constructivism. As can be seen in Kuhn (1970) and Piaget (1978), the Copernican revolution is only one example of how science is constructed by progressive approximation, by going through one level after another of being "wrong." To cite another example, Aristotle's law of falling bodies (in the same medium, bodies fall with speeds proportional to their weights) was corrected by Galileo, who stated, "In a medium totally devoid of resistance all bodies will fall at the same speed . . . (and) . . . during equal intervals of time (a falling body) receives equal increments of velocity . . ." (March, 1978, p. 12). Newton then built on Galileo's physics, and Einstein and quantum mechanics in turn went beyond Newton's theory. All of science is thus built by constantly reinterpreting "facts," seeking new "facts," putting them into new relationships, and constructing new paradigms.

Piaget (1971, 1972a, 1972b, 1973a, 1973b) showed that children's spontaneous theories about causes in the material world, too, undergo many similar revolutions.

How Are Operations Constructed?

Three of the ways Piaget answers this question are "By dissociation from the content of thought," "By thinking about content (i.e., phenomena) and not by exercises in logic," and "By equilibration." Each of these is elaborated below. (A fourth answer some people think of is "By direct teaching." Direct teaching of bits and pieces, however, is the antithesis of the construction of knowledge from within as a whole, especially of its fundamental organization.)

By Dissociation From the Content of Thought

According to Piaget (1971), all actions have two aspects, a physical-material-observable aspect, in which the subject's attention is oriented towards the specificity of the event, and a logico-mathematical aspect, in which the subject is oriented towards what is general in the action that produced the event. During the sensory-motor period, the child's interest focuses on the physical aspects of his action. The baby constructs objects and learns what happens to them when he pushes them, pulls them, shakes them, and drops them. However, none of these actions is limited exclusively to the physical side, since, as stated before, to recognize a rattle, for example, the child has to fit the object into a classificatory scheme. There could obviously be no knowledge of objects if each observation were an isolated incident unrelated to previous knowledge.

During the preoperational period, the physical and logico-mathematical aspects of knowledge continue to be relatively undifferentiated, with the physical side still dominating the child's thinking. All the prelogical thinking of this period can, in fact, be interpreted in terms of the primacy of the physical-observable side. For example, the child understands the pouring of liquid in physical-observable terms. Since physical actions on objects usually change something observable in objects, pouring liquid into another container is also thought to cause a change in the object. Modifying the shape of a clay ball is likewise understood in physical-observable terms.

During the period of concrete operations, the logico-mathematical aspect of knowledge becomes partially dissociated from the physical aspect as relationships become coordinated into closed, coherent, operational structures. The structures appear first with contents that are easy to structure. The conservation of discrete quantities thus appears before the conservation of liquid and clay. Because weight can be known only kinesthetically as a force pressing down, it is even harder to "logicize" than amount of liquid and clay.

Eventually, the logico-mathematical aspect of knowledge becomes sufficiently differentiated from the physical content to make operations on operations (formal operations) possible. In using formal operations in sciences other than mathematics, however, the adolescent still thinks about content rather than applying pure logic to content.

Logic and mathematics are completely dissociated from content and independent of it. Logico-mathematical knowledge thus becomes increasingly more independent of content as the child grows older. Physical knowledge, on the other hand, becomes increasingly more dependent on logico-mathematical knowledge. Aristotle's law of falling bodies is an example of the logico-mathematization of content.

If operations are constructed by gradual dissociation of systems of relationships from the content of thought, the reader may think that Piaget would advocate exercises in the construction and coordination of relationships. To avoid this inference, I would like to give a second answer to the question "How are operations constructed?"

By Thinking About Content (i.e., Phenomena) and Not by Exercises in Logic

Piaget certainly does not advocate exercises in logic or even classification as can be seen in the following quote:

> . . . 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 (Piaget, 1971, p. 17).

Operations develop by being used, and they develop best when the focus of thinking is on phenomena and not on the logical form. The more operations develop, the better children can observe and understand phenomena as we saw earlier in children's observation of liquid in U-shaped glass tubes. The better they read reality and understand it, the more operations will in turn develop.

By Equilibration

This is the third way of describing how operations are constructed. Equilibration, it will be recalled, is one of the four factors Piaget cites to explain development. (The other three are maturation in the biological sense, experience with objects in a physical as well as logico-mathematical sense, and social transmission.) Equilibration is the most important of the four factors because it is the internal self-regulating process of coordinating the influence of the three other factors.

Equilibration is the process of tending toward equilibrium (i.e., coherence). Piaget's equilibrium does not refer to homeostasis, or a return to the previous state of equilibrium. His equilibration is a constructive process which he recently called "equilibration majorante" (Piaget, 1975). In this book he distinguished three forms of equilibration:

1. Between the subject and the object

2. Between (or among) schemes or subsystems

3. Between the totality of knowledge and its parts.

The first form can be seen in the construction of physical knowledge. The child apprehends reality by assimilating it into classificatory schemes and situating it in series and by accommodating these schemes.

The second and third forms take place within the subject. The second is seen mainly in the construction of logico-mathematical knowledge. The characteristic of the third form is the differentiation of schemes and their integration in the totality of knowledge. This third form dominates the other two. This emphasis on the totality is the hallmark of a biological conception of knowledge. Just as an embryo grows by progressive differentiation and integration, knowledge, according to Piaget, develops as a whole from the beginning. The totality has a cohesive power, which imposes the constraint of coherence.

Before going on to some principles of teaching, I would like to conclude this theoretical part with a few words about creativity. "Creativity" can be understood in two ways: (a) in a strict, narrow sense which refers to the unusual originality of a Piaget, Copernicus, or Darwin and (b) in a broad sense. As we saw above, knowledge is constructed, or created, by each child (except for surface bits such as the alphabet, ability to count, and names of things, which can be taught). If all children construct operations, concepts, and theories, all of them must be said to be creative. In education, if we fostered this natural creativity instead of trying to transmit ready-made knowledge, I believe we could produce adults who think more logically and creatively than the average adult of today, as well as scientists who make extraordinary contributions.

PRINCIPLES OF TEACHING

The most general and fundamental principle of teaching that can be derived from constructivism is that children acquire a great deal of knowledge outside school, and education must mesh with and support this natural process. The question then is: How can we enhance this process? I delineate below nine principles of teaching for elementary science education. They will frequently be illustrated with examples from one of the units on sinking and floating of the Elementary Science Study, Teacher's Guide for Clay Boats (Education Development Center, 1969). In my opinion, the Elementary Science Study is the most Piagetian approach to elementary science education published in this country.

1. Provide Physical Materials for Students to Act On

There are two reasons for this principle. One is that physical knowledge is acquired by acting on objects and seeing how objects react. For example, to find out whether a clay ball can be made to float on water, or whether two pendulums with strings of unequal length can be made to swing together, the student has to act on objects and get the answer from them. As he varies his actions, he puts into relationship the variation in his actions and the variation in the object's reactions. He thus develops not only physical knowledge but also logico-arithmetical and spatio-temporal knowledge.

The second reason for my belief in students' working with objects is that this is the only way they can logico-mathematize reality. It is not by learning words that students become better able to think about the material world.

Part of the logico-mathematization of the material world is the construction of relevant variables. In a study I did with Piaget (1974b) with the balance shown in Figure 6, for example, I observed children's difficulty in coordinating A and B with A' and B'. This large balance had two plates (A and B) that made the weight (washers) in them *pull* the bar down. It also had two sticks (A' and B') on the bar, and when the child put washers on them, the weight *pushed* the bar down. Children of elementary school age had no trouble reasoning that if there were six washers in A, there had to be six in B, too, to make the bar horizontal. They likewise had no trouble coordinating the relationship between the weight on A' and B'. However, when there were six washers each in A and B, and I asked what would happen if I took one of them out of B and put it on B', they kept alternating their predictions between "The B side will go down" and "The A side will go down." They usually began by predicting that B' would go down (because there would be one washer on B'

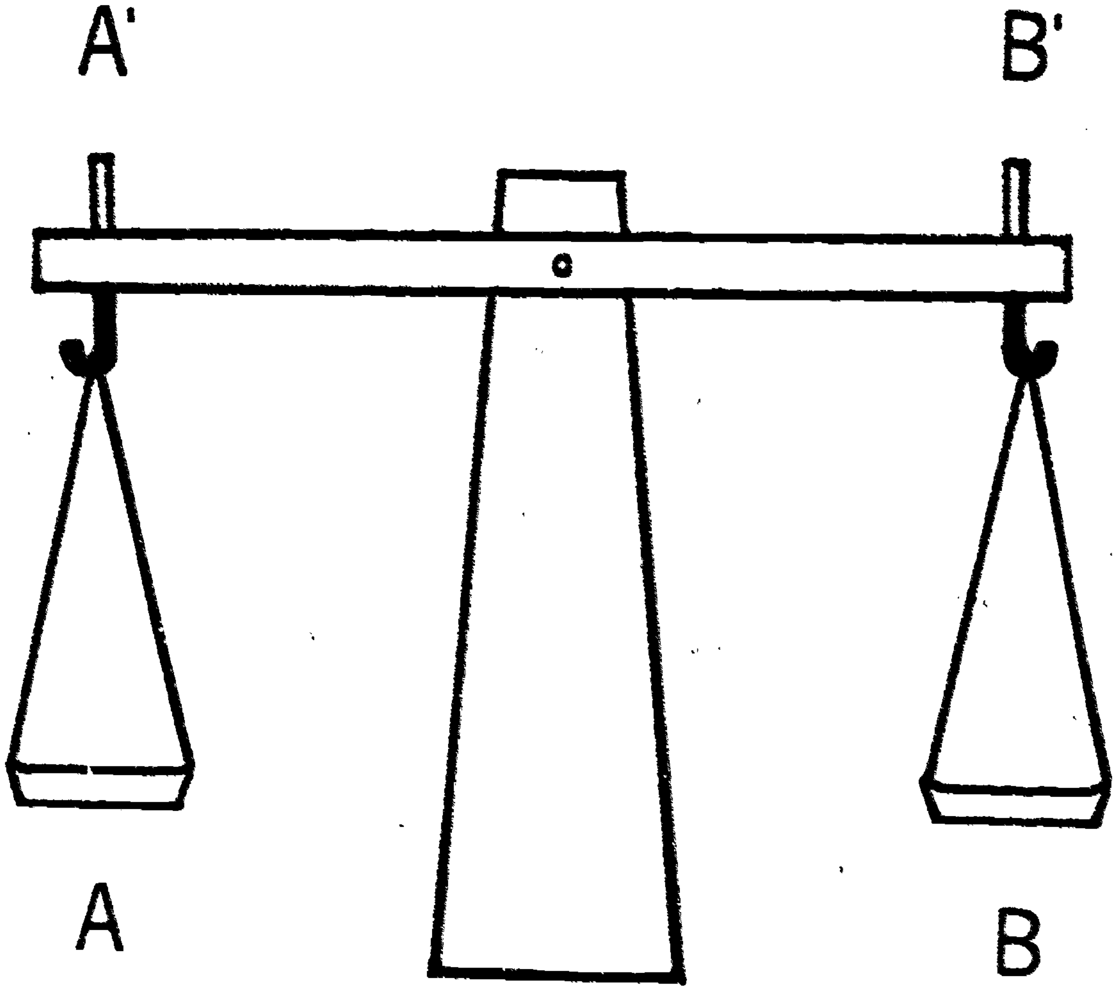


Figure 6

The Balance Which Showed Children's Difficulty in Coordinating Two Subsystems (AB and A'B') and none on A'). When I then pointed out that there would be six in A and five in B, they changed their minds and said, "Oh, it's A that will go down." I would then point out that there would be one on B' and none on A', and they would change their minds again, and again. This is an example of how children take "facts" from reality and put them into small, local relationships before they become able to coordinate them into one large system. Without real objects, they would not have opportunities to construct from reality the variables that are relevant to a question.

The logico-mathematization of a simple balance (without the two subsystems, AB and A'B') is straightforward. We can see in Inhelder and Piaget (1955) that, as they grow older, children quantify relationships with increasing precision. The quantification is at first only qualitative, or logical (i.e., "The *farther* the weight is from the fulcrum, the *more force* it has"). It is in the period of formal operations that the quantification becomes mathematically precise and students can reinvent the law of inverse proportionality (i.e., "If the distance is increased three times, the weight must be decreased to 1/3").

2. *Keep in Mind the Following Four Ways of Acting on Objects and Choose the Approach That is Appropriate to the Students' Developmental Level*

   a. Acting on objects and seeing how they react

   b. Acting on objects to produce a desired effect

   c. Becoming aware of how one produced the desired effect

   d. Explaining

The first two approaches are self-explanatory, but the third one is not. By the time children are four or five years of age, they are able to do many things at the level of practical intelligence, but they are not aware of *how* they produced the desired result. For example, Piaget (1974a) found that most four-year-olds could twirl an object on a string, dragging it lightly on the floor, and let it go just at the right moment to make it land in a box several feet away. When asked at what point in the object's revolution they let go of the string, however, they were unable to give a correct description (at the position of 9 o'clock in a clockwise revolution, and at the position of 3 o'clock in a counter-clockwise revolution). In fact, he found the following three levels of description:

Level I: Four- and five-year-olds said that they let it go right in front of themselves, at the position of 6 o'clock.

Level II: Seven- to nine-year-olds said they they let it go in front of themselves but at the position of 12 o'clock.

Level III: Around nine or ten years of age, children were able to describe accurately what they had actually done.

Until age nine or ten, in other words, children did one thing but said something else when asked to describe how they produced the desired effect. This cognizance is a construction that is much harder and takes a longer time than common sense leads us to expect.

Explaining, the fourth way, can take the form of straight explanation of phenomena as can be seen in Piaget (1971, 1972a, 1972b, 1973a, 1973b) or of the systematic testing of hypotheses as can be seen in Inhelder and Piaget (1955). The danger of focusing on explanations in an educational setting is that they often turn into verbalism.

When the first two of the four approaches are used ("acting on objects and seeing how they react" and "acting on objects to produce a desired effect"), explanations can often be worked in in a more thought-provoking way. In "Clay Boats," for example, the teacher is using the second approach when he asks students if they can make a clay ball float on water. Later, when he asks what will happen if the child puts objects in the clay boat, he is using the first approach. These two approaches, as well as the third one, which is discussed below, contain elements of explanation and are generally much better than the teaching of an explanation, which is too hard for students in the period of concrete operations anyway (Inhelder and Piaget, 1955, Chapter 2).

The third approach, becoming aware of how one produced the desired effect, can best be used when the teacher encourages a student to ask another student how he accomplished a feat. This is an example of a situation which is educationally good both for the student who teaches something and the one who is taught something. In "Clay Boats," the teacher is advised that students who cannot find a way to get the clay ball to float might be encouraged to go around the room looking for help from other students.

3. *Introduce an Appropriate, Interesting Activity, and Allow Students the Freedom to Reject the Teacher's Suggestion*

The activities in ESS have all been tested in classrooms, with students' interest as the most important criterion of success. The activities are, therefore, likely to appeal to students, but they must not be imposed on them. The student should have the freedom to pursue his own interest, as thought can develop only when the student is involved.

4. *Emphasize the Creation of Questions and Problems (Goals) as Well as Their Solutions*

Educators nowadays often advocate "problem solving," but we seldom hear about the importance of creating problems (or goals) and raising questions. An important part of constructivism is the construction of questions. Besides, when students try to answer their own questions or solve their own problems, they are motivated to work surprisingly hard.

I remember Piaget's saying in class one day that a scientist's research is only as good as the questions he raises. The formulation of questions is one of the most important and creative parts of science, which is neglected in science education.

5. *Encourage Students to Interact with Each Other*

According to Piaget (1947, Chapter 6), exchange of ideas is indispensable for the development of reasoning. Although reasoning cannot be taught directly, its development can be stimulated by critical confrontations, especially with peers. Just as confrontation of points of view is essential for the construction of science, this is indispensable for students to build both physical and logico-mathematical knowledge. In education, there is a strong tradition of teaching by getting students to repeat the "right" answer. I prefer to encourage students to have their own opinion (even if it may be "wrong"), express it, defend it, and feel responsible for it. The honest expression of convictions, in the end, will foster constructive equilibration and make students more intelligent and motivated to keep on learning than will learning the "right" answer. [The reader interested in finding out what happens to six-year-olds' thinking when they are made to give the "right" answer about specific gravity is referred to Kamii and Derman (1971).]

Sometimes, the teacher can encourage individuals to compare ideas. At other times, he can organize small groups to solve particular problems A third way of encouraging interaction is to have the entire class compare problems, observations, and interpretations.

6. *Avoid Technical Terms and Emphasize Thinking*

This point must be obvious from the findings from the class-inclusion task, as well as from children's statements about why a key sinks and why a Swiss cannot be a Genevan. Language can clarify and enrich ideas when students are already at a high level of development. Too often, however, words by-pass or interfere with thinking (as can be seen in Kamii and Derman, 1971).

7. *Encourage Students to Think in Their Own Way*

Below is an example from "Clay Boats" which shows students comparing the wrong things:

> Many youngsters . . . feel that the bigger the "lake," the better the "boat" will float. One teacher brought in a dishpan for the youngsters to use. Some children took pieces of clay home and tried them in the bathtub. In one class, children tried to find out how *little* water a boat could float in (p. 12).

According to Inhelder and Piaget (1955), children do compare the weight of the object with the "force" or "ability" of the total amount of water to hold the object up. These are the wrong things to compare, but students must be encouraged to think *in their own way*. Some of their intuitions are correct and others are not, and these ideas must be worked through and coordinated if students are to become clear, precise thinkers. The wrong intuition will get in the way of clear thinking if it is not coordinated with other ideas and contained in a higher-level belief.

8. *Reintroduce the Same Material and Activity Over Several Years*

The same student looking at a mobile, soapbox derby, or any other object or event does not see the same reality at ages six, ten, and fourteen. The reason is that the older student assimilates objects into better structured knowledge than does a younger student. This is why the tight sequencing of content is unnecessary. Besides, Piaget's research has shown that children acquire knowledge in ways that are very different from what adult common sense leads us to believe.

The statement that tight sequencing is unnecessary does not imply that all sequencing must be avoided. For example, "Clay Boats" is recommended for grades two through six. Within this wide age range, the teacher is told that for young students the problem is that of designing an object that will float. For older students, on the other hand, the problem is one of finding out why a particular design holds a bigger load than others and what makes an object sink or float. Another broad outline of sequence can be seen in the following two suggestions after students become able to make their clay float:

> You might now ask the children if they have any objects in their desks which they would risk putting in their boats. The first clay boats are usually loaded with such classroom staples as crayons, pencils, erasers, and paper clips (p. 12).
>
> . . . you may want to give him some of the uniform weights (ceramic tiles, pennies, metal fishline sinkers, washers, or paper clips) and suggest that he find out how many his boat will hold (p. 14).

In each one of the above suggestions, the teacher is taking sinking and floating to a higher level than before. The important thing is that the teacher not impose these ideas. If the right suggestion is made at the right time, it can lead students to high-level questions such as the following:

> Will the same boat always hold the same number of sinkers?
>
> Must the sinkers be placed in the same position every time?
>
> What happens if water gets into the boat?
>
> What happens if the sinkers are dropped into the boat? . . . thrown in? (p. 14)

Note that there is a high degree of interaction between the sequencing done by the teacher and the sequencing done by the students. The art of teaching lies in figuring out when to raise a good question that will stimulate the student to go on to higher-level thinking and when to refrain from asking questions.

9. *Integrate All Aspects of Knowledge*

If knowledge develops as a whole, it is best not to compartmentalize it into subjects such as science, language arts, drawing, and mathematics. Students should be encouraged to record what they did and observed so that they will be able to think more clearly about whatever they are trying to find out. When they make drawings to illustrate important points, they think about perspective and proportions. When they are encouraged to read other students' notebooks and react to them, their written and spoken language develop, as well as their thinking. Measuring, counting, and establishing numerical relationships are also a major part of the logico-mathematization of physical phenomena. A good example given by Duckworth (personal communication) is asking students if they can make one of two pendulums swing 20 times while the other swings ten times. If the climate of the classroom is right, students may go on to ask themselves how short the string should be for the ratio to change to 30:10 and then to 40:10.

The ESS is an example of research on teaching with real teachers in real classrooms. While this is not the only group in science education who has done research in classrooms, I think its constructivist conviction is unmatched by any other group who has published an elementary science curriculum in this country. Further research is necessary to make the theoretical rationale and principles of teaching more precise in the ESS. I hope also that longitudinal evaluation research will be conducted in innovative ways such as the one exemplified by Duckworth (1978).

An unexplored gold mine is Piaget's published (1971, 1972a, 1972b, 1973a, 1973b) and unpublished research on children's notions of causality. Precise information about students' interpretations of specific phenomena at various age levels would be extremely useful for teachers to have. With this information, teachers would be better able to guess which questions might be fruitful to raise and which ones are impossible for students to handle before a certain level of development.

The important question both in teaching and in evaluation based on Piaget's theory is not how *fast* students will go through the stages but how *far* they will go eventually as adults. Findings from research such as that by McKinnon and Renner (1971) and Schwebel (1975) show that the "cream of the crop" of our school population who are successful enough to go to college are, for the most part, not capable of formal operations. The percentages of college freshmen they found to be capable of solid formal operations were 25 and 20, respectively.

Formal operations do not suddenly develop at age 11 or 12. Their foundation develops slowly all through infancy and childhood. There is an enormous challenge ahead with this underdeveloped human potential, and I am convinced that educators will some day become able to meet this challenge.

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INTELLECTUAL DEVELOPMENT AND INSTRUCTION:

A NEO-PIAGETIAN VIEW

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INTRODUCTION

Few psychologists have concerned themselves as directly or as extensively with the development of the rational powers as has Jean Piaget. Piaget's work is of particular relevance for the present volume, since he has taken as his model of rational thought the mental processes of the mature scientist. Of the many questions which Piaget has sought to answer perhaps the most important two are (1) what is the nature of the mental processes on which scientific reasoning depends, and (2) how do these mental processes evolve? His answer to the first question is that the mental processes on which scientific reasoning depends take the form of delicately balanced systems of internalized actions, whose organizational structure may be represented by symbolic logic. His answer to the second question is that these systems of internalized actions (or operational structures as he calls them) evolve through a series of four stages from birth to adolescence. This evolution proceeds as a result of the interaction between the child's spontaneous attempts to construct a coherent picture of his environment, and the nature of the environment to which he is exposed.

In the present chapter I shall present a theory of intellectual development which draws heavily on Piaget's. I shall also suggest how this theory may be utilized for improving the process of instructional design. Finally, I shall attempt to set both the psychological theory and the instructional technology in historical perspective.

THE PROCESS OF INTELLECTUAL DEVELOPMENT

According to Piaget, intellectual development may be divided into the following four stages, each of which has its own distinctive operational structure: the sensorimotor stage (0-2 years), the preoperational stage (2-6 years), the concrete operational stage (6-12 years), and the formal operational stage (11-16 years). The theory of development which I shall outline in the present chapter preserves Piaget's notion of four general stages. However, the theory is somewhat more detailed than Piaget's in specifying the processes that are responsible for propelling children from one stage or substage to the next. In addition, it draws heavily on three ideas which do not derive from Piaget's work, but rather from contemporary cognitive science. The first of these is that the operational structures of each Piagetian stage can be modeled as sets of executive strategies (cf. Bruner, Oliver and Greenfield, 1966; Simon, 1962). The second is that the acquisition and application of any given executive strategy require a specifiable size of working memory (cf. Case, 1968; Halford, 1970; Pascual-Leone, 1969; McLaughlin, 1963). The third is that the more automated an intellectual operation becomes, the less attention it requires for execution (cf. Solomon and Stein, 1896). Stated in more contemporary terms, the more automated an intellectual operation becomes, the lower its demands on working memory (cf. Neisser, 1976; Shiffrin and Schneider, 1977).

In describing my theory, I shall begin with an account of the strategic changes which occur within each Piagetian stage. I shall then describe the more basic processes which I see as underlying these changes. Finally, I shall describe the mechanism which I believe is responsible for producing the transition from one stage to the next.

DEVELOPMENTAL CHANGES IN EXECUTIVE STRATEGIES

Changes During the Stage of Sensorimotor Operations

From the time of birth to the age of one and one-half years, children pass through a series of sub-stages in which their motor strategies become increasingly complex and powerful. Consider, for example, the changes which occur during this period in children's strategies for performing a directed action with their hand (Piaget's "means-ends" scheme).

Sub-stage 1: Isolated Centration

Somewhere between one and four months, children become capable of executing a directed rather than a reflexive manual action. Piaget gives the example of his son, Laurant, whose hand happened to be placed near his mouth by his caretaker. Immediately following this event, the child made 13 attempts in a row to put his hand in his mouth until he had perfected the movement. Although children gain basic control over the movement of their hands during this substage, however, they cannot yet relate this movement to the movement of some other object. Because their reaching strategies involve only a single step (i.e., action of child → gratification), Piaget refers to them as "primary circular reactions."

Sub-stage 2: Unirelational Centration

During the second substage, children become capable of centering not just on one action of their own, but on the relationship between this action and some consequence in the external world. For example, if children happen to strike a mobile in a way which produces a particularly interesting movement, they will repeat that striking action again and again, delighted with the result produced. Because their strategies now involve two components, (i.e., action of subject + reaction of object → attainment of desired end), Piaget calls them "secondary circular reactions."

Sub-stage 3: Birelational Centration

During the third substage, children become capable of executing actions which only indirectly produce interesting results. For example, they become capable of striking a barrier (action 1) so that they can reach a second object (action 2) and produce a reaction which is the real focus of their interest. Their strategy thus incorporates one additional element beyond the previous sub-stage. It can be characterized as: action 1 + action 2 + reaction of object → gratification.

Sub-stage 4: Birelational Centration with Elaboration

During the fourth substage children become capable of more than merely acting on an object which is not the prime focus of their interest to remove it. In addition, they become capable of actively using such an object to attain to a second object which is the real focus of their interest. For example, if an object is sitting on a towel, they may pull the towel, so that the towel will move the object sitting on it, so that they may act on that object. This may be represented as: action 1 (subject on object) + action 2 (object on object) + action 3 (subject on object 2) + reaction of object 2 → gratification.

The most striking characteristic of this sequence is that each successive strategy is a modified and more powerful version of the previous one. That is, although the basic operation (reaching) remains the same, each successive strategy in which this operation is embedded takes into account some new and relevant feature of the infant's world, and incorporates an additional step or set of steps for dealing with it. In Piagetian terms, each successive strategy is both more differentiated and more equilibrated than previous ones. Two broad classes of factors may influence this process. The first class is relatively specific and includes physical and social experience; the second is more general and includes maturation and internal coordination (Piaget, 1964).

Strategy evolution: the specific experiential hypothesis. That experience of a specific sort is necessary for the evolution of the above strategy sequence seems obvious. If children were not exposed to problem situations that were unsolvable by their most primitive action strategies, they would have little motivation for modifying those strategies. For example, one would not expect a child to make the transition from substage 3 to substage 4 unless he encountered situations in which the desired play object was beyond his immediate grasp. At the very least, he would have to have some observational experience in order to understand the effect which one object can have on another.

On the other hand, however, given the remarkable uniformity in the age at which these strategies emerge across different populations, and the difficulty in producing more than a few months acceleration by specific intervention programs, it seems unlikely that specific experience by itself constitutes a sufficient explanation to account for substage transition.

Strategic evolution: the general developmental hypothesis. If one counts the number of events which must be held in immediate memory in order to acquire or to execute the strategy that is characteristic of each substage, one notes a remarkable progression. Given that the child finds the exercise of some basic scheme such as sucking satisfying, the only event which he need hold in immediate memory in order to discover the first strategy is the action he directed his hand to execute immediately prior to the satisfying result. Similarly, the only information he need use to execute the strategy is feedback from his hand. In order to discover the second strategy, he must be able to hold some trace of the original action which he executed, plus some information about the effect this had on the object. Similarly, in order to execute the second strategy, he must be able to coordinate input from his hand with input from the object itself. In order to discover or execute the third strategy, the child must be able to retain both the previously mentioned items of information, plus some information about the action which removed the barrier. Finally, in order to discover or execute the fourth strategy, the child must be able to retain all three of the previously mentioned pieces of information, plus some information about the action of object 2 on object 1. It therefore seems possible that an increase in the span or duration of immediate memory may constitute the general developmental factor which regulates children's progress through the above sequence. Prior to the age of four months, children may not be able to retain the trace of more than one sensory or motor event in their immediate memory. Prior to the age of eight months, they may not be able to retain the trace of more than two such events, and so on. If this were true, it would explain why the age of emergence of each strategy is relatively constant across environments, and why there is a floor below which even carefully planned experience does not appear to have much effect.

In its general form, such a hypothesis is not unique to my own theory. A number of investigators in the area of infancy have made similar suggestions (cf. Bower, 1974; Pascual-Leone, 1976a; Watson, 1967). What is unique to my theory is that the same explanation is advanced to account for the developmental progression within each of Piaget's major stages.

Changes During the Stage of Symbolic Operations

During the years from one to five years, the child passes through another series of sub-stages in which his strategies become more complex and powerful. The content of these strategies differs fundamentally from that of the earlier strategies. In Piagetian terms, the content tends to be symbolic or "representational" rather than sensorimotor. In spite of the difference in content, however, there is a remarkable similarity both in the sequence of sub-stages and in the types of process which must be postulated in order to explain the transition from one sub-stage to the next. Consider, for example, how children's performance changes on the task of encoding and reproducing a meaningful spoken sentence.

Sub-stage 1--Isolated Centration

Somewhere between their first and second birthdays, children begin to isolate frequently heard and pragmatically relevant words from the stream of language to which they are exposed, and to repeat them. If an adult smiles and says one word, they will repeat it successfully. If the adult utters several words, however, they will repeat only the one that is pragmatically or acoustically most salient.

Sub-stage 2--Unirelational Centration

As they approach their second birthday, children enter the "two-word" sub-stage. If they are asked to repeat pairs of words such as "Daddy come," they can do so. However, if they are asked to repeat a sentence with subject, verb, and object, they will repeat only two of the three possible words.

Sub-stage 3--Birelational Centration

The two-word sub-stage does not last long. Children soon master more differentiated patterns or "frames" that refer to objects or actions (e.g., "a big boy" or "wanna go"). By about age three, children can repeat a sentence with a differentiated subject, verb, and object (e.g., The little boy wants to feed the puppies). As Bever (1970) has pointed out, this is also the age when children start misinterpreting more complex sentences by imposing a subject-verb-object pattern on them.

Sub-stage 4--Birelational Centration with Elaboration

During the fourth substage (four to five years), children can encode and repeat sentences having several fully differentiated linguistic frames arranged in the conventional subject-verb-object pattern, even those with a modifier frame attached. A sentence repetition item which appears on the Stanford Binet, for example, is "Jack likes to feed the little puppies in the barn."

There is a clear parallel between the above sequence of substages and that observed during infancy. The basic type of operation (linguistic encoding or decoding) remains the same. However, at each successive substage the child becomes capable of using this type of operation in a linguistic performance which takes account of some new element in the target sentence, and which incorporates a procedure for storing and repeating it. Given this parallel sequence, it seems likely that there is a parallel in the underlying process which produces the sequence. First, specific experience almost certainly affects the rate of progression. Children do not learn just any language. They learn the language of their own culture. And it would be strange if the quality and quantity of language stimulation did not affect the rate of this learning. Second, given the relatively narrow range in the age at which each pattern is observed, some general developmental factor very probably affects the rate of progress as well. As a number of psycholinguists have noted, a certain minimum size short-term memory appears to be prerequisite for discovering and utilizing each of the linguistic constructions appearing in this period (cf., Bates, 1976; Slobin, 1973). Although there is no standard procedure for segmenting sentences and counting their memory demands, segmentation may proceed according to the frame-analysis proposed by Halliday and utilized by Winograd in his computer simulation of natural language comprehension (Winograd, 1972). If this is the case, and if one unit of short-term memory is necessary to store each frame to be repeated, then the absolute numerical progression across stages is also the same as on the means-ends task. The demand for segmenting and reproducing at the first level is one unit, at the second level two units, at the third level three units, and at the fourth level four units.

A similar trend is observed during the next major stage of development.

Changes During the Stage of Concrete Operations

During the age range from four to eleven years, children again go through a number of qualitatively distinct substages in which their thinking becomes increasingly complex and powerful. The content of the strategies which they are capable of utilizing differs fundamentally from the content of the strategies which they are capable of using during the representational stage. In Piagetian terms, the content tends to be transformational or operational rather than symbolic or imitative. In spite of the difference in content, however, there is once again a remarkable similarity, both in the sequence of substages that is observed, and in the type of process that presumably underlies this sequence. Consider, for example, how children's strategies change on a task designed by Noelting (1975).

In Noelting's task, children are shown two large pitchers, A and B. The experimenter explains that he is going to dump several tumblers of orange juice and several tumblers of water into each pitcher. The children's task is to predict which pitcher will taste more strongly of orange juice. They may count the tumblers of each liquid that will be poured into each pitcher, but they may not pour the tumblers in to see if they are right. Table 1 presents several of the specific problems and the ages at which these problems are first passed.

Noelting has modeled children's reasoning at each substage both in terms of the executive strategies they use and the logical structures which these strategies imply. It is his account of the executive strategies that is of interest from the point of view of the present theory.

Table 1

Sequence of Strategies Observed on Noelting's Juice Problem

Developmental Level	Age of Assession	Type of Item Passed		Global Description of Strategy
1	3-4	U	U	Isolated Centration
2	4-5	U U U U U	U U U U U	Unidimensional Comparison*
3	7-8	U U U U	U U U U U U U	Bidimensional Comparison
4	9-10	U U U U U	U U U U U U U U	Bidimensional Comparison,** with Quantification

*Noelting's data shows the age of accession for this item as four years. Our data suggests that this is true only for very simple number comparisons, e.g., 1 vs. 3. Thus, I have listed the age of accession as four to five years.

**The strategy for this item has been induced from Noelting's error data. His own description is somewhat different.

Substage 1: Isolated Centration

By the age of three or four, children are usually capable of counting a small array of objects. However, they do not use this capability in Noelting's task to compare the two arrays. Instead, they evaluate each array in isolation, noticing only one global feature: the presence or absence of juice. They therefore succeed on problems where just one side receives juice, but fail in all other instances.

Substage 2: Unirelational Centration

During the second substage (four and one-half to six years), children notice not only the presence or absence of juice on each side, but also the quantity of juice. That is, they begin to use their counting ability for comparing the amount of juice on each side. Their strategy is to pick the side with the greater number of juice tumblers and to say it will taste more strongly of juice.

Substage 3: Birelational Centration

At the next substage (seven to eight years), children notice the number of water tumblers on each side as well as the number of juice tumblers. They count the number of water and juice tumblers on each side, and pick the side having an excess of juice over water. However, if both sides have an excess of juice over water, they simply guess.

Substage 4: Birelational Centration with Elaboration

By age nine, unless each side has the same simple proportion of water to juice, children notice the extent of the excess or deficit of juice over water on each side and make their decision on this basis. They therefore succeed on any item where simple ratios are involved, or where the correct answer may be obtained by determining which side has the greater excess of juice over water. They continue to fail, however, on all other items.

Once again, there would appear to be a definite parallel between the sequence of substages in Noelting's task and the sequence of substages in the sentence repetition and object retrieval tasks. The basic operation at each substage remains the same (counting). However, each successive strategy into which this operation is embedded takes account of some additional feature of the array of tumblers, and incorporates some additional procedure for dealing with it.

Given the parallel sequence, there is very probably a parallel in the underlying process which propels children through the sequence. First, specific experience must affect the rate of progression through the sequence. The greater the child's exposure to juice mixing situations, the greater the likelihood that he will reach a high level of strategic development at any early age. Second, some general developmental factor very probably affects the rate of progress. If one counts the number of items which must be held in working memory to execute Noelting's strategies, one notices the same progression as during previous stages. For the simplest strategy, only one item must be considered: the presence or absence of juice. For the second strategy, two items must be considered: the number of orange juice tumblers poured into A, and the number poured into B. For the third strategy, three items must be considered: the number of orange juice tumblers in B, the number of water tumblers in B, and the stored conclusion of the relative quantity in A. Finally, for the fourth strategy, four items must be considered; the additional item being the exact quantity of the difference between orange juice and water in A. A more detailed calculation of these values is presented in Table 2. As may be seen, the calculations are based not on the total number of items an external observer might count, but rather on the total number of items the subject must hold in working memory at each step of his thinking. This step places the maximum load on the system and therefore is the point where insufficient working memory will lead to failure.

Table 2

Working Memory Demands for Executing Concrete Operational Strategies on Noelting's Task

Strategy	Steps Involved	Items in Working Memory (i.e., items being attended to)	Memory Demand
Isolated Centration (Preoperational) (3-4 years)	Step 1 - Look for orange juice in A, if it is there, say it will taste of orange juice, if it is not there, say it won't taste of orange juice.	(i) colour of tumblers in array A	1
	Step 2 - Look for orange juice in B, if it is there, say it will taste of orange juice, too. If not, say it won't.	(i) *colour of tumblers in array B	1
Unidimensional Comparison (5-6 years)	Step 1 - Count the number of orange juice tumblers to be dumped into A. (Store)	(i) # of orange juice (A)	1
	Step 2 - Count the number of orange juice tumblers to be dumped into B. (Store)	(i) # of orange juice (A) (ii) # of orange juice (B)	2
	Step 3 - Select larger number and predict that the side with that number will taste stronger. If the two numbers are equal, say they will taste the same.	(i) # of orange juice (A) (ii) # of orange juice (B)	2
Bidimensional Comparison (7-8 years)	Step 1 - Count the number of orange juice tumblers to be dumped into A. (Store)	(i) # of orange juice (A)	
	Step 2 - Count the number of water tumblers to be dumped into A. (Store)	(i) **# of orange juice (A) (ii) # of H_2O (A)	
	Step 3 - Note whether relative amount of orange juice is more, or less than amount of water. (Store)	(i) orange juice $\gtreqless$ H_2O (A)	1
	Step 4 - Count number of orange juice tumblers to be dumped into B. (Store)	(i) **orange juice $\gtreqless$ H_2O (A) (ii) # of orange juice (B)	2
	Step 5 - Count the number of water tumblers to be dumped into B. (Store)	(i) **# of orange juice $\gtreqless$ H_2O (A) (ii) **# of orange juice (B) (iii) # of H_2O (B)	3
	Step 6 - Note whether amount of orange juice in B is more, less, or same as amount of water in B. (Store)	(i) **orange juice $\gtreqless$ H_2O (A) (ii) **orange juice $\gtreqless$ H_2O (B)	2
	Step 7 - Pick side with more orange juice than water (as more), or side with less orange juice than water (as less). If relative amount on each side is in the same direction, say they have the same.	(i) orange juice $\gtreqless$ H_2O (A) (ii) orange juice $\gtreqless$ H_2O (B)	2
Bidimensional Comparison with Quantification (9-10 years)	Step 1 - Count orange juice in A. (Store)	(i) # of orange juice (A)	1
	Step 2 - Count water in A. (Store)	(i) **# of orange juice (A) (ii) # of H_2O (A)	2
	Step 3 - Note which has more, and how much more. (Store)	(i) orange juice $\gtreqless$ H_2O (ii) difference = X	2
	Step 4 - Count orange juice in B. (Store)	(i) **orange juice $\gtreqless$ H_2O (A) (ii) **difference = X (iii) # of orange juice (B)	3
	Step 5 - Count water in B. (Store)	(i) **orange juice $\gtreqless$ H_2O (A) (ii) **difference = X (iii) **# of orange juice (B) (iv) # of H_2O (B)	4
	Step 6 - Note which has more, and how much more.	(i) **orange juice $\gtreqless$ H_2O (A) (ii) **difference = X (iii) **orange juice $\gtreqless$ H_2O (B) (iv) **difference = Y	4
	Step 7 - Apply same decision rule as in Strategy III, unless relationship is the same on both sides, in which case say equal if difference is equal, or make judgment on basis of greater difference (e.g., H_2O > OJ by 5 in A, and by 3 in B, pick A as weaker).		

*The reason this is not listed as a second item in working memory is that the first item has already been responded to, and no longer needs to be stored.

**This item, which was generated in a previous step, must be stored for use in a subsequent step.

Given that Noelting's sequence of strategies shows this progressively increasing demand on working memory, the obvious "general developmental" hypothesis is the same as that which was advanced for the earlier stages: that the child's rate of progress through the sequence is determined not only by the quantity or quality of his specific experiences, but also by the rate of growth of his working memory. A number of investigators have proposed such an hypothesis to account for the general-organismic factor during this stage (cf., Bruner, 1966a; Case, 1968; Halford and MacDonald, 1977; McLaughlin, 1963; Pascual-Leone, 1969; Piaget, 1920). However, the approach that I have used for computing the memory load is based on a modification of the procedure proposed by Pascual-Leone (cf., Pascual-Leone, 1970; Case, 1974). Consider now the sort of strategy sequence which is observed during the fourth and final of Piaget's stages.

Changes During the Stage of Formal Operations

The nature of the development which occurs during the stage of formal operations is probably less well understood than that which occurs during any other stage. Nevertheless, if Noelting's task is at all representative, it seems likely that children may once again go through a series of qualitatively distinct substages in which the type of content is different (being "formal" rather than concrete) but in which the underlying process is the same. Consider the strategies which are observed on Noelting's juice-mixing task in the age range from 8 to 16.

Substage 1: Isolated Centration

By the age of eight or nine, children in Western societies are normally capable of understanding and computing a simple ratio. However, they do not use this capability to compare side A with side B. Instead, they consider each side in isolation, and classify each side as having more, less, or the same amount of juice as water (see substage 3, concrete operations).

Substage 2: Unirelational Centration

During the second substage (at about 11 years), children do use their understanding of ratio to compare side A with side B. If the two ratios are equal, they respond that both sides will taste the same. If the two ratios are clearly unequal (e.g., 2/4 vs. 3/4 or 1/4 vs. 1/3) they also respond appropriately. If the two ratios are not directly comparable, however (e.g., 1/3 vs. 4/9), they fall back on the most sophisticated concrete operational strategy, namely computing the difference between the number of juice and water tumblers on each side.

Substage 3: Birelational Centration

During the third substage (11-14 years), children take the relationship between the two denominators into account as well. Thus, if the two ratios are not directly comparable, they compute the factorial relationship between them, and use this factor to put the two ratios in a comparable form. For example, if the two original ratios are 1/3 and 4/6, they notice that 6 = 3 x 2, and convert the 1/3 to 2/6. They then compare 2/6 with 4/6 and answer appropriately.

Substage 4: Birelational Centration with Elaboration

At the final substage (15-18 years). children become capable of solving the problem even when the relationship between the two denominators is not a simple factorial one. First they multiply the first ratio by the denominator of the second ratio, thus generating a new fraction as in the previous substage. Then they repeat this operation in reverse, multiplying the second ratio by the denominator of the first ratio, and obtaining a second new fraction. Finally, they compare the two new fractions and respond accordingly.

The detailed procedure for executing each step of each strategy is represented in Table 3. However, even without consulting this table, it will no doubt be apparent that the sequence of substages is formally identical to that which is observed during the earlier stages. The basic operation at each substage remains the same (ratio). However, at each successive substage children take account of some additional feature of the problem, and incorporate a new step or set of steps for dealing with it. Given this fact, the same two general factors may be postulated as underlying the process of strategy reorganization, namely specific experience and an increase in working memory. The working memory which is required for executing each of the strategies is listed in Table 3. As may be seen, the values once again increase from one at the beginning of the stage to four at the end.

So far, I have analyzed a task from each of Piaget's stages to make three simple yet central points: (1) as children pass through a sequence of substages within each major stage their strategies or rules for approaching the problems of that stage become increasingly complex, (2) one necessary condition for strategy restructuring is exposure to information of relevance to the specific domain in question, and (3) a second necessary condition is an increase in the working memory space for coordinating the information of relevance to the strategy. I turn now to a consideration of two further points: (1) How it is that working memory increases within any given stage, and (2) how it is that children make the transition from one major stage of thought to the next?

Table 3

Working Memory Demands for Executing Formal Operational Strategies on Noelting's Task

Strategy	Steps Involved		Items in Working Memory (i.e., Items Being Attended To)	Memory Demand
Isolated Centration			See Table 2	
Unirelational Comparison	Step 1	Compute number of water for every orange juice in A.	(i) Number representing $H_2O_A \div OJ_A$	1
	Step 2	Compute number of orange juice for every water in B.	(ii) Number representing $H_2O_B \div OJ_B$	2
	Step 3	Compare two stored products. Pick side with smaller number as stronger.		
Birelational Comparison	Step 1	Compute number of orange juice in B for every orange juice in A.	(i) Number representing $OJ_B \div OJ_A$	1
	Step 2	Multiply product of Step 1 by number of orange juice in A.	(i) Number representing $OJ_B \div OJ_A$ (product of 1) (ii) Number of OJ_A	2
	Step 3	Compare OJ_A and OJ_B. Note equality.	(i) Number in OJ_B (ii) New number in OJ_A (from Step 2)	2
	Step 4	Multiply factor which produced equality in OJ by number of H_2O in A.	(i) $OJ_A = OJ_B$ (ii) $OJ_B \div OJ_A$ (factor) (iii) Number representing H_2O_B	3
	Step 5	Compare new number of H_2O in A with number in A with number of H_2O in B.	(i) $OJ_A = OJ_B$ (ii) H_2O_A (new) (iii) H_2O_B	3
	Step 6	Given equality of OJ, pick side with larger H_2O as weaker mixture.		
Trirelational Comparison	Step 1	Compute total number of glasses in A.	(i) total A	1
	Step 2	Compute total number of glasses in B.	(i) total A (ii) total B	2
	Step 3	Compute common denominator (i.e., multiply total A by total B).	(i) total A x total B	2
	Step 4	Adjust number of OJ in A by same factor used to generate common denominator (i.e., total B).	(i) Common denominator (total A x total B) (ii) OJ_A (iii) Factor which produced denominator A (total B)	3
	Step 5	Adjust number of OJ in B by factor which produced common denominator.	(i) Adjusted number of OJ in A (ii) Common denominator (total A x total B) (iii) Factor which produced new denominator in B (i.e., total A) (iv) OJ_B	4
	Step 6	Compare adjusted OJ_A with adjusted OJ_B.	(i) Common denominator (total A x total B) (ii) Adjusted OJ_A (iii) Adjusted OJ_B	3
	Step 7	Given common denominator, pick side with larger numerator as stronger mixture.	(i) Common denominator (ii) $OJ_A \gtrless OJ_B$	2

DEVELOPMENTAL CHANGES IN ATTENTIONAL CAPACITY

As the reader will no doubt have noted, I have proposed four different quantitative scales, each of which shows a similar growth curve and each of which is presumed to exert a similar influence on strategic development. One possible explanation for this pattern is that there are four different working memories in the human psychological system, or at least four different sources of scheme activation. Each of these memories could then be postulated to exhibit its most rapid growth during a different Piagetian stage. An explanation which is more parsimonious, however, and which (to me, at least) is more satisfying, is the following: (1) There is one central working memory which can serve as a space for storing information or as a space for operating on it (cf. Broadbent, 1958; Pascual-Leone, 1969), (2) The underlying capacity of this working memory does not grow with age, at least after the age of 2 (cf. Case, 1978; Chi, 1975; Dempster, 1976; Simon, 1972), (3) The measured increase in storage capacity within each stage is due to a decrease in the capacity required to execute the underlying operations which are characteristic of that stage.

Symbolically, these three propositions may be represented as follows:

$o + s = k$

where o = the functional capacity required for executing a given operation

s = the functional capacity available for storing the products of that operation

k = a constant, equal to the total structural capacity of the organism.

To say that the *structural* capacity of the human organism does not change with development is not to belie the importance of the *functional* changes that occur; it simply pushes the chain of explanation back one step. Just as the increasing sophistication of children's executive strategies within a stage may be partially explained by increasing storage space, so the increasing storage space may be partially explained by the decreasing attentional control required to execute the basic operations which the strategies entail. Presumably one reason for the decreasing attentional control is the increase in general experience, that is, the practice in executing the basic operations across a variety of specific domains. However, it is conceivable that maturation might also place some limit on the speed of the automization process, particularly in the earliest stages.

DEVELOPMENTAL CHANGES IN BASIC OPERATIONS

Throughout this chapter I have argued (following Piaget) that the operations that characterize each major period of development are qualitatively distinct. This raises two questions: (1) how best to characterize the qualitative differences among elementary operations, and (2) how to account for the fact that the sequence and approximate timing of their emergence is invariant.

In discussing the achievements of each stage, I have spoken as though the differences between the underlying operations (sensorimotor, representational, concrete operational, and formal operational) were obvious. In fact, although their labels represent rather "natural" categories, they suffer from the same disadvantage as all such terms. The entities they represent are relatively easy to recognize, but not to define, and not even to discriminate once the examples are not prototypic. For the moment, the best definition I can offer is that a sensorimotor operation is one whose releasing component is some sensory input, and whose effecting component is a physical movement. A representational operation is one whose releasing component is some sensory input, and whose effecting component is an abstract encoding of that input. A "transformational," or "concrete operational" operation is one whose releasing component is an abstract coding of a situation, and whose effecting component is some other coding of the same situation. Finally, a formal operation is one which takes the product of two or more concrete operations as input, and generates some new coding as output. While these definitions capture some of the meaning I attribute to each type of operation, it remains to be seen whether they will adequately classify the full range of developmental phenomena.

What about the sequential relationship among the operations? Why does the emergence of an operation at one stage seem to await the attainment of a high substage of functioning at the previous stage? Piaget's position is clear: higher order structures build on and incorporate lower order structures. Until a structure at one level is fully consolidated, it cannot be used as a building block for assembling a structure at the next level. It seems to me that Piaget's position is fundamentally correct: the basic operations which are characteristic of any given stage are assembled out of the components of the previous stage, and the assembly process cannot take place until a reasonably high level of functioning has been attained at the previous stage. In keeping with the general framework which I have presented thus far, I would explain the necessity for attaining a high level of functioning at the previous stage in terms of the working memory demands of the assembly process, rather than in terms of "structural consolidation." Nevertheless, the basic form of the explanation would be the same.

Consider, for example, the transition from the stage of sensorimotor operations to the stage of representational operations. Why does the child not assemble the basic encoding and decoding operations which are characteristic of the representational stage until about the age of one year? It seems to me that the reason is that, until that time, the child does not have sufficient working memory to generate a set of sounds, compare them with those uttered by an adult, and modify his original utterance on the basis of this comparison.

As a minimum, it seems to me that the following schemes would be necessary in order to effect this sort of vocal modification (1) a scheme representing the vocal programme which generated the child's utterance, (2) a scheme representing the actual sound which was produced by the child and (3) a scheme representing the corresponding sound when produced by an adult. If these three schemes were necessary it would explain why babbling is observed from the first stages of development (scheme 1), why the production of sound by the child in response to adult sound is observed at 4-8 months (schemes 1 + 3), and why the reproduction of adult sound is not observed until the age of 8 to 12 months (schemes 1-3). It would also explain why socially appropriate or truly symbolic use of words is not observed until 12-18 months. In addition to schemes 1-3, a scheme representing the situation to be symbolized would be necessary for this achievement.

A similar sort of contingency might be present at the next transition point, where a certain minimum working memory using representational operations may be necessary for executing an elementary concrete operation. Consider the basic operation underlying the concrete strategies in Noelting's task--counting. Granted that even two-year-olds have some understanding of counting (Gelman, 1978), a certain functional storage space may still be necessary for counting in adult fashion. One unit of space may be required to monitor the set of objects just counted, one to monitor the next object to be counted, one to monitor the number just said, and one to monitor the number about to be said. Since a functional storage space of 4 is not attained during the representational period until age 4 or 5, this would explain why accurate counting is rarely observed prior to this age. It would also explain why children do not progress through Noelting's series of strategies until that time.

Finally, a similar sort of contingency may be present at the transition point from concrete to formal operations. Consider the basic operations underlying the formal strategies in Noelting's task--multiplication and division. If an understanding of multiplication requires an understanding that counting to x a given number of times (y) always yields the same result, then the minimum functional storage space which would be required to develop this would be three: one for the number being counted to (x), one for the number of times it was counted to (y), and one for the result which was obtained (xy). This would explain why instruction in multiplication and is not usually successful prior to the second or third grade. It would also explain why the first formal operational strategies on Noelting's task are not observed until the age of 10 or 11, when a multiplication or division can be executed while at the same time the product of such an operation is stored.

My exposition of the basic postulates of my theory is now complete. However, there are two corollaries which deserve some additional comment. These are (1) that any factor which affects the difficulty of an intellectual operation within a stage will produce a horizontal decalage, that is, a shift in the first stage at which the strategy involving that operation is observed, (2) that the shift from a functional memory of one to a functional memory of two within any given stage has important consequences for learning.

OPERATIONAL DIFFICULTY AND THE PROBLEM OF HORIZONTAL DECALAGE

If functional working memory is equal to working memory capacity minus the space necessary to execute whatever operation is required, and if the ability to employ a strategy of a given complexity is dependent on the functional working memory which is available, it follows that any factor which affects the space required to execute the basic underlying operations entailed by a strategy should also affect the age at which the strategy is first observed. This would include factors such as learning and experience, but would not be restricted to them. In infancy, for example, one would expect that secondary circulary responses would be observed earlier for motor responses which require little attentional control such as eye movement, than they would be for motor responses which require a good deal of attentional control such as hand movement. This is, in fact, the case (Cf. Watson, 1967). In early childhood one would expect that two-frame sentences could be repeated at an earlier age if the words involved were monosyllabic than if they were polysyllabic, even with word familiarity controlled. In middle childhood, one would expect that strategies requiring bidimensional centration would appear earlier for arrays which were easily quantifiable than for arrays for which quantification was difficult. Finally, in adolescence, one would expect that high level strategies entailing only multiplication would be observed at an earlier age than parallel strategies entailing division (which is normally experienced as "more difficult"). Similarly, one would expect that problems requiring the manipulation of large numbers should be solved at a later age than problems requiring the manipulation of small numbers (Collis, 1975).

In general, then, one would expect that functional working memory, and consequently the development of intellectual strategies, should not follow one growth curve but rather a series of parallel curves.

RELATIONAL CENTRATION AND THE PROBLEM OF LEARNING EXPLOSIONS

Implicit in my theory of development is the assumption which underlies a number of previous general theories (cf. Tolman, 1949; Pascual-Leone, 1976), namely that there is more than one kind of learning process at work in the human system. The sort of process by which automization occurs requires massive practice, and normally takes place only over a period of many years. By contrast, the sort of learning by which strategy acquisition takes place occurs very rapidly, and may require as little as one trial. The only real requirement is that the schemes whose connection is to be established be simultaneously present in working memory for some brief period of time.

Given that rapid relational learning requires the simultaneous centration of at least two schemes in working memory, it follows that there should be "learning explosions" associated with the transition from a functional memory of one to a functional memory of two within any given stage of development.

One such shift has in fact been noted by White (1970), at the time when children's functional working memory for concrete operational tasks goes from 1 to 2 (namely five years of age). Another such shift appears to occur for language tasks at the age when functional memory goes from one to two. Language learning from the age of 12 to 20 months appears to be a very slow, laborious affair. As soon as the child enters the two-word stage, however, a learning explosion occurs which has led a number of psycholinguists to conclude that language learning must be maturationally programmed. Why this "programming" would have to wait until about the age of 20 months might not be obvious within the context of linguistic theory, but in the context of the present theory the explanation would be as follows: Until age 20 months the sort of rapid learning which takes place within working memory does not have a chance to operate, because the requisite two units of working memory are not yet available. If this notion is correct, similar explosions in learning should be detected in infancy at about the age of four months, and in formal operational tasks at about the age of 11.

IMPLICATIONS FOR INSTRUCTION

The sort of instructional situation for which my theory has the clearest implications is one where the objective of the instruction is to teach students an intellectual strategy for tackling a class of problems, yet where the students have great difficulty in mastering this strategy via current instructional methods. Under these circumstances, it follows from the theory that students' difficulties may very often be traceable to one of the following sources.

1. The students are approaching the task with some preconceived concept or strategy. This concept or strategy is reasonable but oversimplified. As a consequence, it interferes with their apprehension of the correct strategy.

2. The students are incapable of coping with the informational demands which are placed on them by the teacher or the curriculum. That is, the demand which the learning situation places on their working memory is greater than the maximum which is available at their age level.

3. The functional working memory which the students have available for the particular task is less than the maximum which would normally be available at their age level, because they find the operations which the task requires to be unusually difficult.

Given that students' difficulties do stem from one of the above three sources, it also follows from the theory that the difficulties can be remediated in one of two fashions: either by waiting for the process of development to occur spontaneously, or by isolating the source of the difficulty precisely, and adjusting the instructional conditions so that it no longer occurs.

The option of waiting for development to occur spontaneously requires little comment. The appropriate age for the introduction of any particular strategy given currently available methods can always be determined empirically. One simply teaches the strategy using conventional methods at a number of different age levels, and selects that age at which the failure rate meets some minimum level. If there is no particular cost attached to delaying instruction in the strategy then, this option is a simple, straightforward means of dealing with students' difficulties.

What about the option of isolating the source of children's difficulties more precisely, and adjusting instructional methods to overcome them? There are many instances where there is a cost attached to delaying instruction in a strategy. Thus, this second option should also be explored. Exactly what guidance can be derived from the theory?

1. Consider first the possibility that students may be approaching the task with an incorrect strategy. This difficulty should be able to be reduced by a two-step procedure. The first step is to examine the errors which students are making on the task, and to diagnose the strategy which is leading them to make these errors. The second step is to provide the students with a sequence of activities which will demonstrate the inadequacy of their current strategy to them, and which will provide them with the opportunity to develop and consolidate a more adequate strategy.

2. Consider next the possibility that the instructional sequence may be overtaxing students' working memories. This difficulty should be able to be reduced by minimizing the number of items of information to which the students must attend in order to understand the basic task paradigm, and by maximizing the familiarity and salience of this information. (The more familiar and salient a cue, the less working memory needs to be devoted to the task of extracting and utilizing it.)

3. Finally, consider the possibility that the basic operations required by the strategy which is being taught may be over-taxing

students' working memories. This difficulty should be able to be reduced by analyzing the basic operations which are required by the strategy, and by providing daily practice in these operations throughout the curriculum.

The above steps constitute the core of what might be termed a "Neo-Piagetian" approach to the design of instruction. That is, they constitute the core of the approach which would be dictated by the Neo-Piagetian theory which I described in the previous section, for any situation where (1) the object of instruction is to teach a difficult intellectual strategy, and (2) the alternative of delaying instruction until a higher level of development has been reached is for some reason not a practical one.

My objective in the present section is to elaborate on the above general approach, and to provide the reader with sufficient information that he may apply the approach to his own area of interest, whether this be science teaching in the classroom or the design of new science curricula. In order to do this, I shall first present a concrete example of a science problem to which the approach was applied, and where a new "mini-curriculum" resulted. I shall then present some data on the effectiveness of this mini-curriculum, and of others like it. Finally, I shall provide a slightly more formal and detailed description of the approach. Hopefully, this description will permit the approach to be applied to a broader range of situations where the goal is to develop students' rational powers to their fullest.

A DIFFICULT SCIENTIFIC TASK: CONTROLLING VARIABLES

The instructional task which I shall use as an illustration has been studied in some detail by Inhelder and Piaget (1958). It is normally referred to as *Controlling Variables*. One of the tests which was designed by Inhelder and Piaget to assess children's understanding in this area is called *Bending Rods*. In this test, children are presented with an apparatus consisting of a set of rods which vary in length, diameter, material, and cross-sectional area attached to a stationary block of wood. The rods extend horizontally from the wood. The children are to utilize the apparatus to determine what makes some of the rods bend more than others when weights are placed on the ends of the rods. After they have conducted a preliminary investigation, they are asked to design an experiment to determine whether or not some particular variable (eq. rod diameter) exerts an effect on rod flexibility.

While the necessity of controlling variables in this test may appear quite obvious to the college educated adult, it is not at all obvious to the child. The task is rarely passed prior to adolescence, and even then is passed consistently by no more than 50 percent of the population. As a consequence, recent curricula in science have begun to include units on controlling variables which are based on Piaget's work, and which use this task or tasks like it as post tests (cf. Karplus, 1963). Even though children appear to enjoy these curricula, however, it is not always the case that they pass the Bending Rods problem when it is administered as a posttest.

Suppose, therefore, that one's objective was to teach children how to control variables, and that for some reason one did not want to wait until the last years of high school to do so. How would one proceed?

Diagnosis of Children's Incorrect Strategies

1.1 In order to determine whether children who fail the *Bending Rods* task do so because they apply a systematic but incomplete strategy, the first step I took was to examine Inhelder's protocols of children's responses to the task. As even a cursory examination of these protocols reveals, children in the age range from 7 to 12 generate responses which are highly consistent. For example, when asked to determine whether diameter exerts an effect on rod flexibility, they pick a pair of rods which differ in diameter but which also differ along a number of other dimensions. They then place an equal size weight on each rod and note whether or not there is a difference in vertical displacement. If there is, they conclude that diameter affects rod flexibility. If there is not, they conclude that it does not.

1.2 Having examined the incorrect responses which young children generate, my next step was to generate a hypothesis concerning the nature of the underlying strategy that children employ on the task. The first possibility which occurred to me was that children's strategy is to manipulate diameter and to observe the effect on flexibility, without any regard to other possible variables which should be controlled. A second possibility which occurred to me was that children's strategy might [illegible] to manipulate diameter *and* to control all possible confounding variables. The reason for their errors in this case would be they were less aware than older children of what other variables might be of importance.

1.3 In order to determine which of the two strategies children were using, I modified the testing procedure for the Bending Rods situation somewhat. I increased the length of time children were given for exploring the rods, and I asked them enough probing questions during the pre-test period to ensure that they discovered all the variables which were relevant. I then asked them to summarize their findings, and reminded them of any variable which they left out of their summary. Under these conditions, I discovered that children's responses remained essentially unchanged. They still selected a pair of rods which differed in a number of respects other than diameter. I therefore concluded that their strategy was to vary the independent variable of interest, and to note its effect on the dependent variable, without paying any attention to confounding variables. While this strategy is of course quite reasonable, it is also incomplete.

Design of a Sequence to Bring Children from the Incorrect to the Correct Strategy

2.1 My first step in dealing with children's incomplete strategy was to design an instructional paradigm which would permit them to determine on their own the consequences of their method of approaching the task. The *Bending Rods* task is a good assessment device, but it does not provide children with the sort of feedback which I felt they needed for realizing that their current approach was inadequate. A child who believes that diameter affects flexibility, and who sees that the thin rod which he has chosen does indeed bend more than the fat rod, receives no feedback from the task that his strategy is inadequate. He also has no motivation for searching out such feedback. In order to provide children with this sort of feedback, I decided to use a task which had been designed by a colleague of mine, Robert Kenzie (Kenzie, 1972). Kenzie's task is illustrated in Figure 1. The child is asked to determine which weigh more, the dark coloured rods or the light coloured rods. As may be seen, the rods are embedded in blocks which may also vary in weight. The types of rods vary from trial to trial, and the child's task is to establish their relative weight without removing them from the blocks. However, the child is allowed to check the validity of his conclusion after every trial by removing the rods and weighing them separately.

In addition to providing the child with a procedure for determining the effectiveness of his current strategy, the rod and block paradigm satisfies the three criteria which I mentioned in the introduction for minimizing the load on working memory. First, it minimizes the number of items of information which must be dealt with. There is only one possible confounding variable, not three or four as in the *Bending Rods* task. Second, it presents a task situation and a set of cues which are familiar. In the *Bending Rods* situation some of the relevant cues (e.g., rod shape) are unfamiliar. Finally, the cues which the task presents are both distinct and salient. In the *Bending Rods* task, a number of dimensions overlap. The cues which indicate that a rod is round, for example, are the same as those which indicate that it is large. Thus, the work of disentangling them is left to the subject. Similarly, the differences within any dimension are often hard to detect. The differences in diameter, for example, are on the order of 2-3mm. This leaves the work of isolating variables entirely up to the subject, and places an unnecessary load on his working memory.

2.2 Having found a procedure whereby the child could determine the effectiveness of his current strategy with minimal attentional effort, my next step was to present him with problems for which his current strategy was inadequate. I did this by inserting lead weights in the dark coloured blocks, and then presenting children with the visual array presented in Figure 2 (Case, 1974). When I did this I found that all the children chose the pair of blocks which was closest to them, and concluded that the silver rod (aluminum) was heavier than the gold rod (brass). As soon as they checked their conclusion by removing the rods, they realized they had made an error.

Figure 1

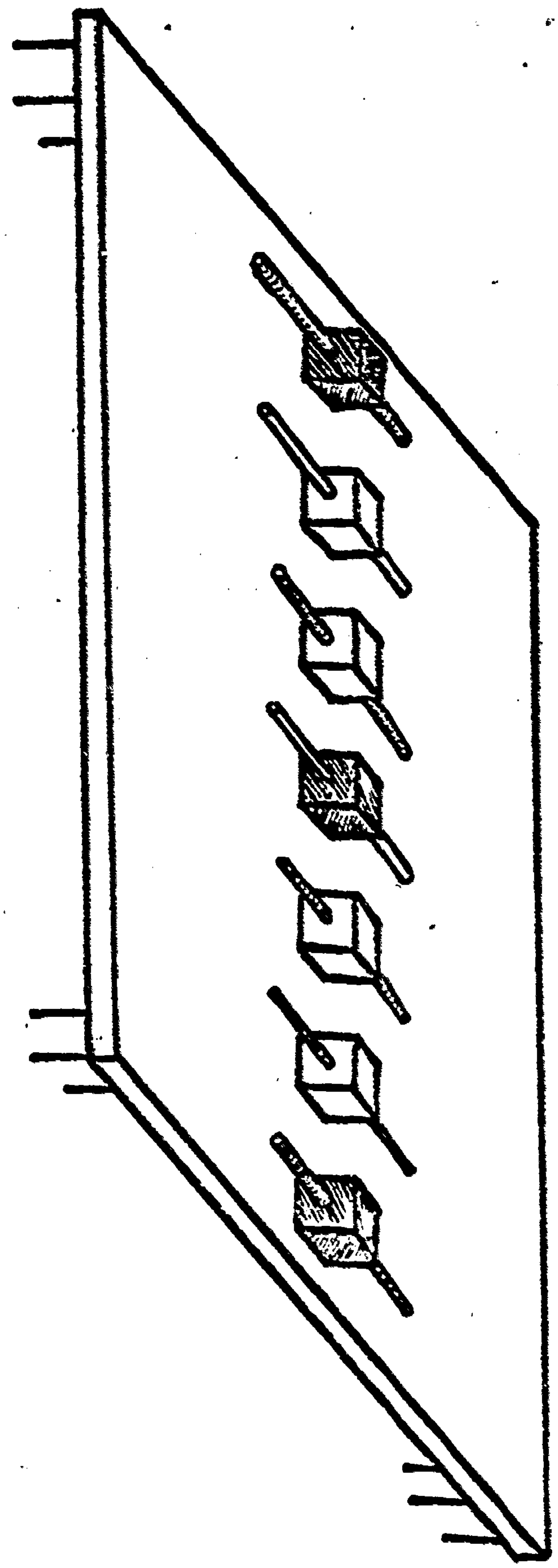
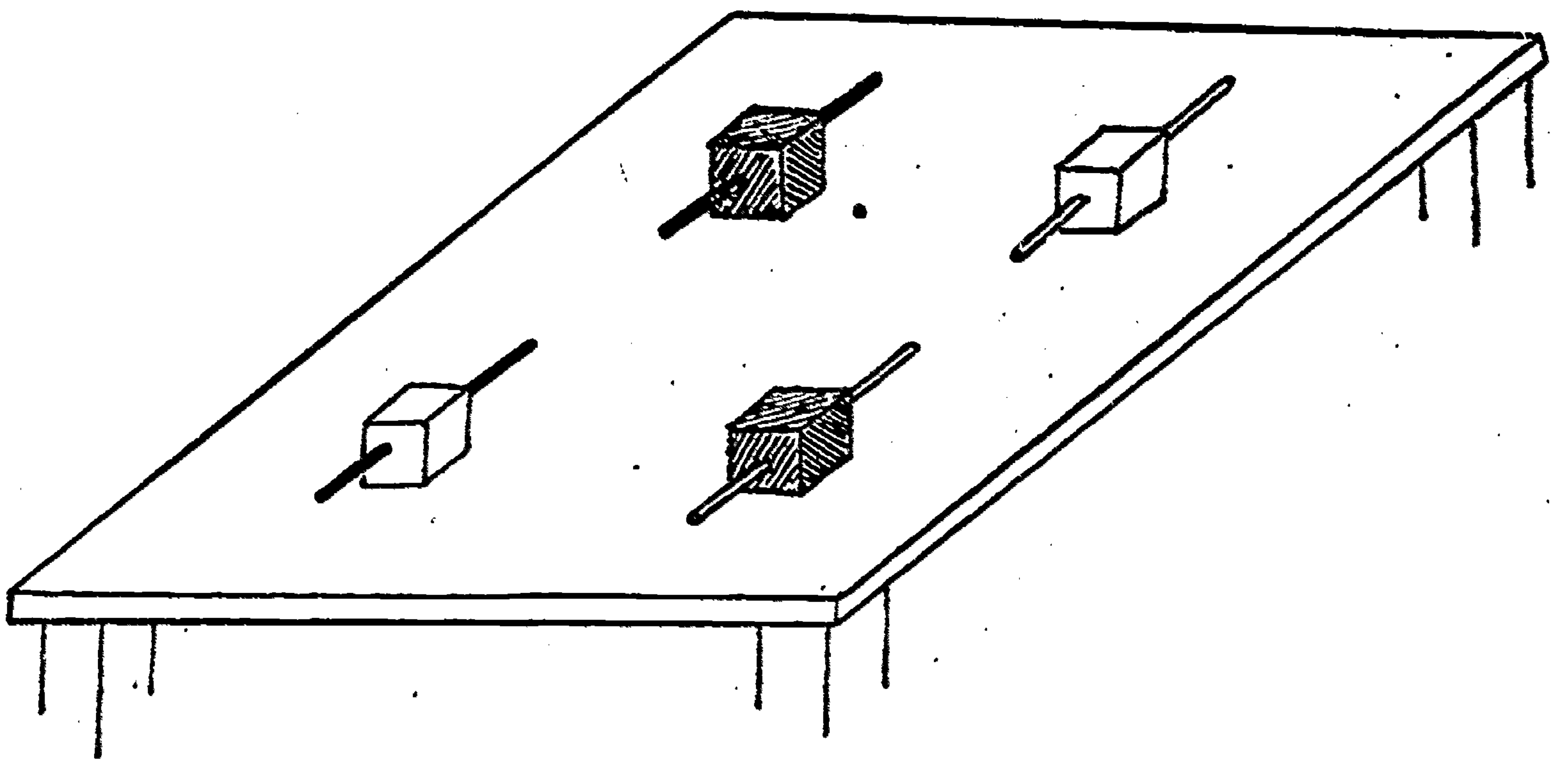


Figure 2



2.3 Having devised a demonstration of the inadequacy of the children's incorrect strategy, my next step was to devise an explanation for why the strategy was inadequate. I invited all the children to figure out the reason on their own. However, for those who were unable to do so (over half the children tested) I provided the following explanation:

> Feel these blocks. I fooled you because this block was so heavy that it pulled the balance down (gesture). It made the silver rod *look* heavier, even though it was not.

Note that the above explanation again satisfies the three criteria which were mentioned with regard to the load on working memory. First, it reduces the number of items of information which must be dealt with to a bare minimum. The language is simple, and the subject does not even have to focus on both blocks, only on the one which is heavy. Second, the explanation maximizes the familiarity of the information to be dealt with. No reference is even made to a variable as such, only to blocks and their weight. Finally, the explanation renders the cues which must be attended to salient verbally, and further highlights them by having the child feel the block.

2.4 Having demonstrated the inadequacy of the strategy which the child utilized spontaneously, my next step was to provide a demonstration of the correct strategy. I did this by inviting the child to think of a way he could have done the experiment so that he would have obtained the right answer. If he could not figure this out on his own (as very few could), I demonstrated the correct strategy as follows. I picked up a light block with an aluminum rod, and placed it on one side of the balance. I then picked up another light block with a brass rod, and placed it on the other side of the balance. Then I said:

> You should pick up two rods where the blocks are the same. See (releasing the balance). It doesn't fool you. The silver one doesn't look heavier this time.

Note once again that this demonstration places only a minimal load on the child's working memory. The number of items of information which need to be attended to is low, the content and language are familiar, and the perceptual configuration is extremely clear.

2.5 After demonstrating the correct strategy, I provided the following elaboration and explanation:

> Now pay attention carefully and I'll explain *why* the blocks have to be the same (putting two different coloured rods on the balance). Which is heavier? Right, the brass. Now see (putting a light block on each pan, but not connecting them to rods) when the blocks are the same, the brass one *still* looks heavier. The blocks don't fool you because they're the same (demonstrating the equality by removing the rods, and showing that the two blocks balance). See, they balance, so they can't fool you. Even if I use these two

(putting on two heavy blocks) they can't fool you, because they're the same. They can't make the silver one look heavier. But look what happens when I put two different ones on. See, this one can make the silver one look heavier, even though it isn't (demonstrating). It always works that way. If you make two blocks the same, they can't fool you. You can tell which rod is heavier. But if you don't, it (the heavy block) can fool you.

In retrospect, it seems possible that I might have been able to simplify the above explanation further. Nevertheless, even in the above form, the explanation showed the child why the correct strategy works in terms which are relatively simple and familiar, and in a context where the information which had to be coordinated was highly salient.

2.6 My final step was to provide a period of practice, coaching, and generalization. This practice took about 80 minutes, and was spread across four sessions. After the above demonstration had been provided, children were given several more examples where the relative weight of two (new) rods had to be determined. During this period, they were allowed to proceed on their own, and I only intervened if they made some error. After each trial, I took out the rods and allowed the child to check the accuracy of his inference. If the child had made an error, I repeated my explanation and demonstration.

On the second day I reviewed the same task and then presented the child with a situation where the two variables in question could not be disassociated from each other physically. The situation involved bouncing two different kinds of squash balls from different heights. If the child made an error, I drew an analogy to the block situation, and asked "How do you know it (eg., *bounced higher*) because (eg., *it's made of harder rubber*)? Maybe it's just because (eg., *It was dropped from higher up*).

On the third day, I again reviewed the block demonstration, and then introduced a three variable problem. This problem involved determining which of two rollers would win a race down an inclined plane. The rollers were of different diameters and different materials. In addition, some were filled with wax and some were hollow. If the child controlled one of the two possibly confounding variables, but not the third, I told him he had been "fooled," and asked him to look more closely to make sure that the two objects were the same in all respects except the one he was interested in. Finally, at the end of this session, I introduced a counter-suggestion: "Would this be another fair way to prove it?" This sensitized the child to the possibility that another test which yields the same results is not necessarily an adequate one.

On the fourth day, again after a review, I introduced a task for which the number of variables was the same as the *Bending Rods* problem. This task involved dropping chips of varying sizes and materials and thicknesses down long tubes filled with water. The chips also contained holes which varied in sizes and positions. The question was what variables affected the speed with which the chip would float down to the bottom of the tube. Once again, I left the child to his own devices unless he slipped back into his original strategy or failed to notice one of the variables. Once again, too, I presented a counter suggestion at the end of each trial.

Although it may not be obvious, the above sequence did more than simply provide children with practice in consolidating their newly acquired strategy. It also minimized the load on their working memory while they did so. New components were introduced to the task only one at a time, and after extensive practice on the basic strategy. This minimized the number of items of information to be dealt with at any one time, and maximized the familiarity of previous items of information. In addition, when any new component was introduced, it was always rendered salient by me at first, and then gradually allowed to assume its normal salience as the subject became accustomed to taking it into account.

Finally, there was very probably a modification of the strategy which was used for success, which resulted in a further reduction in the load on children's working memories. When adults perform the task, they appear to form a mental checklist of the variables to be controlled and then search for rods which meet all of the appropriate dimensional criteria at once. The effect of my asking the children "to check again to see if they had missed anything" was very probably to encourage them to do in sequence what the adults do in parallel. For example, instead of looking for a long rod which was brass, thin and round, they probably just looked for a rod which was long and similar in its global appearance to the short rod they had already selected. Then, after they had found a long rod, they very probably scanned its perceptual characteristics one by one, and compared them to those of the short rod. This sort of strategy would reduce the working memory load associated with controlling variables from three to one.

Effectiveness of the Neo-Piagetian Approach

To date, only a few studies have been conducted on the effectiveness of the approach which I described in the previous section. However, the results have been uniformally positive.

The *Control of Variables* program was tried out with a group of eight-year-olds, and compared with the effect produced by a period of structured test experience (Case, 1974). By itself, the structured test experience produced some improvement in performance, as is often the case with Piaget's formal tasks (cf. Stone and Day, 1978). Twenty percent of the subjects who received this treatment showed clear evidence of controlling variables on the *Bending Rods* posttest. By contrast, however, 80 percent of the subjects who received the neo-Piagetian curriculum showed a comparable degree of mastery. As a consequence, the mean score of this group was higher than that normally attained by untrained 15 and 16-year-olds. Furthermore, there was no decrement in performance when the test was readministered two months later. In fact, there was an increment. These results have now been replicated on two occasions, using a variety of posttests which the children do not encounter during the training period (cf. Case, 1977).

A program for teaching the *Missing Addend* problem (i.e., 2 + □ = 5) was tried out with a group of kindergarten children, and the results were compared to those produced by the curriculum currently in use in the California school system (Gold, 1974). On a posttest given two days after the instruction, only 10 percent of the group receiving the conventional curriculum showed evidence of having mastered the task. By contrast, 80 percent of the group who received the specially designed curriculum showed a comparable degree of mastery.

In a subsequent study, the same program was tried out with a group of kindergarten and grade one children, as well as with a group of math-disabled grade two children (Gold, 1978). In addition, the program was compared to a program based on Gagné's approach. When compared to the conventional approach to instruction, the results were essentially identical to those mentioned above. On a posttest administered one month after the instruction, none of the children who received the conventional program performed at the designated mastery level. By contrast, 72 percent of the children who received the neo-Piagetian program performed at that level. There was no significant quantitative difference between the neo-Piagetian and the Gagné based programs. However, interestingly enough, there was a qualitative difference. The students who had received the neo-Piagetian program continued to solve the problem by the strategy which they had been taught. By contrast, many of the students who received the Gagné based instruction used a different method from the one they had been taught.

To date, only two other systematic evaluations of the neo-Piagetian approach have been conducted. In the first, a neo-Piagetian conservation training program was administered to a group of middle class kindergarten children with working memories of two and three (Case, 1977). Its effect was compared with that produced by a period of either structured test experience, or structured test experience coupled with informative feedback. Once again, the two control treatments both had a positive effect. On a posttest which was administered several days after the instruction and which utilized different materials, 23 percent of the children receiving the structured test experience showed clear evidence of conservation, and 32 percent of the children receiving the test experience plus feedback showed a comparable degree of mastery. By contrast, 79 percent of the children receiving the developmentally based curriculum satisfied the mastery criterion.

Finally, similar results were obtained with a neo-Piagetian curriculum for teaching children to solve *Proportion Problems* (Gold, 1978). This program was tried out with groups of normal grade four and five students, as well as with a group of math-disabled grade six and seven students. It was compared with the effect of a conventional curriculum, as well as with a Gagné-based curriculum. On a posttest given one month after the instruction, only 22 percent of the children in the conventional group showed clear evidence of having mastered the concept. By contrast, 100 percent of the neo-Piagetian group attained the designated mastery criterion. The Gagné program was also quite effective for the normal group. Seventy-eight percent of the children in this group succeeded on the posttest. However, it was not significantly better than the conventional instruction for the math-disabled group. Only 33 percent of the math-disabled children in the Gagné group succeeded on the posttest. One qualitative result was again of interest. Virtually all successful subjects in the neo-Piagetian groups utilized the strategy which they had been taught on the posttest. By contrast, many of the subjects in the Gagné group, even those who succeeded, utilized a strategy which was different from the one they had been taught.

Although only four experimental studies have been completed so far, a number of case studies have been conducted. Once again, the results have been quite consistent.

Steinbach (1977) applied the approach to teaching her son how to tell the time. She found that his incorrect strategy was to use the numbers on the clock to read both the minutes and the hours. He responded well to her explanation of why this was not correct, and to coaching in the correct strategy.

Lam (1977) applied the approach to teaching the missing subtrahend problem. She found that the error which children exhibited was the same as they exhibit on the missing addend problem. They responded well to a program which was formally the same as that which was described above, although it did not use faces for the initial introduction.

Stevens (1977) worked with two children who were having difficulty learning to add fractions. He found that one child added both the numerators and the denominators without converting to a common denominator. The other child found the common denominator but then did not convert the numerator. The treatments which he devised were different for each child, but both appeared to be successful.

On the basis of the case study data, it may be concluded that the neo-Piagetian approach has a reasonably wide degree of applicability. On the basis of the experimental data, it may be concluded that, when the approach *is* applicable, it can produce results which are dramatically superior to conventional curricula. Finally, there is even some indication that the results may be superior to those produced by Gagné-based curricula, at least for those students who need the greatest assistance.

This being the case, it seems worthwhile to provide a description of the approach which is sufficiently general to cover a variety of instructional problems, and which is sufficiently detailed and concrete to permit easy application by practitioners.

Detailed Specification of the Neo-Piagetian Approach

Diagnosis of Reasonable but Oversimplified Strategies

The first task of an instructor is to determine whether or not the students in the target population tend to approach the task with an oversimplified strategy. If they do, he must characterize their strategy with sufficient precision that he will be able to work out a procedure for demonstrating its inadequacy. In order to accomplish this objective, the following steps are useful.

1.1 The first step is to present the task to be performed to a group of children in the target population, and to record the errors which they produce. This is of course the cornerstone of the developmental method (cf. Binet, 1903). If children are capable of executing the task after a brief introduction and demonstration, there is no reason to proceed any further, since the task is clearly not one which they find difficult. If they are not capable of executing the task, however, and if they tend to arrive at the same wrong answer consistently, then it is likely that they are applying a strategy which is systematic yet oversimplified.

1.2 The second step is to generate hypotheses concerning the nature of the oversimplified strategy. In the examples which were presented, the nature of the oversimplified strategies became obvious as soon as the errors were examined. In situations where this is not the case, however, it may be useful to watch the sequence of motor and eye movements which the children exhibit as they execute the task, and to ask them how they arrived at their answers. Another technique is a rational rather than an empirical one: Ask yourself whether there is some modified problem, or some reduced set of information for which the children's answers could actually be correct. Then specify the strategy for solving that problem.

1.3 If more than one strategy might possibly underlie children's errors, the next step is to gather data which will permit a choice to be made among them. The most powerful technique for accomplishing this objective is to present children with a modified version of the task such that, if they are approaching the task one way, they will generate one response, and if they are approaching it another way they will generate a different response. This technique was originally designed by Piaget and was illustrated in both the *Controlling Variables and Missing Addend* problems. Further illustrations are available in Noelting (1975) and Siegler (1978).

1.4 Having determined the strategy which children use spontaneously, it is sometimes useful to specify it as a series of steps unfolding in time. A useful technique for describing a strategy in this fashion is analogous to that involved in writing computer programs. First break the strategy down into a series of global steps. Then break each global step into a series of substeps. The description may then be "debugged" or refined by reading each step to an adult, and instructing him to do only what he is told. If a point is reached where the adult's behavior deviates from that observed in the population in question, then some modification in the description of the strategy must also be introduced.

Modifying Inadequate Strategies

Having determined the strategy which children apply to the problem spontaneously, the next task is to design a series of activities which will lead the child from this strategy to one which is more effective. This of course requires that the instructor be able to specify the strategy he wants to teach. However, under normal circumstances this is a trivial problem. Given that the student's spontaneously-applied strategy and the strategy to be taught have both been specified at a level of detail which seems appropriate, the following steps are useful for creating an instructional sequence.

2.1 The first step is to design a procedure so that the child will be able to determine whether or not his current strategy is effective. In both the *Controlling Variables* and the *Missing Addend* examples, the task was set in a situation similar to one which the child encounters in his daily life, and the indicator of success was one with which the children were already familiar. Regardless of whether or not an already-familiar task situation is used, the important thing is that the goal of the task be made clear, and that the child be provided with a meaningful procedure for determining *on his own* whether or not he has reached it.

2.3 The third step is to help the child to understand *why* his spontaneous strategy does not work. The most obvious technique to employ at this step is to invite the child to figure out the reason on his own. If he cannot do so, an alternative is to guide him to the realization with a series of probing questions or to provide him with a brief didactic exposition as was done in the *Control of Variables and Missing Addend* examples. One final possibility is to design a demonstration using "thinking out loud." Under these conditions, the teacher models the incorrect strategy, wondering aloud why it does not work. He then "discovers" the reason, and sets about finding a better approach. This technique is often used on television shows such as Sesame Street. Its effectiveness has also been demonstrated experimentally (cf. Sullivan, 1967; Zimmerman and Rosenthal, 1974).

2.4 The fourth step is to prepare a demonstration of the correct strategy. Once again, guided discovery, didactic exposition, and modeling may all be incorporated into the instructional sequence at this point.

2.5 The fifth step is to devise an explanation of why the correct strategy works more effectively than the spontaneously-applied strategy.

2.6 The sixth step is to provide a period of practice in using the new strategy, together with the opportunity to transfer it to new and more complex situations.

Reducing the Load on Working Memory

The load on working memory cannot be taken into account after the strategy to be taught has been selected and the sequence of the instructional activities has been planned. Rather, it must be taken into account at each step in the design process (i.e., Steps 2.1 - 2.6). Although no sequentially ordered set of activities can be suggested for minimizing the load on working memory, three considerations which should be taken into account may be suggested.

3.1 The first consideration is the number of items of information to which the child must attend at any point in the learning sequence. By definition, the lower this number, the smaller the load on working memory (cf. Broadbent, 1958; Miller, 1956). In designing the paradigm for demonstrating the inadequacy of the student's current strategy, this number may be minimized by asking what features of the task are absolutely essential, and what features can be eliminated without changing the basic goal which is to be achieved. In designing the feedback, the information load can be minimized by insuring that success or failure is indicated by the presence or absence of only one or at most two cues. Finally, in designing the explanation for the inadequacy of the current strategy, the information load can be minimized by referring to one aspect of the task at a time, and by using language which is as simple as possible. This means that sentences should be short, nouns should be concrete, and verbs should be in the active voice.

The same points may be made with regard to the selection and introduction of the strategies to be taught. After the various possible ways of succeeding at the task have been identified (either by experimental or rational analysis), the one which is the simplest from a conceptional point of view should be selected. All possible complications should then be stripped from this strategy, and steps which require parallel consideration of cues should be altered to permit sequential consideration whenever possible. The demonstration of the strategies should then be arranged so that only one cue or at most two, need to be considered at a time. In addition, the explanation should be constructed so that the language is concrete and minimally complex. Finally, as the complications which were stripped from the task paradigm initially are reintroduced, care should be taken to insure that only one new feature is added to the problem at a time.

3.2 The second consideration is to maximize the familiarity of the items of information to which the child must attend. The more familiar a cue, the less working memory need be devoted to the task of extracting it from its context. Similarly, the more familiar a response, the less working memory need be devoted to its execution. In order to maximize the familiarity of the cues and responses at the outset of the training, it is of course necessary to know something about the child's previous experience and his repertoire of operations. However, given that the instructor has some acquaintance with the students he intends to teach, this does not usually constitute a problem. In order to maximize the familiarity of the cues and responses in the course of the training, it is important that the pace be gradual. When any new complication is introduced, a good deal of practice should be provided before further cues are added. It may also be desirable to "back down" to simpler versions of the problem until each new complication is mastered. For example, given a problem with components a, b, c, d, it may be desirable to introduce them as follows: a, a+b, a+c, a+b+c, a+d, a+b+d, a+b+c+d.

3.3 The third consideration which must be taken into account if the information load is to be minimized is the salience of the stimuli to which the subject must attend. The more salient a stimulus, the less working memory need be devoted to the task of extracting it from its context (cf. Pascual-Leone, 1969, 1974; Case and Globerson, 1974). The salience of cues may be altered either by redesigning the task materials or by verbally drawing subjects' attention to cues which are not salient. Since salience is a variable which can change with experience, the same principle can be applied as was mentioned in 3.2. That is, as subjects become practiced at the task, the salience of the cues to which they must attend can be gradually decreased to their original level (cf. Scardamalia, 1977).

Maximizing the Automaticity of Basic Operations

The sequences of instruction for teaching the *Control of Variables* problem and the *Missing Addend* problem were isolated ones. No attempt was made to design a comprehensive curriculum which would bring a whole new domain of tasks within a child's competence. Since this is very often the object in practical situations, however, it should not be forgotten that the amount of working memory which is available to children is not an unalterable quantity. Although its maximum value at any age level may be fixed by the child's level of development, considerable variation can be expected as a function of the degree of automaticity of his basic operations. What this implies is that a concern for conceptual strategies and a concern for "basics" should proceed hand in hand. In the curriculum for elementary arithmetic, for example, students should have massive opportunities for practicing the basic operations of counting and addition. Otherwise these operations will take up so much working memory that little will be left over for considering the complications of the tasks to which these operations must be applied (e.g., the position of the box and the equal sign). Similarly, in the curriculum for elementary science, massive opportunities should be provided for abstracting variables which are of interest in a situation and for determining the value of these variables for a variety of objects.

One final point is worth mentioning. Throughout this chapter I have spoken of the general procedure which I have described primarily as a tool for the systematic design of curricula. There is another use to which the procedure can be put which has a much lower cost, and perhaps wider ultimate utility. That is the improvement of conventional classroom instruction by the suggestion of informal on-the-spot remediation techniques. Regardless of how well designed a particular curriculum may be, and regardless of how motivated the students, it is not normally the case that every student who is capable of grasping a particular concept or skill on any given day actually does so. The informal reports I have received from teachers suggest that the general procedure which I have described--once it is mastered--enables them to deal with the difficulties of individual learners much more quickly and effectively. They report that they are able to diagnose the underlying reason for the difficulties which their students encounter quite rapidly, and to invent supplementary exercises on the spot for helping them overcome these difficulties. Scardamalia (personal communication) has received similar feedback from the teachers in her training program, which utilizes a similar neo-Piagetian approach. It may conceivably turn out to be the case, then, that the neo-Piagetian methodology which I have described will prove most useful not as a tool for curriculum designers, but for regular classroom teachers who are interested in tuning their instruction more finely to the cognitive strategies and resources of their pupils.

SUMMARY AND HISTORICAL PERSPECTIVE

At the beginning of this chapter, I mentioned that the theory I would present would be based on Piaget's account of the development of scientific reasoning, but that it would incorporate several notions whose origins lie in contemporary cognitive science. In conclusion, it seems worthwhile to point out which aspects of the theory are Piagetian, and which aspects of the theory constitute modifications inspired by contemporary work. It also seems worthwhile to specify what the consequences of the modifications are, both with regard to the sorts of theoretical problems that can be solved and the sorts of instructional implications that may be suggested.

The following postulates of my theory have been taken directly from Piaget:

1. Development proceeds through a series of four major stages: the sensorimotor stage, the preoperational stage, the concrete operational stage, and the formal operational stage.

2. At each stage, the type of intellectual operation of which the child is capable is different.

3. The operational structures of later stages build on, yet transform, the operational structures of earlier stages.

4. Within each stage, a series of qualitatively distinct substages may be identified.

5. There is a formal parallel between the sequence of substages through which the child progresses during the early stages development and the sequence of substages through which he progresses during later stages. (In Piaget's theory this is referred to as vertical décalage.)

6. Specific experience constitutes a necessary but insufficient condition for transition from one substage to the next, or from one general stage to the next.

7. Before specific experience can be appropriately utilized, some sort of change in the child's general level of operativity is necessary as well.

8. Given that this level of operativity has been attained, and given that the child is exposed to appropriate experience, change takes place through the attempts of the child to eliminate inconsistency and to produce a coherent picture of his environment.

The following postulates of my theory have been taken from work in contemporary cognitive science, and constitute modifications of the Piagetian position:

1. Developmental structures are best represented as groups of executive strategies (cf. Simon, 1962), rather than as logicomathematical groupings, or groups.

2. The general factor in development (that is, the factor transcending the presence or absence of any specific structure) is best conceptualized as a quantifiable level of working memory (cf. McLaughlin, 1963; Pascual-Leone, 1969), rather than as a characteristic of a structure of the whole.

3. Change in the general factor is best conceptualized as a stemming from an increase in the automaticity of basic operations, rather than from the spontaneous equilibrative activity of the child. While equilibrative activity is one potential source of changes in automaticity, it is not the only one. Practice and maturation might be expected to have an equal effect.

None of the above three changes are completely incompatible with Piagetian theorizing. Genevans have for some time suggested that, had Piaget done his pioneering work after the revolution in cognitive science rather than before it, he might well have used the computer-derived notion of a strategy rather than the logic-derived notion of a grouping or group in order to represent children's operational structures (cf. Cellerier, 1972). In addition, the notion of operational automaticity bears a similarity to Piaget's notion of operativity, and together with the other two notions, might better be conceived of as an explication of Piaget's notion of stage transition rather than an outright modification. Nevertheless, although the changes appear to be broadly compatible with Piaget's account of development, and although none of them individually is unique to the present theory, taken together they do generate a picture of development which has its own unique organization, and which suggests answers to at least three theoretical problems that are difficult to solve within the Piagetian framework.

1. The problem of learning presents a serious problem for Piagetian psychologists. Since general structures are seen both as the products of development, and as the only real mechanism of development, it is hard to explain the results of training studies which show that children can be enabled to acquire certain structures many years before they could do so spontaneously, and many years before they acquire the general structure of which the specific structures are normally a part. Within the present framework, it is possible to see how genuinely effective strategies, which are a product of true understanding, can be generated by training, without requiring a general structure of the whole.

2. The existence of horizontal décalages, that is, the acquisition of a given level of functioning at different ages for different content areas, is difficult to explain within the classical Piagetian framework. Within the present framework, this can be explained by the fact that different demands are placed on working memory by different tasks, either as a result of the number of items to be coordinated (cf. Pascual-Leone, 1972), or as a result of a different degree of operational automaticity.

3. Finally, the new theory suggests a reason for the fact that children's language learning evidences a great spurt at the age of about two years, and that their learning of school-type relationships evidences a similar spurt at about the age of five or six years. That Piaget's theory does not offer an explanation for these phenomena can not really be cited as a "problem." Nevertheless, the new theory highlights the similarity in these phenomena and provide an explanation for it.

Given the similarities between the present theory and Piaget's theory, it is of course not surprising that there are similarities in the instructional implications as well. The following features of my instructional approach follow directly from Piaget's theory, and in fact have been suggested previously either by Piaget himself, or by those who have attempted to apply his ideas to education.

1. Begin by assessing students' current level of functioning.

2. Present the children with tasks which require some (moderate) extension of this level of functioning.

3. Provide children with opportunities for consolidating and extending a new level of functioning once they have attained it.

The following suggestions do not follow directly from Piaget's theory, but from the elements of my theory which derive from contemporary cognitive science:

1. The assessment of children's initial level of functioning can be done by noting the strategy with which the child approaches the instructional task spontaneously.

2. While children should be shown what is wrong with their current strategy, a number of techniques, including modeling and didactic exposition, may be used for introducing a more adequate strategy.

3. In introducing a new strategy, or showing the problems with an old one, great care should be taken not to exceed the capacity of children's working memory.

4. Higher order gains in understanding can be permitted by drill in lower order operations.

As is the case with the theoretical modifications, the instructional modifications suggest solutions to a number of problems which have traditionally beset the educator interested in translating Piaget's theory into practice.

1. The first of these problems is how to assess children's current level of functioning. The assessment of children's "logical structures" is by no means an easy matter, from either a theoretical or practical point of view. The same is true for the specification of the structure required to learn a given type of content (cf. Case, 1978). By contrast, the assessment of children's spontaneous strategies, and the specification of the strategy to be taught, are relatively straightforward activities.

2. A priori determination of what will constitute "moderate novelty" is problematic within a classic Piagetian framework. In the present framework it may be defined as the addition of one new variable or item of information.

3. What constitutes consolidation, and exactly how much improvement can be expected via instruction, are difficult to specify within the classic Piagetian framework. In addition, there is a general pessimism about the possibilities inherent in instruction, due to the fact that the structure of the whole functions both as the product of development and the limiting factor on future development. Within the present framework, these difficulties are eliminated. The only need is to keep the complexity of the task within the learner's available capacity. As long as this can be done, there is no limit to the learning which is possible.

If the instructional approach I have outlined bears a resemblance to the sort of approach which would be suggested on the basis of Piaget's theory, it bears an even stronger resemblance to the sort of approach which has been suggested by Gagné, on the basis of his theory of cumulative learning. The reason for this is historical. I did not begin with a theory of development and attempt to apply it to the task of improving educational technology. Rather, I began with an educational technology (Gagné's), and attempted to apply it to the task of fostering young children's intellectual development (Case, 1968). What I discovered as a result of this attempt was that Gagné's approach had to be modified in order to take account of young children's limited working memory and their tendency to apply incorrect strategies in response to salient perceptual cues (Case, 1968).

As the reader who is familiar with Gagné's approach may already have noted, then, the approach that I have developed is similar to his in the following respects:

1. It suggests that the first step in improving children's instruction is to analyze the task which they are to be taught, preferably as a step-by-step strategy which unfolds through time.*

2. It suggests that the next step is to assess the learner's entering behaviour.

3. It suggests that the sequencing of instruction should be based on a careful analysis of the steps which separate the learner's initial behaviour or skill level from the level to which the instructor desires to bring him.

On the other hand, the approach is also different from Gagné's in the following respects.

1. It recommends the assessment of children's entering behaviour not as a set of isolated components, but as the same sort of organized strategy as is desired at the conclusion of the instruction.

2. It recommends the sequencing of activities so that the load on the learner's short-term memory is minimum.

3. It recommends the constant prodding of the learner to think out the consequences of his current approach and to think of some modification of them.

A similar point can be made with regard to the theory of development that I have presented. If this theory bears a close resemblance to Piaget's theory in its basic postulates, it bears an even closer resemblance to Pascual-Leone's theory. Once again, the reason for this is historical. Having developed an instructional approach that highlighted the importance of children's limited working memory, and their tendency to apply oversimplified strategies in response to salient perceptual cues, I began to search for a theory of development which would assign these limitations a central role. When I encountered Pascual-Leone's neo-Piagetian theory (Pascual-Leone, 1969), the fit was a natural one, and I worked within that framework for some time. The

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*Actually, in Gagné's early work he did not propose that the analysis should be a temporal one. This suggestion was introduced later, presumably as a result of work in computer simulation and information processing (cf. Anderson and Faust, 1973; Gagne and Briggs, 1976; Resnick, 1967).

present theory did not result directly from an attempt to extend Piaget's theory, then, but rather from an attempt to extend Pascual-Leone's theory. The particular stimulus which prodded my own extension was the attempt to explain the cyclic pattern of growth which emerged when I applied the sort of analysis Pascual-Leone had already developed for concrete operational tasks, to tasks at other developmental stages.

As the reader who is familiar with Pascual-Leone's theory may already have noted, then, my theory is similar to his in the following respects:

1. It suggests that Piagetian structures can be thought of in the fashion suggested by Simon: as groups of executive strategies which govern the unfolding of performance through time.*

2. It suggests that an important reason that complex strategies are so slow in developing is that the requisite working memory is also slow in developing.

On the other hand, the approach is also different from Pascual-Leone's in the following respects:

1. In my theory, it is assumed that the underlying reserve of attentional energy (Pascual-Leone's M) is fixed from a very young age. In Pascual-Leone's theory, it is assumed to grow.

2. In my theory, measured differences in span are ascribed to differences in operational automaticity. In Pascual-Leone's theory, measured differences in span are ascribed to differences in underlying capacity. The amount of attention required to execute well-practiced operations is presumed to be constant.

3. In my theory, a distinction is made between within-stage and across-stage development. Within-stage development is presumed to be lateral (it involves the addition of new loops to pre-existing strategies), whereas across-stage development is presumed to be hierarchical. In Pascual-Leone's theory, no such distinction is made (although the mechanism for it does exist, via LM learning).

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*In Pascual-Leone's original work, his structural analyses are atemporal, just as are Gagné's (cf. Pascual-Leone and Smith, 1969; Pascual-Leone, 1969). However, the suggestion that the analyses should be temporal has been made quite explicit in his recent work, presumably as a result of work in computer simulation and human information processing (cf. Case, 1970, 1974; Pascual-Leone, 1976).

When seen in historical perspective, then, it becomes clear that the theory and technology which I have proposed in the present chapter combine the basic elements of a number of different theories or technologies, most notably those of Piaget, Pascual-Leone, Gagne, and (with the emphasis in strategies) Simon. Although the individual parts are all familiar ones, however, it is my hope that the organization which I have suggested in this chapter will prove to be genuinely novel, and that it will lead to further research and understanding, both with regard to the spontaneous development of children's rational powers, and with regard to methods of optimizing this development in the classroom.

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A THEORY OF TEACHING FOR CONCEPTUAL UNDERSTANDING, RATIONAL THOUGHT, AND CREATIVITY

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INTRODUCTION

We accept the Educational Policies Commission's (1961) argument that the central (but not only) purpose of American Education is the development of the rational powers. Our objective in this chapter is to develop a comprehensive theory to provide a framework for designing and implementing instruction to facilitate the development and use of the rational powers. Importantly, we do not view the development of the ability to think as divorced from subject matter. One does not develop the ability to think, without some object, event or situation to think about. Further, as our theory develops, we will argue that our statements do not apply to purely rational behavior alone, but that they apply to motivation, attitude, values, and creativity as well. Indeed, in our view, the primary educational goal is to contribute to the growth, development, and evolution of the creative process. All other aspects of instruction are subsumed by this purpose.

The central aim of education then can be viewed as the development of the rational powers provided it is acknowledged that not all mental activity of value is purely rational. But this view has two very serious shortcomings. First the rational powers simply represent a list of powers that appear to be important but have no common thread tying them together. What is a rational power anyway? Why did the Educational Policies Commission list ten and not six, seven or eleven? And second, how do these powers develop? To these questions the Educational Policies Commission has not provided sufficient answers. For answers to these questions, we must turn to the field of developmental psychology.

Recent advances in developmental psychology have provided a framework for conceptualizing what the key mental abilities and cognitive strategies are and how they are acquired during childhood and adolescence. Piagetian psychology in particular has been extremely helpful in suggesting fundamental mental abilities and in suggesting sequences through which reasoning develops. Crucial questions that must be addressed are: What are the fundamental mental abilities and cognitive strategies? How are they normally acquired? How can instruction be designed and implemented to encourage their development and use if their out-of-school, i.e., "spontaneous," acquisition is slowed or lacking?

A primary objective of this chapter then is to provide answers to these questions. Because of our fundamental assumption that thinking and creativity do not develop without something to think about, we will first attempt to elucidate the nature of what we teach--that is, concepts and conceptual systems. We will include a classification scheme of the various kinds of concepts and their different sources of meaning as well as discussion of how concepts are mentally related to form both descriptive and theoretical conceptual systems. This will be followed by a discussion of the psychological mechanism responsible for concept formation.

We then turn to a discussion of a three-phase learning cycle which, if carried out properly, will facilitate students' meaningful understanding of concepts and conceptual systems. If we stopped at this point, however, the students will have meaningful understanding of important concepts and conceptual systems but they may have not developed their abilities to modify those conceptual systems or build new ones if their present conceptual knowledge is found inadequate. Thus we turn to a discussion of how cognitive strategies and creative abilities develop through use of what we term the organizing process. This discussion leads to the identification of the fundamental mental abilities and cognitive strategies involved in creative problem solving as well as the identification of the factors and mechanism responsible for their development. Finally we discuss how classroom instruction can be carried out to aid in this development.

The result of instruction carried out in the suggested way will be students who have acquired meaningful understanding of the major concepts and conceptual systems of importance in our society and students who have developed the intellectual ability and confidence to creatively and rationally solve problems of importance, i.e., to successfully utilize the Educational Policies Commission's rational powers. We first turn to a discussion of concepts and conceptual systems.

A CLASSIFICATION OF CONCEPTS AND CONCEPTUAL SYSTEMS

From the teacher's and curriculum developer's points of view, subject matter of the disciplines is composed of a series of concepts of various degrees of complexity, abstractness, and importance. These are the primary units of instruction. We teach concepts. Students learn concepts. But what is a concept?

Adequately defining the term *concept* is no simple matter. Nevertheless the following definition should prove sufficient for our purposes. A concept has been formed whenever two or more distinguishable objects, events or situations have been grouped or classified together and set apart from other objects, events or situations on the basis of some common feature, form or properties of both (after Bourne, 1966, p. 2). A concept can be considered to be a unit of thought. We typically use terms to refer to these units. This does not deny the existence of nonverbalized knowledge yet we choose to think of concept formation as involving both the recognition of some common form, feature, or property from some phenomena plus the addition of some term or a combination of terms to refer to that which is common to the otherwise varied phenomena. Chairs, dogs, atoms, democracy, hunger, love, and so on all are terms to which meaning has been attributed. Hence these terms represent concepts.

Concepts do not stand alone. Rather they are related into meaningful systems often with hierarchical structure of subordinate and superordinate concepts (cf. Bruner, 1963; Gagne, 1970; Lawson, 1958; Suppes, 1968; Preece, 1978). We choose to call these systems of interrelated concepts "conceptual systems." An example of such a conceptual system is the ecosystem from ecological theory. This conceptual system consists of concepts such as trees, sunlight, frogs, producers, consumers, food webs, community, environmental factors, and ecosystem itself. The hierarchy of concepts with the basic units of trees, frogs, sunlight and so on at the bottom and ecosystem at the top form the conceptual system known as ecosystem. The concept ecosystem is all inclusive. All of the previously mentioned concepts are mentally integrated under the term "ecosystem." Figure 1 shows a number of the subordinate concepts which must be interrelated to form the inclusive concept of ecosystem.

A classification of concepts and conceptual systems is extremely important since a major issue which confronts educators concerns what concepts should be taught, in what order, and to whom? Should one attempt to teach the concept of relativity to first graders? If so, why? If not, why not? Should one wait to teach the concepts of addition and subtraction to high school sophomores? If so, why? If not, why not? What is called for is a rational means of classifying concepts into meaningful categories and a means of relating those categories to the intellectual capabilities of learners so that they cannot only gain significant insight into the concept's meaning, but so that the learning experience itself will contribute to a growth of those intellectual capabilities. The purpose of this section is to detail a classification of concepts and to discuss the nature of conceptual systems. This discussion will form the basis for deciding how to sequence concepts to effectively teach conceptual systems.

As previously defined, a concept refers to some pattern (regularity) to which a term or terms have been applied. Terms fall into different types according to the different sources of meaning. There are, we believe, three major ways in which meaning can be assigned to terms. Hence, there are three major types of concepts.

One can have concepts about immediately sensed input such as the color green, hot - cold, sharp - dull, internal states such as hunger, thirst, tiredness and so on. The complete meaning of such terms is derived immediately from the internal or external environment. The color blue derives its complete meaning from something that is immediately apprehended, something purely inductive. Thus, concepts *by apprehension* are the first major type of concept (Northrop, 1947). Such concepts form the basis for description of our internal and external environment.

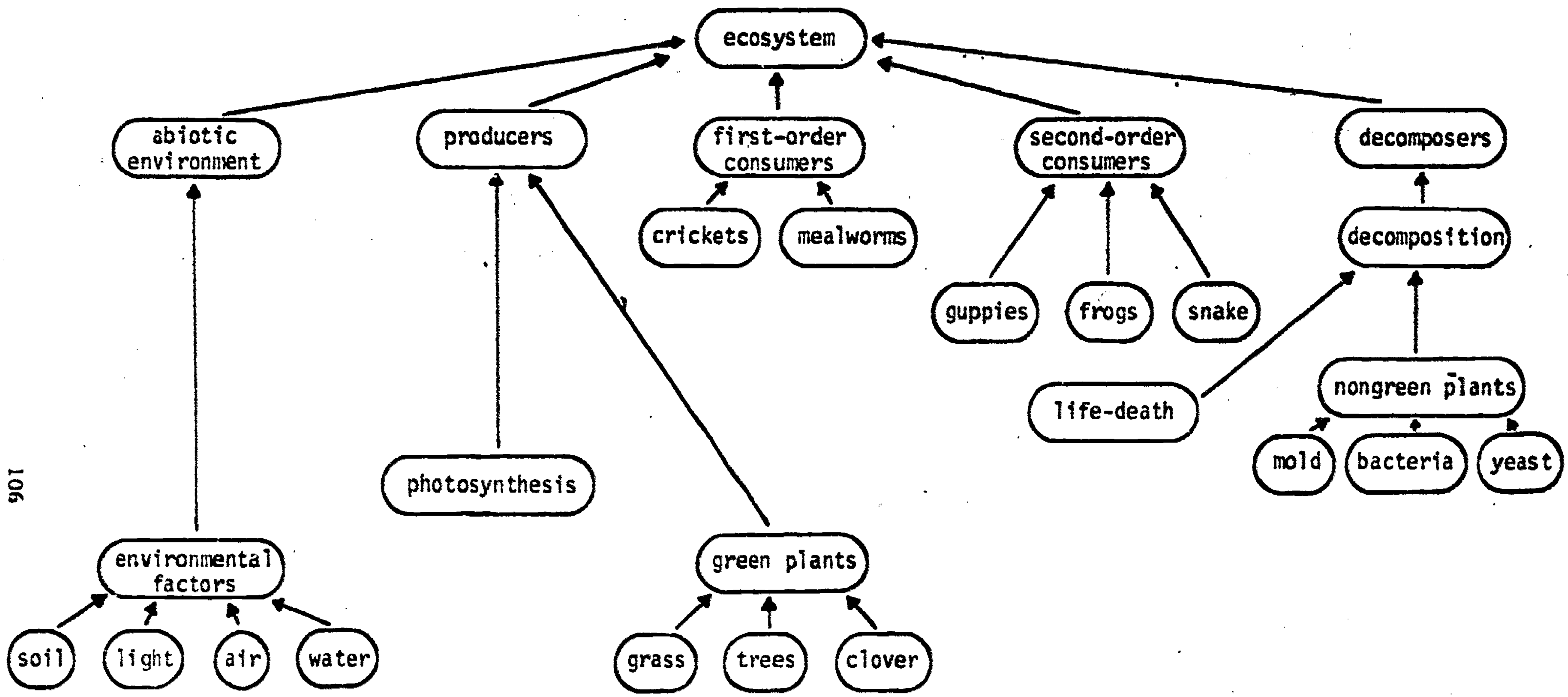

Figure 1.--A number of interrelated concepts which are subordinate to the inclusive concept of "ecosystem." Interrelationships among subordinate concepts are complex, yet generally hierarchical.

The second type of concept we call *descriptive* concepts. Objects such as tables, chairs, other persons, the room; events such as running, resting, playing, eating; situations such as on top of, before, under, next to, and so on are not immediately apprehended. The meaning of such terms must come through direct interaction with the "world out there." Babies are not born with the ability to perceive objects in their environment as they perceive them later on (Piaget, 1952). As Northrup (1947) said, "perceptual objects are not immediately apprehended factors; they are postulates of common sense so thoroughly and frequently and unconsciously verified through their deductive consequences that only the critical realize them to be postulated rather than immediately apprehended" (p. 93). In other words, even tables and chairs are hypothesized entities. Yet we lose sight of this fact in that we have gathered so much data to support their hypothesized validity.

Descriptive concepts also refer to perceived relations of objects and events. Taller, heavier, wider, older, on top of, before, under, are all terms that derive meaning from a direct comparison of objects or events. To understand the meaning of such terms, the individual must mentally construct order from environmental encounters. However, his mental constructions can always be compared with and thus verified or falsified by direct experience. Such concepts allow us to order and describe direct experience.

The third type of concept we distinguish is one that is also produced by postulation. However, they differ from descriptive concepts in that their validity cannot be checked through direct empirical test. The primary use of these concepts is to function as explanations for events that need causes but for which no causes can be perceived. Fairies, poltergeists and ghosts fall into this category. Common examples from science are genes, atoms, molecules, electrons, etc. We have named these concepts *theoretical concepts*. The reason for the existence of theoretical concepts of imaginary objects and interactions lies in a basic assumption humans make about their world and universe—that is that events do not occur without a cause. Thus if we perceive certain events but cannot perceive objects that cause such events we do not conclude that the events are spontaneous and without cause. Instead we invent unseen objects and interactions that explain the events in traditional causal terms.

Theoretical concepts function in a way analogous to the entities invented by the child as he attempts to explain his world. The very young child, for instance, behaves as though objects that are out of sight do not exist (Piaget, 1951). Soon, however, so many objects appear and disappear but some exhibit such striking similarities the child appears to invent the idea that objects continue to exist even when out of sight. Thus the child's understanding of his world is simplified. Many fewer objects exist. Later the child believes that the amount of material in some objects changes whenever the shape of the object changes (Piaget and Inhelder, 1941). Again this leads to a very complex and cumbersome mental model so eventually it also is replaced by the more parsimonious explanation that even in the face of perceptual transformation, objects remain the same, first in amount, later in weight, and still later in volume, i.e., these quantities are "conserved" (Piaget and Inhelder, 1941).

In order for any of these conservations to be recognized, however, the child must recognize what it is that stays the same in the face of perceptual transformation. We believe this to be the case in all concept formation. Something stays the same, something changes. For instance, some chairs are brown, green, yellow. Some are made of wood, metal, cloth. Some are soft, hard, big, small. But all chairs have something in common or they would not be chairs--they have four legs, a back, a seat. They have a common form. When the child comes to recognize what it is that stays the same--he has a concept, e.g., chair, amount, number, weight, length, volume.

So it is with theoretical concepts such as atoms, energy, electrons, and so on. Little wonder that we have conservation of energy laws. These laws were crucial to the advance of physics such as the conservation of weight is crucial to the intellectual advance of the child. The scientist invents the concept of atom, energy, and defines them in the context of other concepts to form a conceptual system to fill a need in his understanding. Once the concept has been invented, it represents the "thing" that remains the same while the phenomena change. It is conserved. It creates the continuity and the glue which holds concepts together in theoretical conceptual systems. Once the entity has been created the other concepts of the system are then able to be interrelated. They can be mentally related into a single dynamic system--a single conceptual system.

Because theoretical concepts are imagined and function to explain the otherwise unexplainable, they can be given whatever properties or qualities necessary in terms of the theory of which they are a part. That is, they derive their meaning in terms of the postulates of the specific theory (Lawson, 1958; Northrop, 1947; Suppes, 1968).

Of extreme significance to the educator attempting to teach theoretical concepts such as the electron, a young child may be quite capable of imagining tiny particles and calling them electrons, if the teacher wishes, but with little or no awareness or understanding 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 led to the postulation of the existence of these "tiny particles" in the first place. To the young child with no understanding of the nature of theoretical systems and their relationship to empirical data, the idea of the electron and other theoretical concepts must seem to have derived meaning as if by magic or perhaps by decree of some omniscient scientist. In short, one cannot fully comprehend the meaning of any single theoretical concept without some appreciation and awareness of the theoretical system of which it is but a part and of the empirical data upon which that system is based (c.f., Lawson and Karplus, 1977).

Conceptual Systems--Concepts by apprehension, descriptive concepts, and theoretical concepts are the bricks that, when cemented together, make up the conceptual systems that represent our knowledge of the world and universe, the conceptual systems that make up the laws of the land, the philosophies and religions that guide human lives--in short, the contents of human minds.

Basically, conceptual systems are of two types, descriptive or theoretical, depending on the nature of the concepts which comprise the system. A descriptive conceptual system is comprised of concepts by apprehension and descriptive concepts only. A theoretical system is comprised of concepts by apprehension, descriptive concepts, and theoretical concepts.

Examples of descriptive conceptual systems are: human anatomy, early Greek cosmology; taxonomies, and games such as chess, football and baseball. Each of these systems consists of concepts about perceivable objects and the interactions of these objects.

Theoretical conceptual systems are exemplified by atomic-molecular theory and Mendelian genetics. In atomic-molecular theory, the atoms and molecules were imagined to exist and to have certain properties and behaviors, none of which could be observed. However, by assigning certain properties to atoms that included combining with each other to form molecules, observable chemical changes could be explained. In the same manner, Mendel imagined genes to exist that occurred in pairs, separated at the time of gamete formation, combined when egg and sperm united, and determined the course of development of the embryo. By assuming the gene to exist and to have certain properties and behavior, Mendel could explain the observable results from crosses of plants and animals.

CONCEPT FORMATION

How, then, are concepts formed in the mind? A fundamental idea that underlies our conception of the way the mind functions to modify inappropriate, or incomplete knowledge and develop new knowledge is the idea of mental structures. A discussion of the nature of mental structure, therefore, must precede an attempt to explicate the process of concept formation. Basically, mental structures are hypothesized "mental blueprints" that guide behavior (c.f., Piaget, 1970; Case, 1972).

Mental structures represent the "something" in the mind that is formed during concept formation. They are the something behind the unit thoughts (concepts). And as we have seen, concepts are often related into complex conceptual systems. Thus mental structures are often related into complex systems as well.

At this point in the study of human mental functioning it is not possible to specify the exact neurological or chemical nature of these structures. Rather, their nature and their very existence must be inferred from observable behavior. These hypothesized mental structures function to organize our experiences so that we can function successfully. In this sense, the development of mental structures carries adaptive value. This adaptation is analogous to the genetic adaption of evolving species.

In the course of intellectual development from infancy to adulthood, these mental structures are acquired, differentiated and integrated within the brain. At birth the infant apparently has very few poorly differentiated structures from which to begin the process of differentiating and integrating more useful and adaptive mental structures. For example, with respect to the sense of sight, a child in his first month of life is able to differentiate figure from ground and has the ability to perceive colors, lines, and angles but is unable to perceive three-dimensional objects (Hebb, 1949). His entire visual world must be constructed from these basic pieces.

The acquisition, differentiation and integration, of mental structures then is viewed as the fundamental process in intellectual development. Our structures, in effect, determine how and what we think and how we interact with our environment. In a very real sense, they represent our knowledge and thinking about both the physical world and the world of ideas.

Useful structures do not come from simply making a mental record of the world, that is, by keeping eyes and ears open. Unfortunately, it would appear that many teachers believe they do. The work done by von Senden with congenitally blind persons who had gained sight after surgery, yet could not visually distinguish a key from a book when both lay before them, provides an interesting example of this point (cited in Hebb, 1949).

According to Piaget, a person is unable to perceive a thing until his mind has developed a structure which enables its perception (assimilation is his term). Without the development of an adequate mental structure, things which seem obvious to most adults, such as the difference between a key and a book, a square and a circle, or a plant and an animal, are simply not noticed. But this leads us to a fundamental problem. If organizing experience requires the development of mental structures, and if structures are needed in order to perceive and learn, and if they are not derived from simply photographing the external world, then from where do they come?

Plato's answer to this question was simple. The structures were innate and developed through the passage of time and development of the brain, albeit nourished by environmental encounters. Of course, at the other end of the spectrum is the belief that these structures are derived directly from the environment. This is the classical empiricist's view; but as von Senden's work with formerly blind persons clearly shows, this view is untenable.

The Platonic view must be rejected, except to admit that certain very primary structures must be present at birth. Our view is that all structures (i.e., all knowledge whether sensory-motor, perceptual or conceptual) is acquired through a seven-step process called the organizing process.

The Organizing Process

The organizing process consists of a sequence of events as follows:

1. Encounter of some new phenomenon (either material or symbolic) which can in some way be sensed.

2. Structuring of the sensory data by the sensory-nervous system to produce a perception or conception--a whole, total or Gestalt. This constitutes an initial undifferentiated mental structure, however, it does not constitute an adequate mental representation of the material or symbolic object, event, or situation that was initially sensed.

3. Behavior guided by previously acquired mental structures relative to the material or symbolic object, event, or situation that was sensed. This links in the memory record (a) the initial undifferentiated perception or conception, (b) the behavior and (c) the consequences of the behavior.

4. Repetition of the initial perception or conception and the behavior. At this point the memory record gives the individual an expectation of the outcome of the behavior. If the actual outcome of the behavior is the same as the expected outcome, the behavior and the initial structure are retained. If this occurs then one can say that the new input has been directly assimilated to previous mental structures and no modification of these structures has occurred. If the actual outcome is different from the expected outcome a state of mental "disequilibrium" results and a new behavior is elicited.

5. This new behavior may be an expression of frustration and rejection of the initial phenomenon. Or, if the individual persists in interacting with the new phenomenon, the original behavior will eventually be extinguished and new behavior, which consists of searching, will be elicited. This searching behavior involves a shift of attention from the initial whole to parts of the whole. The result is differentiation of the whole and the initial undifferentiated mental structure.

6. Following differentiation, the parts are mentally related or integrated, either spatially or temporally to create a new organization--a new differentiated mental structure--a new unit thought.

7. The new differentiated mental structure is then tried out in the present context and new contexts through behavior. If the behavior is successful, the new mental structure is retained and will continue to guide that behavior as long as it is successful. This final step in the organizing process is absolutely crucial if the new differentiated mental structure is to become truly useful. The behavior guided by the structure must be tried out in a variety of contexts. If it

successfully organizes information (i.e., is a useful problem-solution), it is retained and remains a significant part of one's cognitive repertoire. (For a more detailed account see Lawson, 1967.)

The organizing process represents a "natural selection" of mental structures analogous to the natural selection of species. The mental structures are creations of the mind prompted by sensory data. They are initially linked to and function to guide behavior. If the behavior is successful, the mental structure is selected for continued existence. If the behavior is unsuccessful, there is a selection against the structure. It must be modified or replaced. Clearly the entire process is not one of assimilation alone. Rather it is an active "constructive" process on the part of the individual involving some assimilation of new input but involving the modification of previous mental structures to that new input as well.

Although both our organizing process and Piaget's process of equilibration are similar (e.g., both involve progressive organizations, the construction of mental structures, differentiation and integration), two subtle but important differences exist. For Piaget mental structures derive from the internalization of physical actions. We agree that all knowledge requires active participation of the learner, however, for us the initial mental structures are created by a spontaneous combinational activity of the brain (i.e., the ability to combine bits and pieces of past experience into new combinations) not by the internalization of external action. Piaget's conception of the acquisition and refinement of mental structures is analogous to Lamark's view of evolution through the inheritance of acquired characteristics (Piaget, 1952, pp. 1-20; c.f., Thomas, 1977). Our conception is analogous to Darwin's view of evolution through natural selection of inherited characteristics. Another difference exists in that Piaget sees his process of equilibration active only in acquisition of logico-mathematical knowledge whereas we see the organizing process operating in the acquisition of all knowledge whether it be physical knowledge, social knowledge or what Piaget terms logico-mathematical knowledge.

In summary, the organizing process is the fundamental way in which persons alter past knowledge and gain new understanding whether it be on a sensori-motor, perceptual or conceptual level. Although there are seven identifiable steps in the process, it is helpful to conceive of it in terms of three main phases. The three phases are basically: (1) exploration of something new that does not completely fit with previous understandings; (2) invention of a pattern, a way of mentally ordering that something new; and (3) the testing of that pattern to see if it is adequate (i.e., leads to successful behavior relative to the something new and to previous understandings).

Our answer to the question "How are concepts formed?" then is through the organizing process. The process involves an initial recognition of some undifferentiated whole (Gestalt), the analysis of that whole resulting in its differentiation of its parts, followed by an integration of the parts back into a single differentiated unit or whole. But just how does this integration of parts take place? We should at least briefly discuss this integration process in that understanding it is necessary to developing instruction based on the organizing process.

The Integration Process

According to Miller (1956) the human mind at any one moment is able to mentally integrate or process only a limited amount of information. Miller introduced the term "chunk" to refer to the discrete units of information that could be simultaneously held in short-term memory and transformed or integrated. He cited considerable evidence to suggest that the maximum number of these discrete chunks was approximately seven.

Clearly, however, we all form understandings of concepts and conceptual systems that contain far more information than seven units. The term ecosystem, as mentioned, subsumes a far greater number of discrete units or chunks than seven. Further, the term ecosystem itself is a concept in the sense that it has a single "form," and it probably occupies but one chunk of space in short-term memory. This implies that a mental process must occur in which previously unrelated parts--that is chunks of information (a maximum of about seven chunks) are assembled by the mind into one higher order chunk or unit of thought in short-term memory and then transferred to long-term memory as single higher order chunks. This process is known as chunking (Simon, 1974). It is the basis of higher order concept formation and abstraction. When single chunks are formed in short-term memory by the recognition of some basic form from previously unrelated parts (chunks) that have been transferred from long-term memory, a higher order concept is formed. The crucial factor is that the mind has identified the key relationship among previously unrelated chunks. Prerequisites for chunking to occur then are that all of the immediately subordinate concepts, parts, chunks, must be held in short-term memory simultaneously and some single form, feature, or property must exist to relate the subordinate concepts to one another. It is this key relationship which constitutes the "form" common feature, or property of the higher order concept and it is what is abstracted from the situation.

The result of higher order concept formation (chunking) is extremely important. It reduces the load on mental capacity and simultaneously opens up additional mental capacity that can then be occupied by additional concepts. This in turn allows one to form still more complex and inclusive concepts (i.e., concepts which subsume greater numbers of subordinate concepts).

We hypothesize that the necessary conditions for chunking to operate in higher order concept formation are: (1) experience with and understanding of the "subordinate" concepts or pieces of information that are to be chunked; (2) the number of separate subordinate chunks to be assembled must not exceed the person's short-term mental capacity (presumably about 7 in adults); (3) some key relationship or form that ties the previously unrelated chunks together; (4) a word, phrase or other symbol (symbolic notation) is introduced that refers to the significant relationship among the subordinate concepts; (5) repeated experience within new contexts occurs that involves the same subordinate concepts and the same symbolic notation that refers to the significant relationship among the subordinate concepts; and (6) sufficient time for the learner to mentally coordinate (chunk) the subordinate concepts and abstract the key relationship from the specific contexts is provided (c.f., Bruner and Kenney, 1970; Lawson and Wollman, 1976).

The symbolic notation introduced is crucial since it assists in identifying and talking about the way or ways in which the subordinate concepts are related to form the new more inclusive concept. This symbolic notation plays another extremely significant role. When new experiences are provided that involve the same subordinate concepts but within new contexts, this symbolic notation remains the same, thus allowing the learner to recognize that the situation is somehow the same even though it may appear different on the surface. This awareness that something is the same and the initial inability to recognize what it is we believe triggers mental searching behavior. Once the searching form or similar feature which will relate the subordinate concepts provided (1) all of the subordinate concepts are understood (that is they themselves have been chunked) and (2) enough additional experience is provided so that the learner can mentally integrate the subordinate concepts and abstract the new relationships. The amount of time and the number of additional experiences this takes is presumably a function of factors such as the individual's pattern recognition ability--perhaps what Spearman (1927) has called "fluid intelligence" or "g."

Notice we have hypothesized that one of the necessary conditions for chunking to take place in the process of higher order concept formation is that the number of separate subordinate chunks to be assembled must not exceed the person's short-term mental capacity, what Piaget (1928) has referred to as the "field of consciousness." Pascual-Leone theorizes that short-term mental capacity, or mental space as he calls it, increases with age from 1 unit at about age three years to 7 units at about age 16 years (Pascual-Leone, 1969; Case, 1972). The units refer to the number of discrete chunks or schemes a person can coordinate in his field of consciousness or mental space. If mental space does in fact increase with age as Pascual-Leone claims, then certain complex concepts that require inordinate mental space for chunking to occur would be beyond the capacity of some students to learn. By knowing the students' mental space and by knowing the concept's mental demand (the number of subordinate chunks) one could accurately predict which concepts could or could not be successfully taught at various age levels.

AN INSTRUCTIONAL SEQUENCE

In light of the previous discussions on concepts, conceptual systems, the organizing process and the process of chunking it becomes possible to identify an instructional sequence to facilitate chunking and conceptual understanding. This instructional sequence forms a cornerstone of our theory of teaching. All instruction is based upon the same sequence whether the goal is conceptual understanding, rational thought or creativity development. At this point, however, we will only discuss how the sequence can lead to the meaningful learning of concepts and conceptual systems. Later we will discuss how it can be modified slightly and used to promote rational thought and creativity development.

The instructional sequence consists of three phases that are repetitive and cumulative, hence the curriculum takes on a spiral form. The three phases of the sequence are called exploration, concept introduction, and concept application. The terms exploration, invention and discovery were first introduced by Karplus and others in conjunction with the learning approach developed by the Science Curriculum Improvement Study (1974) to refer to the same three phases of the sequence.

During the exploration phase, students encounter new objects, events, or situations, and learn through their own actions and reactions. They explore phenomena or ideas new to them with minimal guidance or expectation of specific accomplishment. The new experience should raise questions or complexities that cannot be immediately understood in terms of past ways of thinking and understanding.

Exploration is extremely important in that it provides experience upon which later conceptual understanding can be developed. Further, if the phenomena are well chosen, they will spark student curiosity and effect motivation. When the experience is not entirely understandable, that is, when it cannot be immediately assimilated to previous ways of thinking, it may provoke the learner to spontaneously attempt to search through his past experiences, past conceptual understandings, the ideas of others, or the phenomenon itself for clues that will allow him to find key relationships within the phenomenon to allow various aspects of it to be chunked into one meaningful whole.

The second phase of the learning sequence, 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 students 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. Textbook readings, a film, or another medium can also be used to introduce the concept. The introduction of a way of ordering the experiences provides students with an initial insight into how various aspects of the phenomena are related and how they can be chunked. Indeed, for some students this initial suggestion may be immediately relatable to current thinking and new understanding will result. But for most students, this will not occur. The teacher's suggestions will not immediately allow them to mentally coordinate or chunk the subordinate concepts and abstract the higher order concept from the phenomena and assure an effective ordering of the explorations. This is why the third phase of the sequence, concept application, is so important. In the concept application phase, further activities are presented which involve the same subordinate concepts but within new contexts. That is, the important relationships, features, etc. stay the same but the context varies. Thus with the teacher's repeated highlighting of that which stays the same in the face of perceptual change, the students are gradually able to identify the key regularity and mentally coordinate (chunk) the subordinate concepts and abstract the new higher order concept from its concrete exemplars. Concept application experiences also serve to reinforce, refine, and enlarge the content of the new concept. We will now turn to the larger task of sequencing concepts to develop a model for curriculum development to teach conceptual systems.

IMPLEMENTING INSTRUCTIONAL SEQUENCES FOR TEACHING CONCEPTUAL SYSTEMS

Any conceptual system can be understood only to the extent that it is related in the student's mind to some empirical experience of his own (c.f., Ausubel, 1963). Thus, the beginning of any course of instruction must be an experience with the empirical world, either by direct sensory contact with physical examples, or by secondary experiences such as films or descriptions of events or situations that the student can relate to his past experience.

Efficient learning and understanding of a conceptual system requires an orderly sequencing of learning sequences in which some concepts and relations must be developed before others. The task of the curriculum builder is to identify the basic (subordinate) descriptive concepts and relations that form the foundation of the conceptual system, to present these first so that they can be chunked and provide the framework for the remaining second, and higher-order descriptive concepts and theoretical concepts if any such concepts exist.

When the perceptable experiences are first presented to introduce the descriptive aspects of the conceptual system, they must be presented as an "undifferentiated whole" that integrates the material to be learned (Lawson, 1967). If the student already understands the descriptive aspects of a theoretical conceptual system, then the basic theoretical concepts must also be initially presented as an undifferentiated whole. The sequence of instruction is normally as follows:

1. Perceptable phenomena presented as undifferentiated whole;
2. First-order (subordinate) descriptive concepts;
3. Second-order descriptive concepts;
4. Higher-order descriptive concepts;
5. Theoretical concepts.

The Undifferentiated Whole

The concept of an undifferentiated whole may be vague and elusive, but presumably it plays an essential function in meaningful learning as opposed to memorization of unrelated items. As previously mentioned a "whole" is a mental event (a Gestalt) that results from an interaction of the central nervous system, brain, or mind with sensory input. It becomes differentiated and the resulting parts become integrated into a new and more complex whole as a result of continued interaction of the individual with that part of the environment that produced the initial sensory input. Perhaps an analogy will help clarify the concept of the whole. The whole is in some ways analogous to a zygote. A zygote is an undifferentiated cell that has the potentiality to develop into a mature organism. The process of development involves repeated cell division, differentiation of parts and the integration of those parts into a functional biological system. This development requires a suitable environment from which the zygote obtains the necessary materials. Consider the following examples.

We have identified at least four different types of undifferentiated wholes that are of interest. The four types reflect increasing levels of complexity. The first type involves the perception of objects, the second involves a set of related behaviors, the perception of a system of interrelated objects, while the fourth involves the perception of symbols that represent the interrelationships of concepts.

The first type (perceptual object type) is exemplified by work by Hebb (1949). Hebb was interested in explaining how infants learned to visually perceive objects. Presumably, infants cannot automatically perceive objects, but must learn to do so. Hebb's data came from von Senden's previously mentioned work with congenitally blind persons who had gained sight after surgery. These persons could not identify objects without handling them. They could not visually distinguish a key from a book when both lay on a table. Nor did they report seeing any difference between a square and a circle. Eventually they did learn to distinguish them, but only after a long period of practice. Although the subjects could not visually identify objects at first, they did see something. What they perceived was considered by Hebb to be a primitive unity of figure-on-ground, resulting from the interaction of the stimulus pattern with some function of the nervous system. The primitive unity constitutes the undifferentiated whole in this situation and functioned as an essential part of learning to perceive an object.

The second example (a behavioral whole) comes from Lewis' description of how a child learns new words (Lewis, 1936). The new words are initially integral parts of behavior patterns, which are at first undifferentiated wholes. Lewis describes an example of such a behavior pattern. When Lewis said, "Where's ballie?" to his child, the child turned toward a small white ball, picked it up, and handed it to his father. Lewis commented on this as follows:

> *We must first recall that the child's initial response to the phrase where's ballie? was not simply an awareness of*

the ball, or even merely the turning of his attention to it. His response consisted rather of a series of movements involving the ball, turning towards it, seizing it and presenting it to the speaker, receiving in turn a smile and a word of approbation (p. 200).

The child has learned a particular behavior that involved his father, the phrase, "Where's ballie?" and a particular object. The behavior initiated by "Where's ballie?" and ending with". . .a smile and a word of approbation" constituted a behavioral whole for the child. The child did not know that the small, round, white object was called a "ball" by adults. He did not know the adult meaning of "Where's...," and he did not know that his father was asking a question. He simply carried out a behavior sequence in response to a specific verbal stimulus.

The third example (a perceptable system of objects whole) comes from the Life Science program of the Science Curriculum Improvement Study (SCIS 1974). This project developed an elementary school curriculum for the biological and physical sciences. The biological science program is designed to teach an understanding of the ecosystem to first through sixth graders. The program starts in the first grade with the children observing an aquarium containing sand, water, fish, snails, and various aquatic plants. The choice of the aquarium as a starting place for the investigation of an ecosystem was deliberate. An aquarium is a miniature ecosystem that can be differentiated into parts and the parts interrelated to produce the conceptual system ecosystem.

The aquarium to the first grade children is in a way similar to the object of von Senden's newly sighted patients. The children initially are able to differentiate some parts of the aquarium, but they are blind to many other parts, and to practically all of the interrelations of the parts. For the children, the physical system called an aquarium created in their minds a whole that is largely undifferentiated, but which can be differentiated and eventually integrated into a complex conceptual system. However, at the beginning for the first grade children, the whole is at the pre-conceptual level because their initial reactions are primarily naming the parts they recognize, such as the fish and the plants, and asking for names of other parts such as the sand.

An example of a fourth type of a whole (a descriptive symbolic whole) was selected from <u>American Society, A Sociological Interpretation</u> by Robin M. Williams, Jr., Alfred Knopf, New York, 1956. In this book Williams describes American Society in terms of a descriptive conceptual system. In Chapter 3, he presents what he calls a "model for the analysis of American society." This model is the "undifferentiated whole" in which the author names and defines concepts and describes their relations, i.e., he presents all of the basic concepts (postulates) of the conceptual system. The concepts are all of the descriptive type. The author concludes the chapter with the following:

We now have in hand the basic concepts necessary to begin our substantive analysis: structure, culture, cultural norm, institution, and social organization. Our approximate and incomplete model for the analysis of American society now includes organized activities of a population that interacts in terms of a particular culture as it attempts to realize certain normative goals in relation to other societies and its physical and bio-social environment (p.34).

One further example of an "undifferentiated whole" (a theoretical, symbolic whole) comes from The Principles of Heredity by Snyder and David, D. C. Heath and Company, Boston, 1957. This is a theoretical conceptual system involving both descriptive and theoretical concepts. The authors began with the descriptive concepts. In the first chapter, they describe examples of heredity using pedigree charts of human inheritance. In the first part of Chapter 2, they describe Mendel's experiments with heredity in pea plants. Thus, in the beginning, the empirical descriptive foundation is laid for the introduction of the theoretical conceptual system that explains the empirical data.

In the latter half of Chapter 2, Snyder and David present the theoretical conceptual system. Not the entire system, but the basic descriptive and theoretical concepts (i.e., the basic postulates) to lay a foundation that can be developed into a refined system by the processes of differentiation and integration. This foundation is the undifferentiated whole. In the book it consisted of a diagram depicting the transmission of dominant and recessive genes through three generations, plus definitions of descriptive and theoretical concepts related to the diagram. The rest of the text was an elaboration or modification of the concepts depicted by the diagram.

In all five examples, the primary function of the undifferentiated whole was to provide an initial structure, form, or framework for a wealth of information. It was a form that grew with each additional item of information into a complex object or an interrelated conceptual system.

If the students can be assumed to have had the experiences upon which the concepts of the whole are derived, then a verbal presentation of the undifferentiated whole (as in the case of the books on the American society, and the principles of heredity) is sufficient. However, if the students cannot be assumed to have had these experiences, then these experiences must be provided, as was the case for von Senden's patients and the first grade students.

Further, recall the distinction that was previously made between descriptive and theoretical conceptual systems. Descriptive conceptual systems are based upon a set of concepts that derive from direct physical experience. Theoretical systems are based upon these descriptive concepts, plus theoretical ones that do not derive meaning from direct physical experience. The descriptive aspects of the system, in fact, lead to the need for the invention of the theoretical concepts. Therefore, prior to introducing the theoretical concepts as part of the conceptual system, the descriptive aspects must be presented.

Because the whole in each case functioned as an organizer, it is fair to wonder whether the undifferentiated whole is the same as Ausubel's "advance organizer." Ausubel (1968) wrote concerning the use of organizers:

> *The principal strategy advocated in this book for deliberately manipulating cognitive structure so as to enhance proactive facilitation or to minimize proactive inhibition involves the use of appropriately relevant and inclusive introductory materials (organizers) that are maximally clear and stable. These organizers are introduced in advance of the learning material itself and are also presented at a higher level of abstraction, generality, and inclusiveness; and since the substantive content of a given organizer is selected on the basis of their appropriateness for explaining, integrating, and interrelating the material they precede, this strategy simultaneously satisfied above for enhancing the organizational strength of the cognitive structure. . . In short, the principal function of the organizer is to bridge the gap between what the learner already knows and what he needs to know before he can successfully learn the task at hand (p. 148).*

The above quotation contains statements that suggest that Ausubel's organizer is not the same as our undifferentiated whole. For example, Ausubel stated: "These organizers are introduced in advance of the learning material itself--and are at a higher level of abstraction, generality, and inclusiveness" (1968, p. 148). While our undifferentiated wholes are introduced early in the course of instruction, these are an integral part of the learning material and are not "introduced in advance of the learning material."

Secondly, undifferentiated wholes are not necessarily ". . . at a higher level of abstraction, generality, and inclusiveness. . ." Snyder and David's initial description of gene behavior is quite specific and is not more abstract than statements about two factor crosses or about linkage that are made later in the text.

Thirdly, the principal function of an undifferentiated whole is much more than ". . . to bridge the gap between what the learner already knows and what he needs to know. . ."

On the other hand, Ausubel's organizer and our undifferentiated whole do have something in common in which both are ". . . selected on the basis of their appropriateness for explaining, integrating, and interrelating the material they precede. . . ."

Returning to the problem of building a curriculum, for any subject matter the curriculum builder must be an expert in the area, one who can analyze the conceptual system to discover the basic descriptive concepts and theoretical concepts (if there are any), and one who can create the undifferentiated whole and present it at the appropriate level so that it will serve to integrate, and interrelate the content of the discipline. He then must be able to identify first, second-and higher-order descriptive concepts and introduce them through exploration-concept introduction-concept application experiences so that chunking can take place.

Finally, if the system is a theoretical one, he must be able to isolate the basic theoretical concepts, then present them as an undifferentiated whole and then present additional experiences that lead to the extension, refinement, i.e., differentiation of these concepts. This may involve the introduction of corollary concepts such as sex linkage, crossing over and deletion in genetics.

Thus far we have discussed the organizing process and the way in which this process leads to a three-phase instructional model of exploration, concept introduction, and concept application. The result of instruction designed and presented in this way is students who have acquired understanding of certain concepts and groups of concepts known as conceptual systems. Thus, one important goal of the educational system will be accomplished if instruction is carried out in this way.

But what about the central goal--that is--the development of the rational powers? Rational thought development is indeed crucial since our knowledge, which resides in conceptual systems, does not remain static. Ideas change. Old ideas are sometimes found inadequate. We cannot teach everything to students. They must have the rational capability to learn themselves. They must be capable of the modification of old concepts and conceptual systems and developing new ones.

It would be naive indeed to believe that this development will take place if we only concern ourselves with stocking students' minds with concepts and conceptual systems no matter how meaningfully learned they may be. In science, for example, it is clear that there exists more than the concepts of science. There exist the processes of science as well. It is these processes which in fact correspond to the rational and creative powers of the scientist. Thus to develop rational and creative powers we must once again return to the process of acquiring knowledge, the process of the scientist at work, the organizing process.

It is our contention that rational powers and creativity develop when they are used. And they are used when one spontaneously attempts to solve a problem or bring coherence to a new experience through the organizing process. It follows then that to use school activities to develop students' rational powers and creative abilities students must be given opportunities to generate and test knowledge for themselves through use of the organizing process. Since the reader will no doubt readily note the similarity of this position to the discredited position of the faculty psychologists, it should be pointed out that there is nothing inherently wrong with the idea of development through use. After all it is next to impossible to conceive of anything developing without use whether it is someone's gluteus maximus muscle or his mental faculties. The crucial issue is not whether or not use is the path to development but use of what, and development of what. To discover just what is used and just what develops let us again return to an examination of the organizing process.

MENTAL ABILITIES AND COGNITIVE STRATEGIES

The immediate questions raised are: What are the fundamental mental abilities of the organizing process? How does their use lead to the development of rational powers and creativity in individuals who are successful problem solvers? and How can schools aid those students that do not become good problem solvers outside of the school?

Answers to these questions will provide us with a means of attaining the central objective of the school--that is--producing students with command of the rational powers. We will first turn to the task of identifying the fundamental mental abilities of the organizing process. We will then turn to a discussion of how their use leads to the development of explicit cognitive strategies and how the school can aid in this development if it does not take place spontaneously (i.e., as a consequence of experiences in the general social milieu).

In our view the most basic mental abilities of the organizing process are the mind's ability to create and recognize patterns (pattern making and recognizing ability, i.e., clouds sometimes look like faces; star formations look like bears, lions; convection currents above pavement look like water), its ability to link these patterns to expectations (inferring ability), and its ability to compare these expectations to actual outcomes of behavior (comparing ability). The mind's abilities to create and recognize patterns, draw inferences, and make comparisons (at least in their rather undifferentiated states) are assumed to be innate. These abilities are shown in relationship to the major phases of the organizing process in Figure 2.

The abilities function to create and test knowledge of the external world. They are present in all normal persons from the very outset. These abilities are refined and improved (differentiated and integrated) through their use in solving problems, in creating order out of experience. Their use in creating order out of experience results not only in the acquisition of sensori-motor, perceptual, and conceptual knowledge but results in the development of explicit and general guides to problem solving as well. We have chosen to call these guides *cognitive strategies*. We define a cognitive strategy as a plan, plot, or device for bringing order, for generating orderly relationships out of experience. The use of cognitive strategies is dependent upon the operation of the mind guided by some mental structure as is the case for specific concepts. However, the mental structures guiding the use of cognitive strategies differ from those of specific concepts and conceptual systems in that they function as problem-solving strategies potentially applicable to problems in all conceptual systems.

Counting, 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. Seriating is another such device. These cognitive strategies have as their primary aim the adequate description of experience, hence we choose to call these descriptive cognitive strategies.

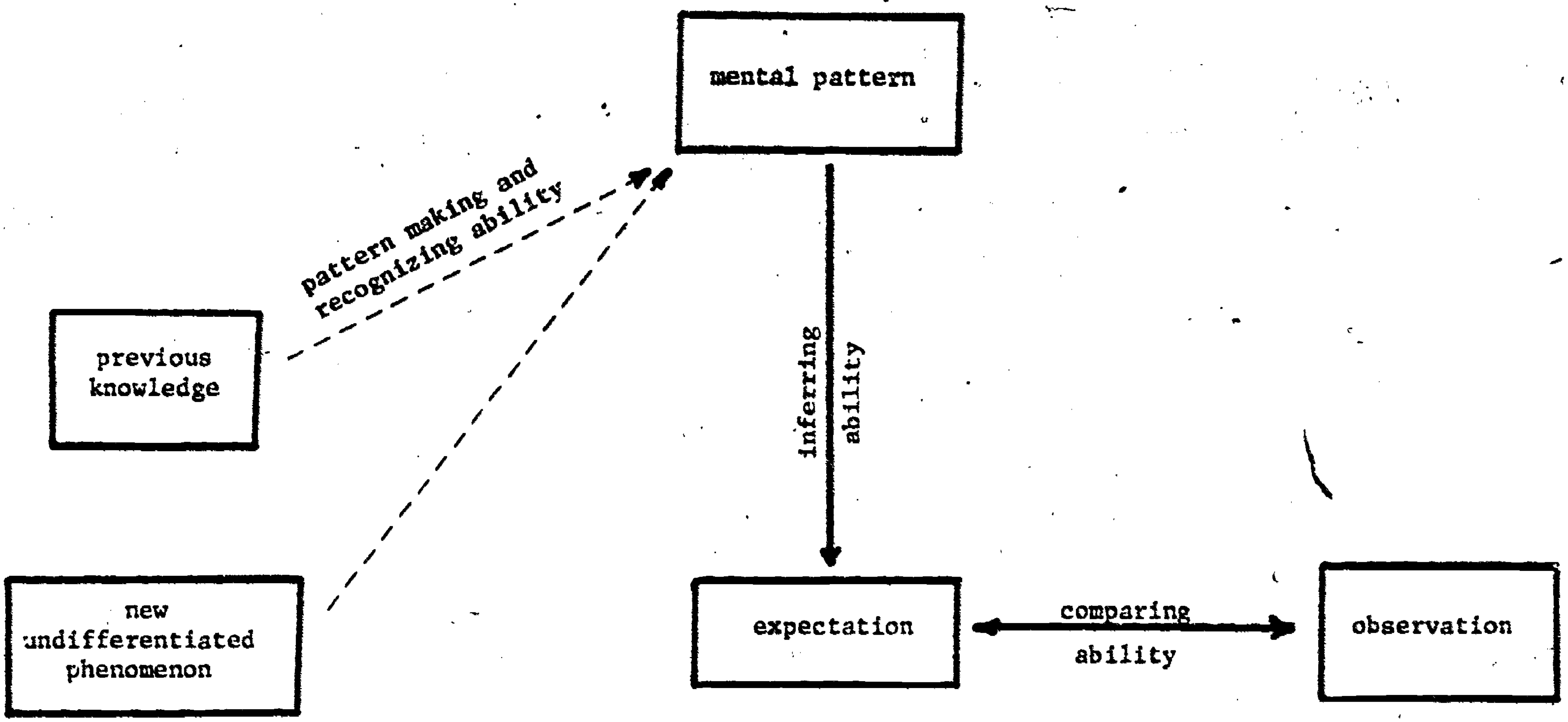

Figure 2.--The basic phases and mental abilities of the organizing process. The three primary innate mental abilities of pattern making--recognizing, inferring, and comparing--operating from the very outset as part of the organizing process. Use of the organizing process results in the acquisition of sensori-motor and conceptual knowledge (i.e., concepts by apprehension descriptive and theoretical concepts). 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 cognitive strategies.

Examples of complex strategies that have as prerequisites for their generation and use these descriptive strategies involve the control of variables, proportional reasoning, correlational reasoning, and probabilistic reasoning. Inhelder and Piaget (1958) refer to these complex cognitive strategies as "formal operational schemata." These strategies function as part of a hypothetico-deductive problem solving procedure, hence, we choose to call these hypothetico-deductive cognitive strategies.

These 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 causal relationships is basic to explanation. Thus cognitive strategies are plans, plots or devices for the organization of experience in terms of description and explanation.

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

One can identify other complex cognitive strategies such as "classification of action sequences," "state evaluation and hill climbing," and "defining subgoals" that are useful in solving special "curiosity" problems such as crypt arithmetic, the Tower of Hanoi problem, or the missionaries and cannibals problem (Wickelgren, 1974). However, these cognitive strategies and special problems are of much less importance than those mentioned previously. These cognitive strategies play no central role in organizing everyday experience into meaningful cause-effect relationships except to the extent that they overlap those already mentioned. Thus they are of relatively less importance to those interested in developing a theory of general education (c.f., Kline, 1977).

Figure 3 represents a model of the way in which the fundamentally important cognitive strategies operate in conjunction with previous knowledge and the basic mental abilities in the cognitively mature individual to solve problems and create new conceptual understanding through the organizing process.

As shown, the cognitive strategies of classification, seriation and correspondence operate as part of the process of differentiating the parts of the new phenomenon. They are needed to order objects and properties and isolate important variables within the phenomenon. 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 and applying it to this new context as was the case when Mendel borrowed algebraic patterns and applied them to organize data from the crosses of pea plants and when Coulomb borrowed Newtonian laws of planetary attraction and applied them to organize data from interaction of subatomic particles.

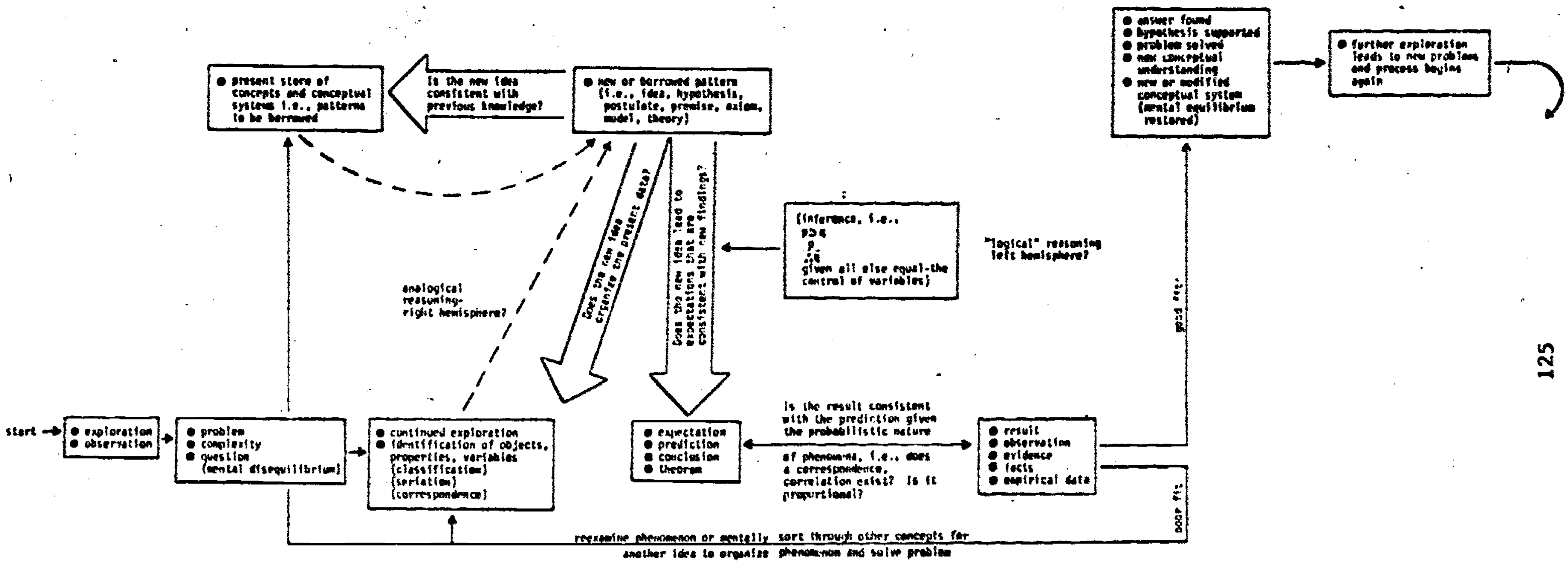

Figure 3.--The basic phases, mental abilities and cognitive strategies used in the organizing process by the cognitively mature problem solver. See text for explanation.

Once the new pattern has been generated it must be tested. This occurs in one or more of three ways. The first question that must be asked is does the new idea in fact adequately organize or solve the present problem? Secondly, 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.

The third way in which the new idea can be tested is through the deduction of its logical consequences and the comparing of these predicted 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 impinging upon a situation the deductions must take the form of a weak modus ponens and modus tollens (c.f., Bunge, 1967). Nevertheless the derivation of predicted consequences, logical conclusions, theorems, etc. requires an understanding of the need to control variables and the probabilistic nature of phenomena. The analysis of data at this point often requires what have been termed proportional and/or correlational reasoning (Adi, Karplus, Lawson, and Pulos, in press; Karplus and Peterson, 1970).

If the problem solver does indeed find that this new idea, hypothesis, model, etc., which 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.

Figure 3 then can be viewed as a model of a mature adult thought. It represents the goal of the educational process in that creativity, rational thought and conceptual understanding are all implied. Although we have stated that, for this type of thinking to develop, the learner must have opportunities to use the organizing process, we still must explain just how its use leads to this development. This is the topic of the next section.

THE DEVELOPMENT OF COGNITIVE STRATEGIES

Clearly experience is a necessary factor for the development of cognitive strategies. If there were no encounters with the environment, no contradiction of present mental structures would arise and no possibility for further exploration into the situation that produced the contradiction would be possible. The contradiction of verbally stated propositions and the ensuing debate and search for their truth or falsity we assume to be the primary factor in the development of cognitive strategies.

Basically there are two main types of propositions that are of a primary importance in the child's and adolescent's intellectual development. They are called categorical and hypothetical causal (Werkmeister, 1948).

The testing of categorical propositions (hypotheses describing the properties and relationships of objects, events, and situations) we believe results in the development of the descriptive cognitive strategies such as classification, seriation, and correspondence. The testing of hypothetical causal propositions (hypotheses explaining objects, events, and situations) results in the development of hypothetico-deductive cognitive strategies such as controlling variables, proportions, correlations, and probability.

The development of the descriptive cognitive strategies is a prerequisite for, and hence occurs prior to, the development of the hypothetico-deductive cognitive strategies. Let us first examine what is required to test categorical propositions.

Testing Categorical Propositions

Truth or falsity of categorical propositions must be determined by an empirical test. That empirical test is simply to check the facts to see if they are, or are not, in accordance with the proposition. For example, the proposition that "Golf is the favorite game of everybody in my family" can be established as true or false by asking the people in my family if golf is, in fact, their favorite game. The proposition that "The books in the next room are arranged alphabetically by author" also can be directly tested by going into the next room and checking. The result of a check on the first proposition may yield the finding that golf is the favorite game of three out of four people in my family. Therefore, strictly speaking, the proposition is false. It could be modified to read, "Golf is the favorite game of most of the people in my family" or "golf is the favorite game of three out of four people in my family."

A check on the truth or falsity of the second proposition could yield a similar result, that is, 25 of the 30 books in the next room are arranged alphabetically. The result yields a ratio of confirming cases over total cases in the case 25/30--previously 3/4.

What kind of understanding is required to successfully test such propositions? In short, testing these propositions requires the understanding of *class-subclass relationships* such as the relationship of the class "family" and its components--"mother," "father," "brother," "sister," etc., the class-subclass relationships between "games" and its subclasses "golf," "bridge," "Monopoly," "basketball"; likewise the class "reading material" and its subclasses "magazines," "books," "newspapers," or "books" and its subclasses, "encyclopedias," "novels," "short-stories," and "fiction." The ability to understand *serial relationships* is also required to order games in terms of the degree of preference, or books alphabetically in terms of the first letter of their author's last name. The resultant ratios of confirming cases or disconfirming cases over total cases (e.g., 3/4 and 25/30) also involves class to subclass relationships.

Therefore the successful testing of categorical propositions requires an understanding of correspondences, class-subclass relationships, and serial relationships. We believe that it is in fact the testing of such categorical propositions that leads to the development of this understanding. At first the understanding is limited to certain familiar situations but eventually through repeated testing of additional categorical propositions these relationships become recognized to be of general applicability. In other words, the child's ability to recognize and abstract patterns or regularities allows him to form strategies of classification, seriation, etc. that can be readily transferred to new contexts. This process is what could be termed development through use.

As we have stated, this development we believe occurs when children argue and seek evidence to support or negate categorical propositions.

An example, given by Gesell (1940) occurred in a dialogue between two children aged four and five.

> *Four:* *I know that Pontius Pilate is a tree.*
> *Five:* *No, Pontius Pilate is not a tree at all.*
> *Four:* *Yes, it was a tree, because it says: "He suffered under Pontius Pilate," so it must have been a tree.*
> *Five:* *No, I am sure Pontius Pilate was a person and not a tree.*
> *Four:* *I know he was a tree, because he suffered under a tree, a big tree.*
> *Five:* *No, he was a person, but he was a very pontius person (p. 55).*

This example illustrates contrary assertions. It also illustrates that what is contradicted is a verbal relationship. Four equates the term "Pontius Pilate" and "tree." Five denies this, instead equating the term "Pontius Pilate" with the term "person." Arguments concern the propositions by which terms are related. The significance of argument is that it causes the participants to attend to the parts of a proposition and to either justify the relationship or question the basis for it. Four justified his relating Pontius Pilate and tree "...because it says: 'He suffered under Pontius Pilate,' so it must have been a tree." Class-subclass relations are examined, e.g., Is Pontius Pilate a member of the class trees or is Pontius Pilate a member of the class persons?

Thus, argument produces contradiction, making it necessary to examine the source of contradiction. When arguments occur about categorical propositions and evidence is sought to establish their truth or falsity, the child gradually develops an awareness of and an ability to use descriptive cognitive strategies such as classification, seriation, and correspondence. Let us now consider the nature of hypothetical propositions and how the testing of hypothetical causal propositions leads to the gradual development of hypothetico-deductive cognitive strategies.

The Nature of Hypothetical Propositions

A proposition is an assertion which is either true or false. But what exactly is being asserted when a hypothetical proposition is said to be true? Clearly it is not asserted that the antecedent is true; nor is it asserted that the consequent is true although both, in fact, may be true. What is asserted is this: that *if* the antecedent is true, then the consequent is *also* true. Such an assertion is often referred to as "implication" (Copi, 1972). The truth of the antecedent implies the truth of the consequent.

Hypothetical propositions of a causal nature play a particularly significant role in thinking and problem solving. There are several reasons for this. First of all, causal relations between objects and events may be readily stated in this hypothetical form: "If animals are deprived of oxygen, they die" (lack of oxygen causes death). "If I drop this glass, then it will break." In the second place, imaginative anticipations and tentative solutions of various problems have at their core hypothetical causal propositions: "If government can deal with the problems of poverty in the same intelligent way in which it dealt with the problems of lunar exploration, then the economic future of the poor is bright" (intelligent government causes solution of problems of poverty). In the third place, hypothetical causal propositions link preparatory actions to future ends and reveal what must be done if a stipulated goal is to be reached: "If the standard of living is to remain high in the next decade, then exports must be increased by 50 percent above the present level" (increased exports causes maintenance of living standards).

Testing Hypothetical Causal Propositions

Establishing the truth or falsity of hypothetical causal propositions also requires that an empirical test be conducted in the natural world. However, unlike the situation which holds for the test of categorical propositions, this empirical test involves more than a simple yes or no answer or a comparison of confirming and disconfirming cases.

For instance, suppose it is asserted that "Cigarette smoking causes lung cancer." This can be stated also in the form if...then as "If one smokes cigarettes (p), then one will get lung cancer (q)" ($p \supset q$). Now it must be kept in mind, that this test, by its very nature, is empirical, not strictly logical. If this were strictly a logical matter, all we would need to do would be to find one person who smokes and did not have cancer and the proposition would be falsified. However, this situation is not that simple. We do not reason with textbook logic. Since the test is conducted in the "real world," we must keep in mind that the "real world" is a complex place. We can never specify all of the variables effecting any one specific phenomena. We live in a probabilistic environment. It must be understood that phenomena themselves are probabilistic in character and any explanatory model, whether mathematical or causal, must involve probabilistic considerations in its axioms and structure (c.f., Fischbein, 1975).

What then do we do? We do what is possible to do, and that is to hunt for *correlations*. In this case a correlation between cigarette smoking and lung cancer is sought. If we find such a correlation we have obtained support for the proposition (hypothesis). If we find no correlation the proposition (hypothesis) has not been supported. If a moderate correlation is found, then we obtain a moderate degree of support. Absolute certainty is not attainable. A hypothesis is never proved.

How then do hypothetico-deductive cognitive strategies develop? We believe this comes about as a consequence of experiences gained in an environment in which hypothetical causal propositions are, in fact, analyzed for truth or falsity. Many children and adolescents grow up in home and school environments where such propositions are made and not questioned. They are accepted by the authority of the person who makes them. No attempt is made to gather and analyze *evidence* that could be used to support or refute such propositions. A person growing up in an authoritarian atmosphere has no opportunity to question propositions, no opportunity to reflect about them to draw inferences from them, to explore their various possibilities, and no opportunity to test them. Therefore, such persons are deprived of the experience essential for the gradual abstraction of generally applicable hypothetico-deductive cognitive strategies from the accumulation of such experiences.

This development is not the consequence of direct short-term teaching. Rather it results from an accumulation and mental coordination of many experiences in which evidence is sought, debated over and the relationship between this evidence and the truth or falsity of the proposition is gradually discovered. Thus classroom instruction designed to promote the ability to use hypothetico-deductive cognitive strategies must allow students every opportunity to generate and test hypothetical causal propositions for their truth or falsity. Frequently used teacher statements in such a classroom must be "What might have caused that?" "What is the evidence?" "How do you know?" "Could there be another reason for that?" "Are you sure?" When asked a question about the truth or falsity of some hypothetical causal proposition the teacher must refrain from answering the question but must respond with suggestions of how the student could investigate the issue to answer the question himself.

With reference once again to the phases of the organizing process we can see why this is so. Recall the first phase of the organizing process is the exploration phase in which the individual encounters some new phenomenon that he does not completely understand which raises a question. Now if he asks the teacher or someone else to answer the question and that someone else answers the question, he will not develop his own ability to generate and test his own hypotheses to try to answer the question himself. However, if the teacher responds by saying, "That's a good question. What do you think might have caused that?" and/or by having the other class members offer alternative hypotheses the individual will be in a position to continue his thinking. With encouragement and appropriate hints and importantly with a means of testing the hypotheses he will begin to gain confidence in his ability to generate and test hypotheses. Through use of the organizing process he and his classmates will gain in their ability to use the process and develop the general hypothetico-deductive cognitive strategies.

In summary we hypothesize that cognitive strategies develop through use of the organizing process in testing categorical and hypothetical-causal propositions for truth or falsity. Ultimate understanding of such propositions requires the understanding of class-subclass relationships, serial relationships, correspondences and so on. The testing of categorical and hypothetical-causal propositions requires the child to carefully analyze the parts of the propositions, the relationships among the parts, and the means of testing the relationships. Thus repeated testing of new propositions gradually results in an awareness of the key relationships which make up propositions as well as the key procedures and reasoning processes needed to adequately test propositions (e.g., the isolation and control of variables, probabilistic reasoning, correlational reasoning). Once these understandings develop the child or adolescent has an ability to anticipate the occurrence of these relationships and an ability to apply these testing procedures to new contents. He has what could be termed "anticipatory schemes," i.e., generalized cognitive strategies that can be employed to more efficiently test novel propositions. In short the person is better able to solve problems. He is better able to modify old concepts and conceptual systems and develop new ones.

TEACHING HYPOTHETICO-DEDUCTIVE COGNITIVE STRATEGIES

Along with the type of classroom climate which encourages students to generate and test knowledge themselves we can specify more explicit instruction to increase students' ability to use the cognitive strategies of the hypothetico-deductive thinker. We can teach cognitive strategies. How can this be done?

Before we attempt to answer the question "How do we teach cognitive strategies?" let us rephrase the question slightly. The child who grows up in an environment that is constantly forcing him to reflect on the truth or falsity of propositions is one that will provide that child with very strong and useful intuitions about what is needed to establish truth or falsity. The question we must ask then is how can specific instruction be designed to help students transform these intuitions into explicit strategies for problem solving?

The Role of Intuition

In the next few pages we will describe a problem and a series of lessons which were used with individual 13-year-old children to solve problems that required the ability to isolate and control of variables. In other words, to solve the problems the student needs a general understanding of the principle that proof of causality requires a test in which only two variables vary; all other variables must be held constant--that is, controlled. First, however, we must understand the role that intuitions play in this development. Researchers have found that children in the descriptive or concrete stage of development have little difficulty in determining when a test is "fair" or "not fair" when the variables concerned are familiar (Wollmann, 1977). However, they lack a general plan of attack or general strategy to use in setting up "fair comparisons." In other words, after a test has been performed they may be able to state if it is fair or not fair--if the variables are familiar (controlled or not controlled), however, they are unable to use this idea as a general guide to behavior. What is lacking is a general verbal rule to serve as an anticipatory guide to behavior. But we must again stress one important point--students as young as five to six years old have an intuitive feeling for what is fair and not fair.

Ausubel (1964) suggests that it is upon this intuitive feeling that we can base environmental encounters which will transform this intuitive understanding into explicit verbal rules to guide behavior. A fair question to ask is where did this intuitive understanding come from? We have assumed that it is derived from situations in which children make comparisons and attempt to evaluate the validity of those comparisons. For example, suppose two children run a race. When the race is over and one child has lost, he blames the loss on the fact that he was wearing street shoes while his friend has on tennis shoes. He claims that the race was not really a fair test of who was the fastest runner. Other familiar examples would not be difficult to imagine. In other words, the intuitions come from argumentation about the truth or falsity of statements (e.g., "I can run faster than you can." "No, you can't, I can run faster than you"). The point is this: from environmental encounters such as this, children develop intuitive understanding of cognitive strategies of the control of variables, probabilities, proportion, etc. What remains is for these intuitions to be transformed into explicit verbal rules so that the child is able to use them as general problem-solving strategies. We hypothesize that six necessary and sufficient conditions exist for this transformation. They are:

1. Students must have sufficient mental capacity to allow an examination of combinations of alternatives (this may be the result of biological maturation);

2. Initial experience with complex phenomena that raises questions and requires the use of the cognitive strategy in question must be provided. One must be aware that his present cognitive strategies are not entirely adequate for understanding the situation and solving the problem;

3. Students must have sufficient ability to disembed the form of the problem solution from its concrete context (a degree of field independence--or something like Spearman's "g", the basic pattern making and recognizing ability). Degree field independence or degree of "g" are probably the products of genetic and/or early child rearing practices and thus are only partially (if at all) amenable to modification by school experience;

4. Prerequisite cognitive strategies must be consolidated. For example, before a student can learn a strategy for controlling variables he must be capable of classifying those variables.

5. Repeated experience requiring the same strategy but in new contexts must be provided;

6. Useful symbolic notation that refers in some way to the strategy and remains the same across transformations in context must be provided. This repeated experience and the constant notation provides the learner with the important clue that the various situations are somehow the same. This triggers mental searching behavior which eventually allows the learner to abstract the pattern or form of the strategy from the concrete contexts.

An Example of Teaching the Strategy of Controlled Experimentation

With respect to the strategy of controlling variables, let us examine the manner in which these conditions can be met and the transformation from intuition to an explicit verbal rule can be met. We will base this discussion on a recent experiment (Lawson and Wollman, 1976) in which 9- and 13-year-old children who, on the basis of initial testing, were unable to demonstrate the ability to control variables in any general sense. In other words, they performed at the concrete level with respect to this strategy. Within four half-hour training sessions these same children were clearly able to demonstrate the ability to control variables systematically and, in most cases, unhesitatingly. Further, as evidence of general ability to use this cognitive strategy, their ability transferred to new tasks, both manipulative tasks and pencil and paper tasks.

Session 1. The first session began by giving the child a brief introduction to the intent and format of the training. He was told that a number of different kinds of materials would be used to try to teach him how to perform "fair tests." This coupled with the initial use of this term in the context of bouncing tennis balls was done to provide him an intuitive feel for what the training was all about, in a sense to provide a "ball park" in which to work. This amounts to the "whole" which will later become differentiated. The materials used in this session were materials very familiar to children; three tennis balls (two which were relatively bouncy and one which was considerably less bouncy), two square pieces of cardboard, two square pieces of foam rubber and a table. The child was told that the first problem was to find out which of the tennis balls was the bounciest. To do this he would instruct the experimenter in how to perform the experiment and the experimenter would carry out the instructions. Although each session varied somewhat, in general the child would begin by telling the experimenter to take two balls and drop them to see which bounced higher (height of bounce then became the dependent variable). The experimenter would then drop the two balls but drop them from different heights (an uncontrolled experiment). The child would then respond by saying: "That isn't fair. Drop them from the same height." On the next trial the height would be equalized, however, one ball would be dropped so that it hit the table top while the other ball hit the floor (again an uncontrolled experiment). This procedure was followed by continually trying to intervene with new uncontrolled variables (spin one ball, push one ball, let one ball hit cardboard or foam rubber). Children were then told that a test was called a "fair test" if all the things (variables) that might make a difference were the same in both balls (except, of course, for the difference in the balls themselves). Each time a test was made in which these variables were not the same was called an "unfair test." Following introduction of those more general statements and terms, several additional examples were given and talked through.

The overall intent of this first session was to start with an undifferentiated whole, capitalize on the children's intuitive understanding, provide numerous particular images, provide contradictions and provide symbolic notation (the phrases "fair" and "unfair tests") which remained invariant across changes in imagery provided by the materials used in the subsequent sessions.

Session 2. The second session began by reminding the child of the intent of the training and by pointing out the new materials. The materials were six metal rods of varying size, shape, and material. These were placed on the table and the child was asked to classify them in as many ways as possible. This was done to determine his ability to form the classes of size, shape, and material and to insure that these differences in the rods were noted. The rods were then placed into a stationary block of wood and all the factors (variables) which might affect the amount of bending of the rods (the dependent variable) were discussed. The child was then asked to perform "fair tests" to find out if the variables of length, thickness, shape, and material of the rods, as well as the amount of weight hung on the end of the rods affects the amount the rods will bend. Whenever he performed a test he was asked: Is this a fair test? Why is it a fair test? Can you be sure that this rod bends more than that one *only* because it is thinner? Is there any other reason (an uncontrolled variable) why it might be bending more? These questions and others were used to focus the child's attention on all the relevant variables and recognize unambiguous experiments in an attempt to lead them to understand the necessity for keeping "all factors the same" except the one being tested to determine causal relationships. A number of examples and counter-examples were discussed at length. The concepts involved in this session were identical to that of the first, the material (the context), however, was different.

Session 3. At the outset of the third session the child was asked to experiment with an apparatus called a Whirly Bird (SCIS, 1970). The Whirly Bird consists of a base which holds a post. An arm is attached to the end of the post. When pushed or propelled by a wound rubber band, the arm will spin around like the rotor on a helicopter. Metal weights can be placed at various positions along the arm. The child was briefly shown how the Whirly Bird worked and was given the task of finding out all the things (variables) which he or she thought might make a difference in the number of times the arm would spin before it came to rest (the dependent variable). Possible variables included the number of times the rubber band was wound, the number of rubber bands, the number of weights placed on the arm, the position of the weights, how tight the arm and post were fastened together, the angle of the base, etc. Following these explorations with the apparatus the child was asked to perform "fair tests" to prove that the independent variables mentioned actually did make a difference in the number of times the arm would spin. Again, whenever a test was performed the child was asked questions such as these: Is this a fair test? Why is it a fair test? Does it prove that it makes a difference? Why else might the arm spin more times? (i.e., were all other independent variables held constant?).

The general intent of this session was similar to that of the second session and the fourth and final session. The strategies underlying the questions and materials were identical in all sessions. The symbolic notation (the language used) remained invariant, while transformations in imagery were gained by using materials extending from the familiar to the unfamiliar. Children were given a variety of concrete experiences so they could learn by doing and at each opportunity they were challenged to transform that doing into language.

Session 4. In this session the use of concrete materials as the source of activity and discussion was replaced by the use of written problems. Problems posed only in a written fashion were considered to represent an additional step away from the concrete and towards the abstract level. Probing questions relative to children's understanding of the written situations were asked as was done in the previous sessions. In a sense learning by doing was replaced by learning by discussion (language alone). The following two written problems were presented and discussed at length.

Written Problem 1

Fifty pieces of various parts of plants were placed in each of five sealed jars of equal size under different conditions of color of light and temperature. At the start of the experiment each jar contained 250 units of carbon dioxide. The amount of carbon dioxide in each jar at the end of the experiment is shown in the table.

Which two jars would you select to make a fair comparison to find out if temperature makes a difference in the amount of carbon dioxide used?

Table 1. Experimental conditions and results.

Jar	Plant Type	Plant Part	Color of Light	Temp (°C)	CO_2*
1	Willow	Leaf	Blue	10	200
2	Maple	Leaf	Purple	23	50
3	Willow	Root	Red	18	300
4	Maple	Stem	Red	23	400
5	Willow	Leaf	Blue	23	150

*This column indicates cm of CO_2 in the jars at the end of the experiment.

Written Problem 2

An experimenter wanted to test the response of mealworms to light and moisture. To do this he set up four boxes as shown in the diagram below. He used lamps for light sources and watered pieces of paper in the boxes for moisture. In the center of each box he placed 20 mealworms. One day later he returned to count the number of mealworms that had crawled to the different ends of the boxes.

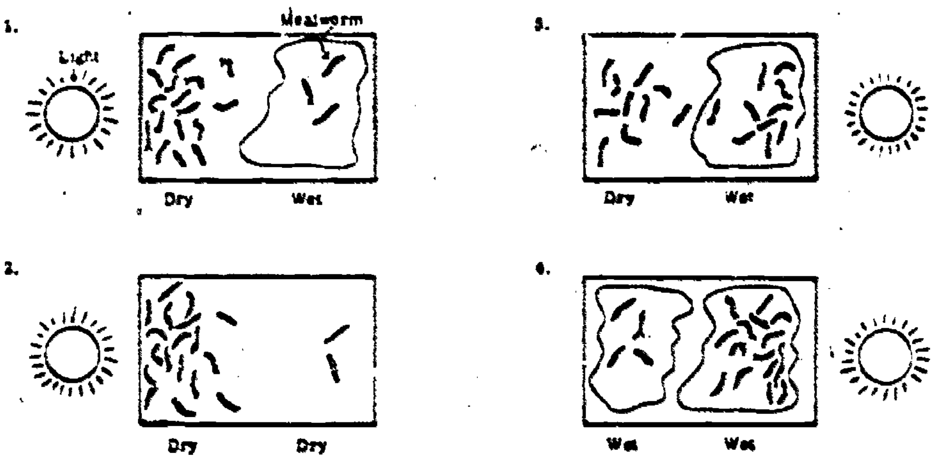

Fig. 4. Mealworm responses to experimental conditions.

The diagrams show that mealworms respond (respond means move to or away from) to:

A. light but not moisture
B. moisture but not light
C. both light and moisture
D. neither light nor moisture

At the onset of the sessions virtually all the children insisted that to determine which tennis ball was the bouncier the balls must be dropped from the same height and hit the same surface on the floor. In each instance they demonstrated an intuitive feeling that the tests were "not fair" and would respond by saying: drop them from the same height, make them both hit the floor, don't spin one, etc. After the comparisons with the tennis balls were made they were able to accept or reject them as fair or unfair but they were unable to state a general rule or procedure for performing fair tests prior to the test itself (i.e., to perform a fair test, keep all the factors equal except that which you are testing). Not even the most articulate children were able to spontaneously respond by telling the teacher to have "everything the same" for both balls. Even when they were asked to summarize their instructions without mentioning specific factors they were initially at a loss for words. They had a feeling for evenness, fairness, and symmetry but not a general rule to act as a guide for behavior--i.e., they lacked the ability to use language to structure their thinking. This phenomenon is very much akin to the experience we all have had when we "know" something is true but just cannot seem to find the words to explain it. Our belief is that the extension of this intuitive understanding to the point where this intuition can be expressed clearly through the use of language and applied successfully to solve problems constitutes the acquisition of a hypothetico-deductive cognitive strategy. For intuitions to manifest themselves in the form of useful linguistic rules (cognitive strategies) we presumed (and the results supported) that children need (1) a variety of concrete problems requiring a specific cognitive strategy for solution and (2) a useful symbolic notation which remains invariant across transformations in images--in this instance the symbolic notation was language, the key words being "fair test" and "unfair test." This, of course, is essentially the position taken by Bruner and Kenney (1970) studying problem solving procedures in mathematics. They designed instructional strategies to teach eight-year-old children who were initially in Piaget's stage of concrete thought the mathematical concepts of factoring, the distributive and commutative properties of addition and multiplication, and quadratic function. They summarized their instructional procedures in this way:

> *It begins with instrumental activity, a kind of definition of things by doing. Such operations become represented and summarized in the form of particular images. Finally, and with the help of symbolic notation that remains invariant across transformations in imagery, the learner comes to grasp the formal or abstract properties of the things he is dealing with (p. 434).*

In other words, this learning begins with physical experience with objects. This experience provides the student with a mental record of what he has done and seen. Symbolic notation is then introduced which aids in the identification of patterns in the experiences. Finally, additional experiences that involve the same strategy are provided along with the repetition of the invented symbolic notation to allow the student to abstract the abstract procedure from the particular situations.

This instructional strategy incorporates key points suggested by Raven (1974) as well. Raven, in designing an instructional strategy to facilitate the acquisition of reasoning suggests three necessary factors: (1) the task organization must correspond to the child's levels of reasoning, (2) the instructional strategy must incorporate the active engagement of the student in using his logical operations in the construction of rules and concepts, and (3) concrete referents must, whenever possible, be provided.

Perceptual learning involves initial attention and behavior towards an undifferential whole. If this behavior is contradicted, the learner is led to an examination of the original behavior, and a search for a new behavior pattern. The new behavior pattern (the new whole) that is "invented" is then tried. If it serves as an effective guide for behavior, the pattern is reinforced and extended. The example above demonstrates how ideas of "fair" and "unfair comparisons," which are evidenced in children around the ages of six or seven, are originally confined to very specific (familiar) situations but with the aid of language (symbolic notation) and a variety of concrete situations and the opportunity for reflection about these activities, these intuitive ideas can become explicit guides to behavior.

In summary, the described instructional procedure involved precisely the same features as that designed to teach specific concepts as detailed previously. Those features were (i) the identification and presentation of an initially undifferentiated whole, (ii) differentiation of the whole through concrete experiences leading to identification of its parts, (iii) the introduction of symbolic notation that remains invariant and provides the key to what stays the same in the face of transformations in imagery provided by (iv) application experiences-repetitions of the same strategy in novel contexts. These application experiences provide the student with repeated opportunities to abstract the form of the strategy (the procedure) from its concrete exemplars.

It should be pointed out that although we believe that relatively short-term teaching efforts such as those just cited can improve the understanding and use of specific cognitive strategies, those improvements will not be of lasting value unless the student returns to an environment (both in and out of school) in which he or she finds it necessary to apply the newly acquired cognitive strategies. Such an environment is one in which evidence is actively sought and debated to test categorical and/or hypothetical causal propositions.

SOME THOUGHTS FOR CURRICULUM DEVELOPMENT FOR INTELLECTUAL DEVELOPMENT AND CREATIVITY

In this section we will describe educational practices that will promote intellectual development in terms of the development of cognitive strategies and creativity. The core idea is that in the course of instruction teachers must create situations that require the student to use the organizing process. Special courses designed only of problem solving situations and devoid of subject matter content are not recommended. The problems should originate within the framework of study of a discipline. The specific manner in which any teacher can create problem situations depends on the teacher's ingenuity plus the nature of the discipline. There are at least three possibilities: (1) independent investigations, (2) an historical model, (3) comparison of contrasting conceptual systems.

The independent investigation method, which might be termed the graduate school model, can be applied in most natural and social science courses, indeed in any subject matter where inquiry takes place. An example from experience in a first grade glass exemplifies the method in the natural sciences. The children were observing classroom aquaria containing aquatic plants, fish, and snails, and recording events and changes. One day the water in the aquaria near the windows became greenish in color because of algae bloom. Several children noticed this and asked: "What made the water green?" Instead of answering the question the teacher asked the pupils for their own ideas. There were a variety of responses, each of which served as a guide for setting up an experiment. At this age the children were incapable of carefully controlled experimentation but with the guidance of the teacher they did several experiments from which the children concluded that sunlight was the significant variable.

Any course involving actual manipulation of materials pertinent to the subject matter repeatedly presents the teacher with opportunities for raising questions that can be used as a starting point for the students' own investigation. Depending on the students' abilities the investigations can be carried out by the class as a whole, under the guidance of the teacher, by smaller groups of students, or by individual students. In any case, the problems must be selected with care. They must be difficult enough to pose a real challenge to the students, but they must not be so difficult that they frustrate the student beyond his abilities. A degree of success in the investigative undertaking is essential to maintain interest and motivation. Constant frustration can only discourage the student and produce rejection on his part.

The historical approach to teaching for intellectual development requires a carefully designed program of student investigations. The Harvard Case Histories which describe the history of the development of a number of scientific disciplines through the actual investigations carried out by famous scientists of the past could be used as a model for designing such a program. Each discipline has a history from the first observations of particular phenomena, the first experiments and continued collection of data to the creation of laws and theories that changed over time as new and contradictory data were revealed.

A course using the historical model follows the actual history of the development of the discipline. The students are introduced to the original problem through exploration of the phenomena that confronted the investigators of the past. Thus students are given the original data from which they attempt to invent their own hypotheses to explain the data. This is followed by testing of those hypotheses. New data is then presented requiring the students to revise their explanations or create new ones. By judicious introduction of data properly correlated with the students' success in deriving, modifying, and creating explanations, the students' growth in understanding the discipline parallels the historical development of the discipline.

The method of comparing contrasting conceptual systems seems to be particularly suited for the social sciences where there is an abundance of conflicting theories. An example is Bruner's Man A Course of Study in which different cultures were contrasted. Different social, economic and political systems are replete with conflict in the modern world. There are different religions and philosophical systems all of which can serve to challenge the student to question, to argue, to search for evidence and importantly to introduce the concept of value in relations to thinking and decision making (Bruner, 1968).

All three of the above suggested procedures stress one essential ingredient--the students' active intellectual involvement in solving problems. The answers the students achieve are only incidental. It is the intellectual process that they go through that gradually produces intellectual development. In these programs there are no right answers, the teacher is not an authority but a guide to encourage and motivate the student to apply his own intellectual abilities and thus to aid their development.

The idea of fitting the tasks to the students' present intellectual abilities is very important in the context of selecting topics of discussion and problems for students to investigate. Take, for instance, the task of having young children investigate some theoretical concept from science such as genes, or atoms. Since you are asking them to examine a possible explanation for some phenomenon from some small part of experience that they likely have never had, the investigation of such theoretical concepts would be largely meaningless. Further the task of explaining this phenomenon is totally unrelated to the intellectual tasks they face each day in spontaneously attempting to understand *their* world. They are still trying to classify, seriate, and describe their perceptible environment and trying to generate meaningful causal relationships in that experience. To have them go beyond this and attempt the task of explaining some unfamiliar and imperceptible phenomenon, while perhaps not impossible is so totally unrelated to their normal intellectual activities and experience that the task would be practically devoid of meaning to them and could do nothing to promote intellectual development. To promote their development in the classroom, tasks have to correspond generally with the sorts of challenges children face in their spontaneous attempts to order and explain their world.

Creativity

In our society creativity is a valued function of the human mind. However, for decades there has been dispute over the nature of the creative process and whether or not it can be developed within the context of a school curriculum.

G. Wallas (1926) described four stages of the creative process. These are:

1. **Preparation** - the stage during which the problem is investigated in all directions.

2. **Incubation** - the stage of non-conscious thinking about the problem. During this stage the person dismisses the problem from his conscious mind and attends to something else.

3. **Illumination** - the spontaneous appearance of "the happy idea."

4. **Verification** - this stage is a conscious and deliberate attempt to test the new idea.

E. Paul Torrance (1967) defined creativity as the process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on; identifying the difficulty, searching for solutions, making guesses, or formulating hypotheses about the deficiencies; testing and retesting these hypotheses and possibly modifying and retesting them; and finally communicating the results.

The similarity of Wallas' and Torrance's descriptions of the process of creativity to our description of the organizing process is remarkable. Presumably they are one and the same. If so, creativity as well as intellectual development can be enhanced by giving students the opportunity to use their own minds in solving problems through use of the organizing process.

In relation to this idea of fostering creativity in the classroom Torrance (1967) said:

> *Many complain that we do not yet know enough about the factors affecting creative growth. In my opinion, we have known enough about these factors since the time of Socrates and Plato to do a far better job of creative education than is commonly done. Socrates knew that it was important to ask provocative questions and to encourage natural ways of learning. He knew that it was not enough to ask questions that call only for the reproduction of what has been learned. He knew that thinking is a skill that is developed through practice and that is important to ask questions that require the learner to do something with what he learns--to evaluate it, produce new ideas from it, and recombine it in new ways (p. 85).*

Intellectual development and creativity can be fostered within our educational system if students are given the opportunity to use the organizing process to generate and test their own ideas. However, providing the proper climate for this to take place is absolutely crucial. We must become accepting of student ideas. We must become more interested in intellectual invention than in the rightness or wrongness of what is invented. We must cease to form judgments of students' inventions and instead let the evidence itself be the judge. As Carl Rogers (1954) has pointed out:

> *When we cease to form judgments of the other individual from our own locus of evaluation, we are fostering creativity (p. 147).*

When students raise questions we have a tremendous opportunity to foster both creative and intellectual development for as we have seen creativity and the intellectual processes operate hand in hand in the organizing process. When questions are raised and students begin to generate their own tentative answers is when we must be extremely-careful of our responses. As a general rule, all sincere student ideas must be accepted as equally valid. Note, however, not all ideas are accepted as equally correct. Ideas represent hypotheses to be tested in the real world for possible consistency or inconsistency. In other words, in a curriculum for intellectual development and creativity the judgment of when an idea is right or wrong is not made by the teacher or by other students but is made by the evidence that the students can gather to either support or contradict the idea.

The result of such an educational enterprise will be students who have confidence in their own abilities to create and test ideas. In other words, they will have attained expertise in the Educational Policies Commission's ten rational powers. However, we must not forget the other essential role of the schools—that is to teach the conceptual systems which in the past have been generated by this intellectually creative enterprise. These conceptual systems are of course important for they represent our accumulated knowledge and understanding but they also serve as a source of ideas to be borrowed for the creation of new systems of understanding. Conceptual understanding, creativity, and intellectual abilities function as one whole. The educational system must recognize all of these aspects of intellectual functioning and present instruction accordingly. If instruction is so designed, our graduates will have the tools they need to face the complex and ever-changing world into which they will enter and must survive within.

SUMMARY

In the preceding pages we have presented our conceptions of the processes of learning and of development and how these processes dictate a specific theory of instruction and curriculum development. At present we will present a brief summary of the major ideas.

We began with the assumption that the educational system has three primary goals (1) to teach conceptual systems, (2) to help students develop intellectually, and (3) to help students gain confidence in their ability to creatively solve problems. Since intellectual development and confidence in one's ability to solve problems cannot be developed without content, we must understand the nature of what we teach—that is, concepts and conceptual systems.

Units of thought to which terms are applied are called concepts. Since units of thought derive meaning in three major ways, there are three major types of concepts (1) concepts by apprehension (e.g., hot, cold, hunger, red) (2) descriptive concepts (e.g., tables, chairs, on top of, below), and (3) theoretical concepts (e.g., atoms, ghosts, genes). These three types of concepts are interrelated in dynamic systems called conceptual systems. We teach conceptual systems.

Concepts are formed when the mind, through use of the organizing process, recognizes common features or relationships among a variety of experiences and is able to integrate or "chunk" these into a single mental unit. For this to occur a number of conditions must be met including (1) all of the subordinate concepts must be understood, (2) some symbolic notation must be introduced and (3) additional experiences must be encountered that exemplify the key features of relationships along with a repetition of the same symbolic notation. A model for instruction that incorporates these features is called the exploration - concept introduction - concept application learning sequence. Use of it leads to the effective learning of specific concepts.

The teaching of conceptual systems must involve the sequencing of the introduction of concepts in a meaningful way. Descriptive concepts must be taught first. These provide the foundation for the teaching of higher order descriptive concepts and eventually for the introduction of theoretical concepts if any such concepts exist within the particular conceptual system under consideration. At each level of conceptual introduction, instruction must begin with the presentation of some initial "undifferentiated whole" and proceed through the process of differentiation and integration.

The result of such instruction will be students with understanding of the conceptual systems that have been taught. This, however, is only one part of the student's education. Such instruction does not result in the development of cognitive strategies useful in general problem solving. Without the development of cognitive strategies, students can only behave according to the basic propositions of any conceptual system. They are not able to modify such systems if in fact they need modification. For this development to occur students need the opportunity to engage in the spontaneous organization of experience and the testing of knowledge--i.e., the organizing process.

The organizing process is basically a three-phase process. The first phase involves an encounter with some experience that does not fit with one's accustomed way of behaving or thinking. This contradiction raises a question, creates a state of "disequilibrium," and will provoke the individual to begin a search for a resolution to the contradiction provided the problem is not so complex that the individual is overwhelmed and is unable to proceed. The initial step towards resolution of the problem is the generation of hypotheses-tentative problem solutions. This represents the second phase of the organizing process. The third phase involves the testing of these hypotheses through inference followed by a comparison of the inferred consequences with the external world. The organizing process operates at all levels of intellectual development. When it functions in the solution of conceptual problems it results in three things (1) the generation of concepts (problem solutions), (2) increased confidence in one's ability to solve problems and (3) the development of cognitive strategies (problem solving processes) that operate in various phases of the process itself. These cognitive strategies are basically of two types depending upon the type of hypotheses that are being tested.

The testing of categorical propositions (hypotheses describing the properties and relationships of objects, events, and situations) results in the development of the descriptive cognitive strategies (e.g., classification, seriation and correspondence). The testing of hypothetical causal propositions (hypotheses explaining objects, events, and situations) results in the development of hypothetico-deductive cognitive strategies (e.g., controlling variables, proportions, correlations, and probability).

In naturalistic settings the development of the descriptive cognitive strategies are prerequisites for, and hence occur prior to the development of the hypothetico-deductive cognitive strategies. The development of descriptive and hypothetico-deductive cognitive strategies mark two general periods or stages in the intellectual development of the child and the adolescent--the descriptive or concrete stage and the hypothetico-deductive or formal stage. Since not all students develop hypothetico-deductive cognitive strategies as a consequence of experience gained outside of school, the schools must assist in this development. To do this at each level of instruction, the teacher must not only teach concepts and conceptual systems but he or she must provide students with the opportunity to engage in the organizing process with problems appropriate to his own level of intellectual development.

Classroom instruction designed to promote the student's ability to use hypothetico-deductive cognitive strategies must provide every opportunity for students to analyze hypothetical causal propositions for their truth or falsity. Use of the organizing process will enable students to gain confidence and a general expertise in its use.

Not only can hypothetico-deductive thought be developed in this general sense but we can explicitly teach hypothetico-deductive cognitive strategies. For this to occur, however, teaching must be based upon the student's intuitive understandings and six conditions must be met: (1) the students must have sufficient mental capacity to allow an examination of combinations of alternatives, (2) initial experience must be provided that raises a question and requires use of the cognitive strategy for solutions, (3) the student must possess a degree of field independence, (4) prerequisite cognitive strategies must be consolidated, (5) repeated experience that requires use of the same cognitive strategy must be provided along with (6) useful symbolic notation that refers to the cognitive strategy and remains the same across transformations in context.

In the design of a curriculum for intellectual development the instructional sequence of exploration-concept introduction-concept application that is used to teach concepts is used again although when explorations raise questions, the teacher does not supply the answers. Instead the students are required to create their own answers, to propose hypotheses and to defend their explanations by resorting to known evidence or to experiment to produce evidence.

There are at least three possible ways in which teachers can create problem situations for students: (1) independent investigation, (2) an historical approach, (3) comparison of contrasting conceptual systems. Each of these approaches provides opportunities for students to confront problems, propose hypothesized solutions and test these solutions for adequacy and consequently develop intellectually.

The improvement of the student's creative abilities can also be enhanced through teaching procedures that encourage students to use the organizing process in that the creative process and the organizing process are one and the same.

FUTURE RESEARCH

Any theory, including the present one, suggests a number of avenues of research. Perhaps the most pressing area for research suggested here would be in the area of cognitive strategies. It is our belief that the use of cognitive strategies such as those discussed in this chapter develop very gradually during childhood and adolescence. Further this development occurs through an identifiable series of levels or "stages." Work by Piaget and his coworkers has certainly led the way in identifying important cognitive strategies and sequences or stages through which they develop. But this is not enough. The work by Fischbein (1975) is a good case in point. His work on probabilistic reasoning has gone beyond, partially replicated and partially refuted, Piaget's earlier findings. Such research appears to be well on the way to suggesting meaningful ways in which instruction can be designed to recapitulate natural developmental sequences hence build upon students' own spontaneous and vitally important problem-solving intuitions rather than compete with them.

Other important questions remain. Is there a fundamentally important set of cognitive strategies? If so, what are they and how do they interrelate with one another? Of course, our answer to the first question is that there is a fundamentally important set of cognitive strategies. Namely those that allow one to understand his environment in the sense that he is able to derive and accurately test predictions. Predictions are the ultimate source of knowledge and the ultimate determiners of survival. Our answer to the question of how the fundamental cognitive strategies interrelate is simply that their operation in the various phases of the organizing process links them together. Of course, a number of other research questions have been alluded to. At this point it is perhaps best to leave it up to the reader to assess for himself the value of research aimed at testing any of the specific hypotheses advanced by the present theory.

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TEACHING FOR THE DEVELOPMENT OF REASONING

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INTRODUCTION

How do you deal with absurdities? Consider the tetrahedron illustrated in Figure 1. You may have the immediate impression that something is wrong, but, like most people, you may have to exert an effort to identify the specific aspect of the diagram that gave rise to this impression. To do so, you have to imagine what the tetrahedron should look like, then compare with the diagram by analyzing the relative positions of vertices and edges, recalling the representation of perspective by light and shadow, evaluating the differences that appear, and deducing that the central upright should pass in front of the left-right edge of the base.

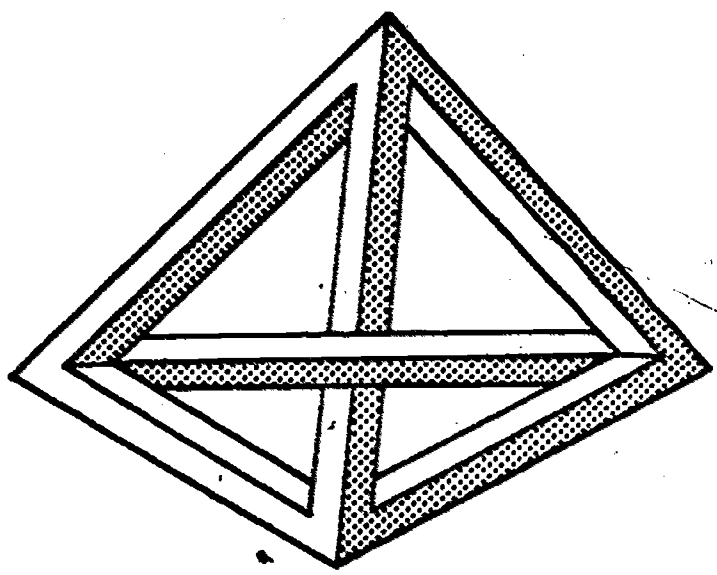

Figure 1.--What's the matter with this pyramid?

The six rational processes used in this procedure--imagining, comparing, analyzing, recalling, evaluating, and deducing--are among the ten rational powers that, according to the Educational Policies Commission (1961), are necessary for a truly free individual to achieve his or her personal goals and to fulfill his or her obligations to society. As a matter of fact, the Commission does not greatly emphasize the particular list of ten items, which also includes classifying, generalizing, synthesizing, and inferring. Instead, the Commission refers repeatedly to the great value of knowledge derived from rational inquiry and the unique contribution of the schools in developing each student's rational powers.

This writer agrees with the Educational Policies Commission that society has an obligation to enhance the rational thinking or reasoning of every individual for personal satisfaction and social benefit.

The family and the schools are unquestionably the social institutions most concerned with the development of reasoning, with the schools providing challenges and extensions beyond the limits of the student's everyday experience. Yet the Commission's statement has an unrealistic tone of optimism about what the schools can achieve. Very real limitations in money, teaching materials, and the knowledge of teachers must be kept in mind, as well as the highly differentiated perceptions of educational needs by the American public, which can express its desires through the local control of school systems (Peterson, 1978).

Unfortunately, the Commission does not provide explicit guidelines for strengthening instruction with respect to the development of reasoning. In the first section of this chapter the notion of reasoning pattern, an alternate to the Commission's rational powers with more direct relevance for teaching, is introduced. Building on this idea, the next section presents a discussion of how subject matter and student reasoning may be matched. The following section presents the learning cycle, a systematic approach to teaching that advances reasoning by allowing students to construct knowledge actively. The concluding section of the chapter is concerned with teaching strategies that can help the development of reasoning in day-to-day classroom activities.

REASONING PATTERNS

To describe the level and progress of reasoning of individual students, the notion of *reasoning pattern* is more useful than the rational powers. A reasoning pattern, such as serial ordering, control of variables, or conservation, is an identifiable and reproducible thought process directed at a type of task. Thus, ordering a set of beakers of water according to their fullness would be a behavior giving evidence of seriation reasoning, while ordering minerals according to hardness, or various liquid and solid materials according to their density, would be others.

Reasoning patterns may be compared with the logical and logical-mathematical operations introduced by Jean Piaget and his collaborators to interpret the thought processes of their subjects. Some of these operations appear to be fairly easily identifiable in a subjects' words and actions, while others require detailed analysis of extensive protocols. By contrast, reasoning patterns, as defined above, are intended to allow teachers to classify their students' thought processes on the basis of classroom conversations, observations, and written work without requiring the resources of the psychological researcher.

Here are examples of some reasoning patterns that occur frequently:

Conservation Reasoning - realizing that a quantity remains the same if nothing is added or taken away.

Additive Reasoning - making inferences from data under conditions of constant differences.

Serial Ordering - arranging a set of objects or systems in order according to a property.

Control of Variables - recognizing the necessity of an experimental design that controls all variables except the one being investigated.

Proportional Reasoning - making inferences from data under conditions of constant ratio.

Functional Reasoning - making inferences from data that give information about the relation between two continuous variables.

Propositional Reasoning - making inferences from given statements, such as the postulates and axioms of a theory.

Analogical Reasoning - establishing correspondences between objects and/or ideas that share the same relationship.

Though this list is lengthy, it is not intended to be exhaustive. Its overlap with the Commission's rational powers is clear.

An important characteristic of all reasoning patterns is that they do not refer to specific facts, experiences, or relationships, but that they are concerned with certain recurring relationships. Thus, conservation or serial ordering may be applied to coins, quantities of liquid, energy, or economic assets; propositional reasoning may be applied to plane geometry, the propagation of light, or the development of intelligence.

Admittedly, the reasoning patterns listed above are not completely independent. Thus, functional reasoning includes additive, proportional, and conservation reasoning, at least when these are concerned with numerically measurable quantities. The addition of more reasoning patterns may lead to more such overlapping relationships. At the present time we do not envisage a "fundamental" set of reasoning patterns that combine in various ways to make up more complicated reasoning processes--empirical research will have to reveal whether and how different reasoning patterns are related.

The various reasoning patterns therefore describe differing types of rational processes. It is valuable to recognize a developmental dimension within each reasoning pattern. Consider conservation, for instance. It is well known that many five- to six-year-old children apply conservation reasoning successfully to number and continuous quantity. Conservation of length and area are achieved only two or three years later and conservation of displaced volume later still. Conservation reasoning applied to energy, angular momentum, or still more esoteric variables has not been investigated extensively, but presumably requires more knowledge and understanding than most adolescents can muster.

Proportional reasoning also exhibits a progression, from situations involving small whole numbers such as 2/1 or 3/1 that are mastered by relatively young children (Lunzer and Pumfrey, 1966), to fractional ratios such as 6/4 or 5/3 that are not applied reliably by many secondary school students (Lovell and Butterworth, 1966; Wollman and Karplus, 1974). With respect to many of the other reasoning patterns, data are not now available regarding such a developmental sequence, but one can hypothesize that analogical reasoning with familiar objects (hand:arm as foot:______ arm, head, leg, bones?) is achieved earlier than with less evident relationships (boy:sugar as tree:______ water, sunlight, soil, fertilizer?). The developmental sequence may also involve several distinct reasoning patterns, as when additive reasoning appears as a precursor to proportional reasoning (Wollman and Karplus, 1974).

In fact, it seems possible to distinguish among non-application of a reasoning pattern and a virtual continuum of applications, from very simple to very complex. To relate the study of reasoning patterns to the work of the Geneva school, this writer has chosen to use the phrase "concrete level" for the simple applications that involve objects, directly observable properties, and simple relationships. The phrase "formal level" will be used for applications to hypothesized or idealized objects with postulated properties; logical, mathematical, or other complex relationships; an individual's thought processes making use of reasoning patterns; and assertions that are contrary to experience. These two levels include the lower and upper ranges of the continuum mentioned before, with the term "transitional" being applied to intermediate applications that do not fall clearly into either of the two levels.

The reader may wonder how the above classification scheme differs from the developmental theory of Piaget (Inhelder and Piaget, 1958). The difference lies in the fact that Piaget's theory postulates the existence of developmental stages in which an individual's reasoning is governed by certain mental structures. In the present proposal, the applications of a reasoning pattern are assigned to a level, with no suggestion that a particular individual possesses an underlying mental structure that facilitates this application or assures the application of other reasoning patterns at the same (concrete or formal) level. The hypotheses proposed here are weaker than Piaget's theory, but they may accord better with teachers' observations and may lead more directly to instructional improvements.

In spite of this difference, the contributions of many scholars who have attempted to characterize concrete and formal reasoning within Piaget's theory can be applied to the classification of applications of reasoning patterns. Lunzer (1978), for example, pointed out that no single criterion could be used to characterize formal thought. Instead, he referred to second-order relations (Lunzer, 1965), acceptance of lack of closure (Collis, 1972), and multiple interacting systems. Fischer (in press) has formulated an approach to classifying a relationship to determine whether understanding of it requires concrete or formal thought. Lovell (1971) has used the distinction between first- and second-order operations to identify concrete vs. formal thought.

All of these criteria share in the notion that concrete level reasoning is direct, deals with observable and familiar conditions (size, time, distance, amount, ...), and makes use of simple relationships. Formal level reasoning, however, can cope with tasks that require an indirect approach, analogous to making a right turn from a freeway by taking a left off-ramp and then looping through 270°. Formal reasoning also may deal with abstract, not directly observable properties (density, acceleration, concentration, genotype, ...), idealizations, limiting processes, and hypotheses contrary to reality. A summary of these characteristics is presented in Table 1. Yet it is clear that the distinction between concrete and formal level reasoning has not been reduced to an algorithm, because all the criteria taken together do not allow for an unambiguous determination in all cases. A certain amount of professional judgment is necessary to assess the degree of complexity of a relationship and decide whether it justifies the label formal or concrete, as suggested by Neimark (1975). Since the two levels are viewed as ranges in a continuum within which applications of a particular reasoning pattern are to be compared, a compact and universal characterization of the two levels is not necessary. Examples of applications of reasoning patterns classified by the author are presented in Tables 2 and 3.

TABLE 1

Applications of Reasoning Patterns

Concrete Level	Formal Level
(a) Needs reference to familiar actions, objects, and observable properties	Can reason with concrete and formal concepts, relationships, intangible properties, and theories
(b) Uses classification, conservation, serial ordering, and one-to-one correspondence in relation to items above	Applies combinatorial, classification, conservation, serial ordering, and proportional reasoning in relation to intangible items (a) above
(c) Needs step-by-step instructions in a lengthy procedure	Can plan a lengthy procedure given certain overall goals and resources
(d) Is not aware of his or her own reasoning, inconsistencies among various statements, or contradictions with other known facts	Is aware and critical of his or her own reasoning, actively checks the validity of conclusions by appealing to other known information

TABLE 2

Examples of Reasoning Patterns Applied at the Concrete Level

C1 Classification - separating a group of objects into several groups according to an observable property (e.g., distinguishing consistently between acids and bases according to the color of litmus paper).

C2 Conservation - realizing that an observable quantity remains the same if nothing is added or taken away, even though it may appear different (e.g., when all the water in a glass is poured into an empty bottle, the amount originally in the glass equals the amount finally in the bottle--unless some was spilled).

C3 Proportional Reasoning - making inferences from data under conditions of a constant ratio equal to a small whole number (e.g., if two pieces of candy cost 25¢, four pieces cost 50¢).

C4 Interactional Reasoning - attributing an easily observable change to interaction among a set of objects (e.g., magnet picking up a nail, rubber band stretching when it is pulled).

C5 Additive Reasoning - making inferences from data under conditions of constant difference or sum (e.g., when Mary is five years old, Joan is ten, so when Mary is ten years old, Joan is fifteen).

One very important behavior usually associated with formal thought is the conscious direction of one's own reasoning. As a result, the individual looks for inconsistencies among conclusions, checks the appropriateness of an approximation, or compares the outcome of a procedure with rough estimates made at the beginning. In the present hypotheses, this behavior is a formal level application of reasoning patterns, as was stated earlier. At the same time, it has some aspects of a personality characteristic, like impulsiveness and reflectivity.

Three important consequences of the above presentation follow for the educator who wishes to respond to the Educational Policy Commission's recommendations and take students' reasoning into account: first, educational subject matter and assignments should be matched to students' reasoning; second, teaching should be concerned with the reasoning that students engage in; third, the formation of new reasoning patterns and more advanced applications of reasoning patterns should be important instructional objectives.

TABLE 3

Examples of Reasoning Patterns Applied at the Formal Level

F1 Classification - arranging a group of items (objects or abstractions) into a multi-level hierarchy according to observable or intangible properties (e.g., classifying the member states of the United Nations according to their form of government, economic system, and standard of living).

F2 Conservation - realizing that certain properties of a system remain the same if nothing is added or taken away, but that this reasoning cannot be applied to all properties (e.g., the total angular momentum of an isolated system is constant, but some students can gain knowledge without depriving others of knowledge).

F3 Proportional Reasoning - making inferences from the data under conditions of a constant ratio not equal to a small whole number (e.g., if twelve pieces of candy cost 16¢, then fifteen pieces cost 20¢).

F4 Correlational Reasoning - recognizing relationships among variables in spite of unpredictable fluctuations that mask them (e.g., drunk driving is associated with increased accidents even though sober drivers also have accidents, and many intoxicated people do not have accidents).

F5 Propositional Reasoning - using postulates or axioms of a theory to derive consequences without regard to the factual basis of the postulates (e.g., making inferences from the theory according to which the earth's crust consists of rigid plates moving in relation to one another).

MATCHING SUBJECT MATTER TO STUDENTS: CONCRETE AND FORMAL CONCEPTS

Since the understanding of concepts requires reasoning, it is clear that much schoolwork involves the application of reasoning patterns. It is therefore helpful for the teacher to know what level of reasoning is required for the understanding of certain concepts, such as temperature, density, cell, erosion, interaction, life cycle, ideal gas, electrical conductor, genotype, and light wave. To what extent do you, the reader, believe that a student could develop an initial understanding of these concepts through (1) direct experience and the use of reasoning patterns applied at the concrete level or (2) inferences from experience and the use of reasoning patterns at the formal level (reasoning with theories, other concepts, mathematical relationships)?

In the opinion of the author, temperature, cell, erosion, interaction, life cycle, and electrical conductor can readily be understood in terms of familiar actions, observations, and examples. In other words, these concepts can be derived from direct experience through reasoning patterns applied at the concrete level. Such concepts may be called *concrete* concepts.

The concepts of density, ideal gas, genotype, and light wave must be understood in terms of other concepts (mass, volume, ratio, pressure), functional relationships (gas law, wave function), inferences, theories, and idealizations. These results cannot be obtained directly from experience but require the application of reasoning at the formal level. Such concepts may be called *formal* concepts.

Some concepts, of course, may be used with more than one meaning and can, therefore, be "concrete" or "formal" depending on their treatment. Thus, temperature can be defined in terms of sensations (hot/cold) or thermometer readings. When this is done, temperature can be understood in terms of reasoning patterns at the concrete level because it is based on easily observed criteria and serial ordering along a previously established scale. Temperature can also, however, be defined as a measure of average molecular kinetic energy. In this event, temperature becomes a "formal" concept that can be understood only in terms of other concepts (molecule, kinetic energy, random motion), the kinetic molecular theory (propositional reasoning), and the mathematical relationships connecting these notions.

To identify the reasoning required of the students in a course, the instructor has to be clear about the meaning attached to the concepts being used. Special care must be taken to use a particular concept, such as temperature, always with a meaning that was explained to the students and not to expect that temperature or another concept introduced as "concrete" can be applied without further explanations with its formal significance.

This may be a good time to mention that the concrete vs. formal distinction is not equivalent to the familiar concrete vs. abstract distinction. All concepts are abstract, abstracted from many specific instances and concrete examples.

Thus, interaction is abstract in that it is very general, applicable to all objects and systems that influence one another, regardless of whether they exchange energy or momentum, modify the chemical composition, or (if living) infect with a disease. Since the interaction of salt with water, a magnet with a nail, two fingers with a rubber band, and numerous other direct experiences are readily available to illustrate the meaning of interaction, interaction is a "concrete" concept that has been taught successfully to second and third graders.

The light wave concept is also abstract, though not quite as generally applicable as interaction. Yet the meaning of light wave depends essentially on interference phenomena, Huygens' principle, and other uses of propositional reasoning, functional relationships, abstract variables, and idealized models that require application of reasoning patterns at the formal level. Hence light wave is a "formal" concept.

All of the "concrete" concepts have, in addition, deeper meanings that can only be grasped by the application of reasoning patterns at the formal level. This fact has already been illustrated for temperature. Consider some of the other concepts. In addition to discriminating electrical conductors from non-conductors by observing how they function in an otherwise closed circuit (concrete level), one can characterize the difference in terms of the density and mobility of electric charge carriers in the material (formal level). Besides observing the visible effects of erosion by a recent rainfall along a road cut or on a hillside used recreationally by motorcyclists (concrete level), one may be concerned about the long-term role played by erosion in the formation of the landscape, taking into account the long-term effects of wind, water, freezing and thawing, steepness of the slope, and resistance of the rocks (formal level).

The knowledge of whether a particular concept in the teaching program is "concrete" or "formal" can be applied fruitfully by the teacher who knows the levels of reasoning of which the students are capable. This information is very difficult to acquire and keep up to date in practice, since it requires extensive and continuing research on the abilities of each student. Several other approaches are therefore recommended.

First of all, past investigations of student reasoning by Piaget, his collaborators, and many others have documented a gradual development that can provide a teacher with rough statistical guidelines about the distribution of abilities to expect in a group of students of a certain age. Thus, preschool and primary grade children would usually apply reasoning patterns at the concrete level or not at all. Pupils in the middle and upper grades would apply reasoning patterns predominantly at the concrete level, with some gaps in application and occasional applications showing formal level reasoning.

Junior high school students can be expected to apply reasoning patterns more consistently at the concrete level than do elementary school children, with fewer gaps and somewhat more frequent applications at the formal level. The gradual shift of the use of reasoning patterns from the concrete level to more advanced ranges of the continuum is extended for high school and college students, but few individuals have been found to apply many differing reasoning patterns consistently at the formal level.

Perhaps the principal significance of this brief survey of the development of reasoning is that every teacher must expect a diversity of approaches by his or her students and by the same student on different occasions. To get more specific information about individual students, the teacher may observe their reasoning closely during class discussions, on homework assignments, and in conversations in which a student has to explain an idea, justify an inference, present evidence, or defend a point of view. Suggestions for organizing such activities, which are intellectually challenging to students and provide valuable information for the teacher, are included in the later section of this chapter concerned with teaching strategies.

Since the secondary school and college teacher is at a disadvantage in observing students because of the reduced contact with individuals, Lawson (1978) has developed a classroom "Test of Formal Reasoning." Such a test is practical because the older students can respond in writing and in a group setting that reduces the time for task administration. Lawson's test, available from its author,* consists of 15 items that require the application of conservation, combinatorial, control of variables, probabilistic, and proportional reasoning. A simple scoring procedure allows the teacher to determine how consistently each student applies these reasoning patterns at the formal level. Lawson's test is certainly not unique, in that different items might be selected and other reasoning patterns might be included. Renner (1977) and his colleagues, for example, have investigated a large number of possible approaches. Nevertheless, Lawson's test is the most practical for use by teachers at the present time.

Two implications of the students' gradual developmental progress in reasoning will now be described. First, the emphasis of instruction in the early elementary grades should be primarily on very simple "concrete" concepts. In the junior high school years, more advanced "concrete" concepts and simple "formal" concepts are appropriate. High school and college courses can include gradually more and more "formal" concepts. Particularly valuable for teaching are concepts, such as cell and temperature, that can be either "concrete" or "formal," depending on the meaning used. These concepts can be introduced with their concrete significance during earlier years, while the meaning is elaborated in higher grades to make use of the students' developing ability to apply reasoning patterns at the formal level.

To illustrate these ideas, examples will be taken from the Science Curriculum Improvement Study (1970-1974), which was designed in accordance with developmental principles. Thus, some of the major concepts in the early grades deal with classification (objects/properties), causality (interaction), class inclusion (systems/subsystems/objects, communities/populations/organisms), serial ordering (life cycle), conservation (keeping track of a system), and transformation (evidence of interaction). All of these are introduced through learning cycles (see next section) that build on the children's own experiences and make reference to objects in the classroom which the children can investigate. In the upper grades, the students come to grips with more advanced concepts such as multiple viewpoints (including self-awareness of the child as observer), transformation (evidence of energy transfer), hypotheses (scientific theory), and multiple interactions (ecosystem).

The second implication derives from the individual differences in reasoning that must be taken into account. To meet the variety of needs, most of the teaching activities should be sufficiently open-ended to allow each student to find a challenge and succeed in meeting it regardless of his or her developmental condition. To this end, success must be defined in terms of the individual's own goals and not in any normative fashion.

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Here are some illustrations, this time taken from Rand McNally SCIIS (Thier, Karplus, Knott, Lawson, and Montgomery, 1977-1978). Primary grade children, working with buttons of various shapes and colors, may arrange them in "pretty" patterns (no reasoning pattern), sort them into several groups according to a property (concrete level application), or construct a classification system that recognizes colors, shapes, and materials hierarchically and not limited to the collection of buttons the child actually has (formal level application --not expected to occur, but logically possible).

As another example, consider the gear sets included in a second-year unit. Some children may just use one gear and turn it rapidly on its base, making the individual cogs blur (no reasoning pattern), others may compare the turning rates of interacting gears of various sizes (concrete level application), while still others may carefully observe the turning rates of different-sized gears and predict the outcome of as yet untried combinations (advanced concrete or formal application, depending on ratio involved). Though extremely few students are likely to make formal level applications of reasoning patterns in these activities, the existence of such challenges is a source of intellectual stimulation and may lead to the formation of new reasoning patterns by some of the children.

Another example of open-endedness with respect to level of reasoning may be found in the investigation of electric circuits of the Rand McNally SCIIS sixth-year physical/earth science unit. A few of the students may strive to light a bulb as brightly as possible, perhaps burning it out through a trial-and-error process without regard to the necessary conditions that bring about this result (no reasoning pattern). Most of the students in a sixth grade class will probably recognize the conditions that result in open or closed circuits and use these reliably to classify objects such as electrical conductors or nonconductors (concrete level application). Finally, some of the students will contribute ideas to the formulation of a scientific theory for explaining the electric energy transfer in terms of electricity flowing through wires (formal level application).

The last example concerns a widely-used high school chemistry laboratory experiment on reaction rates. Here the students mix two given solutions in various proportions, at various temperatures, and with the possible addition of water. They measure the time required for a sudden color change to occur. Some students may mix various combinations of the materials and observe the required time without keeping complete records of their work (no reasoning pattern). Many of the students will make a record of their work and include pairs of trials that differ only with respect to one variable--temperature or the amount of one ingredient (advanced concrete level application). A few of the students will identify concentrations (relative rather than absolute amounts) as the significant variables and carry out series of three to five trials in which all but one independent variable is held constant, finally displaying the results on a graph (formal level application). Since several reasoning patterns are applied in this experiment (control of variables, proportionality, functional reasoning), more detailed examination of a student's work may reveal both strengths and weaknesses.

It is clear that the science laboratory is especially well suited to provide the open-ended activities that have been recommended to allow students to match the reasoning demands of an assignment to their developmental condition. The next two sections of the chapter will describe how suitably planned laboratory instruction, expository teaching, and discussions can be used to advance the students' reasoning.

ADVANCING THE LEVEL OF REASONING: THE LEARNING CYCLE

This author's own observations of students, the work of Piaget and other developmental psychologists, and epistemological considerations have led him to the notion that concept learning and the establishment of new reasoning patterns are active processes for the learner. In this chapter, the term self-regulation will be used to refer to this active internal mental process involved in the formation or adaptation of reasoning patterns. The term is intended to suggest the learner's taking initiative and then adjusting to the feedback received from the environment in response to this initiative. An analogy in physical actions is the experience of driving an unfamiliar car with a brake of differing stiffness than one is accustomed to. One first uses the habitual foot pressure on the pedal, only to discover that the brake responds too much and the car jerks, or too little and the car does not slow down. After trying variations that attempt to correct the error, the driver gradually discovers how to apply pressure that brings the car to a smooth stop. One's first encounter with an unexpected power brake, which responds greatly to a very light touch, can lead to near disaster!

Self-regulation involves the student in a feedback loop with the environment. He or she analyzes a problem situation, considers tentative solutions, evaluates their effectiveness, and uses new approaches when the initial trials do not produce the desired results. Self-regulation that leads to formal level reasoning patterns generally requires the student's awareness of his or her reasoning. Intuitive trial-and-error procedures may lead to self-regulation with respect to reasoning patterns at the concrete level.

As an example of such feedback, consider the relationship of pizza price to pizza size in a pizza parlor. A child using concrete level reasoning may decide that the 8-inch pizza costing $1.40 is too small and orders a 16-inch pizza without looking at the price, expecting that it would cost $2.80, "Because it's twice as big." Imagine the dismay when the gigantic pizza arrives, together with a check for about $5.50! Is the pizza parlor operated by an extortioner? Here is a surprise that may trigger the search for more successful reasoning to cope with the relation of pizza size to pizza price, a mathematical relationship requiring formal reasoning. In other words, the concept of area when circles are being compared is much more demanding than when squares with simple edge ratios are compared, because a large square can be assembled from small squares of half the edge-length set side by side, but the same cannot be done for large and small circles. Applying the memorized formula for the area of a circle is different from the understanding of length and area comparisons needed to derive the formula for the area of a circle.

Whatever one's specific way of coping with a challenge, when the changes required are not too great, one is likely to reorganize one's reasoning patterns appropriately. One may realize that doubling the edge of a square pizza increases the size four-fold, and that doubling the diameter of circular pizza is likely to have a similar outcome. Confirmation of a new reasoning pattern through applications to further similar experiences will stabilize it and will lead to its more frequent use.

If the required changes in reasoning are great, however, an individual may need the help of peers, parents, or teachers to suggest more appropriate reasoning, more effective new concepts. They may suggest, "It's the area of the pizza that determines the price, and the area varies as the square of the diameter." Such direct teaching is not effective, however, unless the learner has had previous experience with length, area, circles, or the other ideas needed, and can subsequently test them against his or her own observations. Reinforcing feedback from the environment is necessary to make sure that the interplay of thought and action, an essential part of self-regulation and the learner's construction of knowledge, continues until the new reasoning patterns are firmly established.

The classroom is a place where experience with the physical environment, social transmission, and self-regulation can occur if the teaching program allows for open-ended activities by the students as well as explanations and suggestions from the teacher. Put more concisely, the teaching program should allow for (1) autonomous activities by the students as they seek challenges, test their ideas, evaluate the feedback from the environment, and then formulate a new hypothesis or other initiative; and (2) conceptual input from the teacher who may provide a definition, model a classification scheme, suggest similarities and differences, or explain an event in terms of familiar experiences. The learning cycle approach introduced as part of the Science Curriculum Improvement Study (1970-1974) combines open-ended student activities and conceptual teacher input in a form of inquiry teaching that has been effective at the elementary school level for the formation of concrete level reasoning patterns. More recent evidence indicates that it is also effective with older students and formal reasoning (Lawson, Blake, and Nordland, 1975; Lawson and Wollman, 1976; Wollman and Lawson, 1978).

What is the learning cycle? Consider the following approaches to teaching the density concept. Here are several activities that appear to be suitable--in what sequence can they be employed most effectively?

(a) Viewing a film in which (1) one cubic decimeter blocks of aluminum, paraffin, styrofoam, iron, and other solid materials are carefully weighed and (2) the volumes of one kilogram blocks of the same materials are calculated from the dimensions. These presentations allow two density determinations of each material to be compared.

(b) Having a laboratory session in which the students can use rulers, calipers, graduated cylinders, and balances to determine the volumes and masses of objects of widely differing shapes and various materials for plotting on graphs of volume vs. mass.

(c) Holding a discussion in which the students can tell of their experiences with floating and sinking objects, including themselves when they swim or play in the water.

(d) Presenting an explanation accompanied by demonstrations in which the teacher weighs ~~various~~ specimens of certain materials, finds their volume by appropriate means, and finally computes the density of each material.

(e) Having a laboratory session in which the students make accurate measurements of the masses and dimensions of carefully machined blocks and rods whose volume can be calculated easily from their linear dimensions.

Note that the laboratory alternatives (b) and (e) allow for physical experiences, that options (a) and (d) provide social transmission with illustrations, and that (c) draws on the students' past experience and allows for social transmission. All five approaches, therefore, include elements that have been identified as important for concept learning and the formation of reasoning patterns.

To differentiate among the approaches, return to the notion that an individual constructs new knowledge actively. Option (b) above fits this requirement most closely. In this laboratory session, the students have a great deal of freedom to use their own judgment, try out their own ideas, and learn from their own mistakes as they gain practical experience with materials, specimens, and instruments that will be used in the definition of density later. The teacher can circulate among the students and diagnose any learning problems they might have, as well as identify the reasoning patterns they use.

After the laboratory experience (b), the concept of density might be introduced by means of the film (a) or the lecture-demonstration (d). Both of these expository procedures employ materials similar to the ones used earlier by the students, so that they will be more easily able to participate in the presentations vicariously. Following this introduction of the density concept by the teacher or film, the discussion of floating and sinking objects (c) and the more careful density measurements in the laboratory (e) can allow for applications of the new concept and an informal assessment of the students' understanding.

The term "learning cycle" has been introduced for the three-phase procedure just described (Eakin and Karplus, 1976; Karplus and Lawson, 1974; Karplus, Lawson, Wollman, Appel, Bernoff, Howe, Rusch, and Sullivan, 1977; Karplus and Thier, 1967). The three phases, here called *exploration, concept, introduction,* and *concept application,* have also been designated by other terms--for instance, exploration, invention, and discovery by the Science Curriculum Improvement Study (1970-1974).

During exploration, the students learn through their own actions and reactions in a new situation. In this phase they explore new materials, ideas, and relationships with minimal guidance or expectation of accomplishments. Besides encouraging the students to apply their previous learning, develop their interest, and satisfy their curiosity, the open-ended conditions of the exploration phase permit the teacher to assess the students' initial understanding and their preconceptions. Through questions and suggestions, the teacher can help students relate the new experience to their existing knowledge.

The new experiences in exploration should raise questions that the students cannot answer with their accustomed patterns of reasoning --relating mass and volume of irregularly-shaped specimens might serve this purpose for the density and ratio concepts. Individual investigations and small group work are important. These two approaches encourage each student to become aware of his or her own ideas as well as providing a supportive social environment with a multiplicity of questions and viewpoints. Students who are not very inventive or thoughtful can learn through sharing the ideas and suggestions of their classmates.

The second phase of the learning cycle, concept introduction, starts with the introduction of a new concept or principle—ratio, density—that leads the students to apply new reasoning patterns to their experiences. The concept may be introduced by the teacher, a textbook, a film, or another medium. This phase, which aids in self-regulation, should always follow exploration and relate directly to the exploration activities. The film in approach (a) above or the demonstration lecture in (d) could well serve as concept introduction sessions following the laboratory activity (b). Students should be encouraged to develop or adapt as much of a reasoning pattern as possible before it is explained to the class, but expecting students to introduce complex ideas completely by themselves is unrealistic.

In the last phase of the learning cycle, concept application, the students apply the new concept and/or reasoning pattern to additional examples. The accurate measurement of densities in laboratory (e) would be an appropriate application activity following the introduction of the density concept. Other application activities might involve the densities of liquids and solutions, floating and sinking, and possibly the densities of gases.

The application phase is necessary to extend the range of applicability of the new concept or principle. Concept application provides additional class time and experiences for self-regulation and the stabilizing of a new reasoning pattern. Group discussions of everyday applications, posing of related problems by members of the class, and comparison of differing interpretations furnish a social setting that helps many individuals refine their thinking.

Without numerous varied applications, the new concept's meaning might remain restricted to the particular examples used to illustrate the definition. Many students may fail to generalize it to other situations, since the concept introduction activity is necessarily limited to a few special cases--often only four or five can be included for lack of time and space.

In addition, application activities aid students whose conceptual reorganization takes place more slowly than average, or who did not adequately relate the teacher's explanation during the introduction phase to their previous experiences. Teachers can observe students during the application phase to evaluate their understanding. If necessary, individual conferences with these students can help resolve the difficulties. Small group discussions where students can compare their ideas can also help individuals reduce their misunderstanding.

Teaching procedures very similar to the learning cycle have been described by others concerned with teacher education (Biggs, 1973; Dienes, 1971). The learning cycle has so many appealing qualities that good teachers may often use it instinctively without articulating their procedures or relating them explicitly to pedagogical and psychological principles.

The learning cycle approach has been applied by Kurtz (1976; Kurtz and Karplus, 1979) to the teaching of proportional reasoning in high school pre-algebra classes. In view of the commonly-occurring confusion of constant ratio and constant difference relationships, Kurtz provided instruction in constant ratio, constant difference, and constant sum problems in his 12-hour course entitled Numerical Relationships (Kurtz, 1975). His intent, accomplished successfully, was to enable more students to discriminate among situations where one or the other relationship would be appropriate.

Eight features distinguish the Numerical Relationships (NR) program from the usual textbook approach to proportions:

(1) It is conceptually organized to challenge students to distinguish among constant ratio, constant difference, and constant sum problems;

(2) Teaching provides for student autonomy and teacher input through learning cycles;

(3) NR directs the students' attention at the variables necessary to describe a relationship;

(4) Graphical means are employed to help students identify the corresponding changes of variables for each constant ratio relationship;

(5) NR makes use of laboratory activities;

(6) NR avoids algorithmic techniques such as equating the products of means and extremes in a proportion;

(7) NR often requires descriptive answers and explanations rather than exclusively numerical solutions to exercises; and

(8) Word problem situations are used to generate sets of closely related numerical questions.

Here is an example of the learning cycle applied to the NR activity concerned with introducing the constant connection between the situational context and the appropriate mathematical numerical relationship. As exploration, the teacher presents a two variables table with the entries

$$X = 4 \quad 6$$
$$Y = 8 \quad ?$$

The students are challenged to propose values for the missing entry and to justify their suggestions with reference to illustrative examples. Many possibilities exist, of course, and at least three numerical values may be derived from the examples studied earlier in the NR program. These are Y = 12 (constant ratio, 4 books cost $8, 6 books cost $12), Y = 10 (constant difference), and Y = 6 (constant sum). Students who are more creative may propose Y = 5.33 (constant product) or Y = 14 (Y = 3X-4), but these are unlikely unless students have been encouraged previously to be inventive.

Concept introduction in this activity presents the idea that the numerical data by themselves are insufficient to determine the answer uniquely, and that other information--the situational context of the numerical data--must be taken into account to determine just which numerical relationship is most appropriate.

The following is an example of an application exercise that requires a descriptive answer and justification but no numerical solution:

> Two parachutists, Bill and Karen, are falling towards the ground with the same velocity. Bill jumped out of the plane later than Karen, so he is originally above her. Both Bill and Karen measure their altitude above ground. The two variables in this situation are __________ and __________. The relationship between these variables is __________ because (please justify your answer ____________________
> ____.

The reader may object at this point that the concept introduction phase of the learning cycle is in conflict with Piaget's notion that the individual must construct knowledge for him- or herself. The author believes that there is no contradiction; that when concept introduction follows exploration, as stated above, then concept introduction serves as a social transmission contribution to development. Self-regulation then takes place as the student relates the new concept or principle to previous experiences gathered in an open-ended situation in which he or she could function with high autonomy.

It is clear, therefore, that beginning instruction with exploration is a key aspect of the learning cycle. It differs from either of two more traditional approaches to rule-learning of (1) providing a rule and then giving examples or (2) giving examples and then summarizing their common properties by the rule. Both of these strategies lack the high degree of autonomy of students during the exploration phase.

For the learning cycle to become widely used, effective exploration activities have to be designed. Not many such activities are available at present because student autonomy in most secondary and college teaching programs has been low. The ADAPT project at the University of Nebraska, Lincoln (ADAPT, 1977) has described a few examples that were developed by the participating faculty. One of these, in anthropology, requires a pair of students to look for the conditions under which a stranger walking in the opposite direction can be made to smile at one of them, while the other observes. Investigating this process prepares the students for introduction of the concepts of social customs and rituals. In an economics class, student exploration of the cost-of-living concept involves them in making an inventory of their own purchases and expenses so as to create a personal "cost of living" before introducing this idea as a composite index for an entire population. In trigonometry, the students have a laboratory activity in which they measure the sides and angles of many cardboard triangles and look for patterns in the ratios of corresponding sides. These patterns lead naturally to the introduction of the trigonometric functions sine, cosine, and so on.

Though based primarily on developmental principles, the learning cycle has aspects compatible with other learning theories. Since educational theories are not rigorous deductive systems, the fact that similar outcomes can follow from differing starting points is not surprising. Thus, the exploration phase permits learning by discovery, concept introduction taken together with exploration provides "guided discovery," and concept application provides for repetition and practice. The approach is even close to Ausubel's Assimilation Theory, whose central ideas are (1) that learning depends on what the learner already knows and (2) that meaningful learning involves a conscious effort on the part of the learner to relate new and existing knowledge in substantive ways (Novak, 1977). The first of these corresponds to the importance of prior experience and existing reasoning patterns emphasized in the present article, while the second is not far from Piaget's view that knowledge is constructed actively by the individual. The Ausubelian and Piagetian approaches appear to be variations on a theme rather than the mutually exclusive alternatives as described by Novak (1977). There is this difference, however: the awareness of one's own reasoning required by Ausubel for meaningful learning (Novak, 1977, p. 456) would limit success of Ausubel's approach to students who use formal level reasoning patterns extensively. In the author's opinion, the learner's connecting new and old knowledge need not be conscious, and is unlikely to be conscious for individuals using primarily concrete level reasoning patterns.

The combination of autonomy and input provided by the learning cycle has been designed to further self-regulation. Assembling a larger teaching program out of many learning cycles is a task that has not been described here; the sequence might well take into account the learning hierarchy approach of Gagne (1977) and the structure of the discipline emphasized by Bruner (1960).

In addition to its direct contribution to learning, autonomy during exploration and concept application has great motivational value. Doing something because you want to do it, and doing it the way you want to do it, are powerful incentives. After a research visit to an eighth grade by the author, one of the students who had responded to a proportional reasoning task, wrote this comment: "I, ...myself have really enjoyed you here today. And I have really learned how to say and write what I and only I think, with no one else to try and tell me." The autonomy enjoyed by this student was merely that of explaining in writing how she had arrived at the prediction of a specified measurement outcome!

TEACHING TO ENHANCE REASONING

In the preceding sections of this chapter, two hypotheses have been presented:

(1) The rational powers can be represented in terms of a large number of reasoning patterns that may be applied over a continuum of levels of complexity, from what has been termed the concrete level to the formal level.

(2) The development of the rational powers, equivalent to the formation of new reasoning patterns and the extension of existing reasoning patterns, requires a process of active learning.

The learning cycle approach to organizing instruction so as to facilitate active learning has been described. In this section there will be presented a variety of teaching strategies that can be used to encourage the development of reasoning without the production of completely new science courses.

Most important for the implementation of these strategies is the teacher's commitment to the development of reasoning in addition to the usual concern with course content. How much time will be needed for modified instruction will depend on the level of the course and the preparation of the students. In the elementary grades, where present textbook series present a very ambitious program including many "concrete" and even "formal" concepts already for the primary grades, a very severe reduction in coverage will have to be effected. The same applies to most standardized science tests, which make completely unrealistic expectations of students and force most of them into an unthinking choice among the alternatives presented by many questions. The laboratory-based inquiry-oriented elementary science courses (Science Curriculum Improvement Study, 1970-1974; Elementary Science Study, 1967; Science--A Process Approach, 1967) already provide for the development of reasoning to some extent and can therefore be applied to the goals outlined in this chapter much more easily.

It has been generally recognized during the last few years that most secondary school science courses are heavily based on the teaching of "formal" concepts and therefore present difficulties for students who use primarily reasoning patterns at the concrete level (Lawson and Renner, 1975; Shayer, 1978). Substantial selection of content, extensive use of open-ended laboratory activities, and other adaptations will have to be made to provide for the development of reasoning (Karplus et al., 1977). Less time and effort will be needed in an advanced placement course, where most students apply reasoning patterns at the formal level and have a substantial background and experience in science. Nevertheless, all students seem to benefit cognitively and affectively from an approach, such as the learning cycle, that permits active learning by them.

Essential in the classroom are activities that call the students' attention to the rational bases of the instructional program. These are regrettably rare occurrences in most teaching programs, which emphasize the presentation and explanation of content but do not bring in what might have been--other alternatives--and the reasons why these other options are not correct or not important. Questions that a teacher might ask to bring out this background are:

Why are you sure of that?

What is the supporting evidence?

How could you explain that to a person who believes that . . . (include an idea that is appropriate but erroneous)?

What other ways of thinking about this problem are there?

Here are additional suggestions for the classroom teacher (adapted from Karplus et al., 1977):

(1) Use concrete concepts defined operationally through demonstrations, examples, and illustrative actions to introduce a new topic. Depending on the sophistication of the students, expand the topic with formal concepts during further instruction.

(2) Begin class discussions with simple demonstrations or puzzles and challenge the students to raise questions or predict the outcome of hypothetical experiments. Then use the actual results to examine unstated assumptions.

(3) Allow the students time and opportunities for abundant and repeated experiences. Alternative ways of perceiving relationships help students to resolve contradictions and become aware of their own reasoning.

(4) Encourage students to interact with one another, in heterogeneous groups, during discussions and problem-solving sessions. By learning about the views of others, especially those who use more advanced reasoning patterns, they will become more aware of their own reasoning.

(5) Model the reasoning behaviors you hope to foster. Reason outloud when you present an explanation or answer a student's question. Let students know that you consider alternative possibilities and are at times unsure of how to proceed.

(6) Be receptive to ideas or hypotheses that may seem off the track. Don't squelch a timid first attempt, but encourage it by drawing attention to its good points and possibly unusual approach.

(7) Before making an assignment from the text, read the selection carefully to identify the demands for reasoning. Perhaps supplement the assignment with materials you have prepared to help students who are using reasoning patterns primarily at the concrete level.

(8) When you select items for a test, make sure that their demands for reasoning and science knowledge are appropriate. Avoid problems in which ingenious reasoning overshadows the science —use these only to challenge gifted students.

(9) Include some test items on which students are required to justify their answers so you can assess their reasoning as well as their knowledge.

(10) Avoid certain behaviors that tend to make the students' thinking remain superficial--allowing so little time to answer questions that few students have the opportunity to formulate thoughtful answers; evaluating the first answer from a student and then taking control of the discussion without waiting for evaluative comments from other students; answering your own questions rather than inviting students to provide even partial solutions; requiring students to recall information as opposed to relating or evaluating information.

The suggestions above, together with the analysis of instruction and the use of the learning cycle, promise to enhance the value of a teaching program for the development of reasoning. Such teaching will further the rational powers of the mind and make progress toward the attendant benefits described by the Educational Policies Commission (1961). The present author believes that the research cited in this chapter helps to answer questions raised by the Commission. The two hypotheses appear to be a useful way for translating the Commission's aims into practice.

In particular, the concept of reasoning patterns seems to allow the researcher to establish a close connection between the rational powers and classroom activities. Further research to investigate the abilities of various groups of students with respect to their use of reasoning patterns would seem to be very fruitful, as would the development of learning cycles concerned with additional science concepts and the related reasoning patterns.

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EDUCATION FOR RATIONAL THINKING: A CRITIQUE

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INTRODUCTION

There is no doubt but that the Educational Policies Commission's ten rational powers (i.e., recalling, imagining, classifying, generalizing, comparing, evaluating, analyzing, synthesizing, deducing, inferring) are crucially important aspects of intellectual functioning when considered in terms of the culture's long-term acquisition of organized bodies of knowledge. However, in terms of the education of individual pupils and of the furtherance of their post-school careers, the facilitation of these powers is subject to so many significant qualifications that they play a relatively subsidiary role in relation to the non-problem-solving aspects of cognitive functioning and even in relation to problem solving itself.

In the first place any such listing of intellectual functions, accompanied by a suggestion that they can be enhanced by appropriate schooling, is a relic of the long-discredited "formal discipline" or faculty psychology approach to education. According to this point of view, each of these functions constitutes a distinct entity or faculty of the mind that can be trained or enhanced by engaging in a difficult course of study such as mathematics, science, classics, etc.; and once established and consolidated such functions are supposedly at the service of any learning or problem-solving situation in which the faculty in question is involved. Over the years, however, this notion has been repeatedly disconfirmed by empirical studies (e.g., E. L. Thorndike, 1924; Carroll, 1940; Rapp, 1945; Strom, 1960).

A second very similar proposition has been put forth that general knowledge of logic (Hyram, 1957) and training in the heuristics of discovery (Bruner, 1961; Suchman, 1961) or in strategies of problem solving (Parnes and Meadow, 1959; Crutchfield, 1966) can enhance knowledge of scientific method as well as problem-solving ability. Universally, however, it has been found that problem-solving and discovery skills that are learned in a general content-free context, or within a given context of problems or a given discipline are not very generalizable to other fields (Crutchfield, 1966; Parnes and Meadow, 1959). Knowledge of scientific method, in other words, tends to be discipline-specific and cannot be learned apart from the content of that discipline; and once learned it cannot be transferred to discovery learning or problem solving in other disciplines.

Third, it is apparent that the problem-solving activity of which most people are capable is either a manifestation of contrived discovery, in which the steps in the solution of the problem are carefully arranged for them by others (as in the typical laboratory situation), or involve the solution of everyday problems rather than the discovery of new knowledge. In the first situation a great deal of rational thought is not required. In the second situation it is clear that the model of scientific or mathematical problem solving in which the ten rational powers mentioned above are prominent, has been greatly oversold as a paradigm of all thought or problem solving. Actually very little logic is applicable to the ordinary problems of living requiring thought. Very few such situations involve the rules of drawing valid inferences from premises but rather habitual or preferred methods of coping, temperamental and emotional preferences, and idiosyncratic values, preconceptions, biases, and impulses. It is not that people are illogical when they have to deal with abstract, non-controversial problems in which they are not emotionally involved. It is rather that in the more typical problems of everyday adjustment, the more potent influence of these other variables requires that problem solving proceeds along alogical lines.

Fourth, although the ten rational powers are an essential aspect of problem solving they contribute less to variance in outcome of the less difficult and novel problems than does the availability in cognitive structure of particular concepts and propositions that are relevant for their solution (Saugstad, 1955; Ring and Novak, 1971). Hence if the school concentrated on enhancing the rational powers to the detriment of transmitting subject-matter content, students would lack the chief ingredient required to solve typical problems in an academic setting.

Fifth, in the case of more difficult and novel problems that are not ordinarily susceptible to the application of relevant content and rational problem-solving processes, a complex of such cognitive personality traits as perseverance, resourcefulness, flexibility, originality, problem sensitivity, venturesomeness, and improvising ability determines most of the variance in outcome. Common experience indicates that such traits are relatively rare, mostly genetically determined, and are not very teachable. For example, there are very few genuinely good diagnosticians in medicine who can cope successfully with the non-common garden variety of cases. These relatively rare individuals are identifiable quite early in their careers before they have had a good deal of clinical experience. Their colleagues who lack these traits, on the other hand, do not improve much in diagnostic ability irrespective of how much supervision, instruction, and experience they may have in diagnosis.

Thus, for both the less and more difficult variety of problems it seems to make more sense for the school to focus on the transmission of subject matter content which is both more teachable and more important for problem solution than to concentrate on producing good problem solvers, who are both less generously distributed in the population and whose special skills necessary for unusual problem-solving ability are not very teachable. And what is true about exceptional degrees of problem-solving capability is even more true about creativity. The creative person who makes a uniquely original contribution to his culture is not only exceedingly rare but most of his creative potential is also genetically determined and is not very susceptible to training. The school at most can encourage him to exercise his creative potentialities and reward their expression.

Lastly, it is important to emphasize the fact that training in the rational powers can be effected through expository teaching and reception learning and need not necessarily be accomplished through practice in discovery learning or problem solving. Admittedly, however, some degree of empirical practice, such as occurs in the laboratory, is necessary and desirable for this purpose. It is also true that even processes involved in reception learning itself, e.g., subordination, superordination, classification, analysis, synthesis, reconciliation, can be learned in an expository teaching context (Lawton, 1977a, b; 1978; Lawton and Wanska, 1977).

To summarize, the rational powers are most important in problem-solving situations that are not especially difficult or novel and that appear in an academic or academic-like settings (e.g., laboratory) in which there is little personal or emotional involvement. They do not account for much of the variance in novel or more difficult problem-solving situations; and since training in one problem-solving context or discipline, or even in a general content-free subject like logic is not generalizable to other particular contents or disciplines, it must be taught separately in each discipline together with the content.

Because relevant content is important in ordinary problem-solving, because the reception learning of subject matter content is eminently teachable to most pupils, and because scientific method itself can be taught in part through expository teaching, the school should concentrate on facilitating the meaningful reception learning (i.e., the active, critical comprehension) of words, concepts and propositions (subject matter). A subsidiary goal, in conjunction with the transmission of subject-matter knowledge, is to instruct children in the processes whereby valid knowledge is discovered (e.g., laboratory exercises). Here the rational powers can be enhanced by expository teaching, by actual problem-solving activity, and by the exercise of those supportive cognitive-personality problem-solving traits in the small minority of those students who possess them.

In a later section of this chapter we shall examine assimilation theory (Ausubel, 1963; Ausubel, Novak and Hanesian, 1978) in detail, that is, the nature, conditions and facilitation of meaningful reception learning through expository teaching. Instruction designed for the development of the rational processes does not differ in principle from the instructional design used for the acquisition of substantive concepts and propositions except that exposition is combined with practice in problem solving (e.g., laboratory exercises).

RECEPTION VERSUS DISCOVERY LEARNING

Before turning to the nature and conditions of meaningful reception learning and of the manipulable variables that influence it, it will be necessary to distinguish briefly between reception and discovery learning and to point out that the reception--discovery and rote--meaningful dimensions of learning are orthogonal to each other.

The distinction between reception and discovery learning is not difficult to understand. In reception learning the principal content of what is to be learned is presented to the learner in more or less final form. The learning does not involve any discovery on his part. He is required only to internalize the material or to incorporate it into his cognitive structure so that it is available for reproduction or other use at some future date. The essential feature of discovery learning, on the other hand, is that the principal content of what is to be learned is not given, but must be discovered by the learner before he can internalize it; the distinctive and prior learning task, in other words, is to discover something. After this phase is completed, the discovered content is internalized just as in reception learning.

MEANINGFUL VERSUS ROTE LEARNING

Now this distinction between reception and discovery learning is so self-evident that it would be entirely unnecessary to belabor the point were it not for the widespread but unwarranted belief that reception learning is invariably rote, and that discovery learning is invariably meaningful. Actually, each distinction constitutes an entirely independent dimension of learning. Thus reception and discovery learning can each be rote or meaningful, depending on the conditions under which learning occurs. In *both* instances meaningful learning takes place if the learning task is related in a nonarbitrary and nonverbatim fashion to the learner's existing structure of knowledge. This presupposes (1) that the learner manifests a *meaningful learning set*, that is, a disposition to relate the new learning task nonarbitrarily and substantively to what he already knows, and (2) that the *learning task* is *potentially meaningful* to him, namely, relatable to his structure of knowledge on a nonarbitrary and nonverbatim basis. The first criterion, nonarbitrariness, implies some plausible or reasonable basis for establishing the relationship between the new material and existing relevant ideas in cognitive structure. The second criterion, substantiveness or nonverbatimness, implies that the potential meaningfulness of the material is never dependent on the exclusive use of particular words and no others, i.e., that the same concept or proposition expressed in synonymous language would induce substantially the same meaning.

The significance of meaningful learning for acquiring and retaining large bodies of subject matter becomes strikingly evident when we consider that human beings, unlike computers, can incorporate only very limited amounts of arbitrary and verbatim material, and also that they can retain such material only over very short intervals of time unless it is greatly overlearned and frequently reproduced. Hence the tremendous efficiency of meaningful learning as an information-processing and storing mechanism can be largely attributed to the two properties that make learning material potentially meaningful.

First, by nonarbitrarily relating potentially meaningful material to established ideas in his cognitive structure, the learner can effectively exploit his existing knowledge as an ideational and organizational matrix for the understanding, incorporation, and fixation of new knowledge. Nonarbitrary incorporation of a learning task into relevant portions of cognitive structure, so that new meanings are acquired, also implies that newly learned meanings become an integral part of an established ideational system; and because this type of anchorage to cognitive structure is possible, learning and retention are no longer dependent on the frail human capacity for acquiring and retaining arbitrary associations. This anchoring process also protects the newly incorporated material from the interfering effects of previously learned and subsequently encountered similar materials that are so damaging in rote learning. The temporal span of retention is therefore greatly extended.

Second, the substantive or nonverbatim nature of thus relating new material to, and incorporating it within, cognitive structure avoids the drastic limitations imposed by the short item and time spans of verbatim learning on the processing and storing of information. Much more can obviously be apprehended and retained if the learner is required to assimilate only the substance of ideas rather than the verbatim language used in expressing them.

It is only when we realize that meaningful learning presupposes only these two previously mentioned conditions, and that the rote-meaningful and reception-discovery dimensions of learning are entirely separate, that we can appreciate the important role of meaningful reception learning in classroom learning. Although, for various reasons, rote reception learning of subject matter is still all too common at all academic levels, this need not be the case if expository teaching is properly conducted. We are gradually beginning to realize not only that good expository teaching can lead to meaningful reception learning, but also that discovery learning or problem solving is no panacea that guarantees meaningful learning. Problem solving in the classroom can be just as rote a process as the outright memorization of a mathematical formula without understanding the meaning of its component terms or their relationships to each other. This is obviously the case, for example, when students simply memorize rotely the sequence of steps involved in solving each of the "type problems" in a course such as algebra (without having the faintest idea of what they are doing and why) and then apply these steps mechanically to the solution of a given problem, after using various rotely memorized cues to identify it as an example of the problem type in question. They get the right answers, but is this learning any more meaningful than the rote memorization of a geometrical theorem as an arbitrary series of connected words?

It is important to bear in mind that the distinction between rote and meaningful learning is not absolute, but rather that the two kinds of learning are at opposite poles of a continuum (Ausubel, 1963). For example, representational learning, in contrast to concept and propositional learning, shares some of the verbatim properties of rote learning in that the name of an object, person, or concept has to be learned identically rather than substantively. Often, too, rote and meaningful learning take place simultaneously or successively as when learning a poem by heart or learning the multiplication table.

In meaningful classroom learning, the balance between reception and discovery learning tends, for several reasons, to be weighted on the reception side: First, because of its tremendous time-cost, discovery learning is generally unfeasible as a primary means of acquiring large bodies of subject-matter knowledge. The very fact that the accumulated discoveries of milennia can be transmitted to each new generation, in the course of childhood and youth, is possible only because it is so much less time consuming for teachers to communicate and explain an idea meaningfully to pupils than to have them rediscover it by themselves.

Second, although discovery learning and problem solving are important educational objectives in their own rights, they are less central objectives of education, in my opinion, than the learning of subject matter. This is the case because the more novel variety of problem solving, as pointed out above, depends on possessing such additional cognitive and personality traits as flexibility, persistence, originality, resourcefulness, improvising ability, and problem-sensitivity that are not only less generously distributed in the population of learners than is the ability to understand and retain verbally presented ideas, but are also less teachable. Thus relatively few good problem solvers can be trained in comparison with the number of persons who can acquire a meaningful grasp of various subject matter fields.

THE NATURE OF MEANINGFUL RECEPTION LEARNING

Like all learning, reception learning is meaningful when the learning task is related in a nonarbitrary and nonverbatim fashion to relevant aspects of what the learner already knows. It follows, therefore, from what was stated above that the first precondition for meaningful reception learning is that it take place under the auspices of a *meaningful learning set*. Thus irrespective of how much potential meaning may inhere in a given proposition, if the learner's intention is to internalize it merely as an arbitrary and verbatim series of words, both the learning process and the learning outcome must be rote or meaningless.

One reason why pupils commonly develop a rote learning set in relation to potentially meaningful subject matter is that they learn from sad experience that substantively correct answers, lacking in verbatim correspondence to what they have been taught, receive no credit whatsoever from certain teachers. Another reason is that because of a generally high level of anxiety, or because of chronic failure experience in a given subject (reflective, in turn, of low aptitude or poor teaching), they lack confidence in their ability to learn meaningfully, and hence they perceive no alternative to panic apart from rote learning. This phenomenon is very familiar to mathematics teachers because of the widespread prevalence of "number shock" or "number anxiety." Lastly, pupils may develop a rote learning set if they are under excessive pressure to exhibit glibness, or to conceal, rather than admit and gradually remedy, original lack of genuine understanding. Under these circumstances it seems both easier and more important to create a spurious impression of facile comprehension by rotely memorizing a few key terms or sentences than to try to understand what they mean. Teachers frequently forget that pupils become very adept at using abstract terms with apparent appropriateness—when they have to—even though their understanding of the underlying concepts is virtually nonexistent.

The second precondition for meaningful reception learning—that the learning task be *potentially meaningful or nonarbitrarily and substantively relatable to the learner's structure of knowledge*—is a somewhat more complex matter than meaningful learning set. At the very least it depends on the two factors involved in establishing this kind of relationship, that is (1) on the nature of the material to be learned, and (2) on the availability of relevant content of the particular learner's cognitive structure. Turning first to the nature of the material, it must obviously be sufficiently plausible and reasonable that it could be related on a nonarbitrary and substantive basis to any hypothetical cognitive structure exhibiting the necessary ideational background. This is seldom a problem in school learning, since most subject-matter content, unlike nonsense syllables and paired adjectives, unquestionably meets these specifications. But inasmuch as meaningful learning or the acquisition of meanings, takes place in *particular* human beings, not in mankind generally, it is not sufficient that the learning task be relatable to relevant ideas simply in the *abstract* or general sense of the term. It is also necessary that the cognitive structure of the *particular* learner include relevant ideational content to which the learning task can be related. Thus, insofar as meaningful learning outcomes in the classroom are concerned, various properties of the learner's cognitive structure constitute the most crucial and variable determinants of potential meaningfulness.

Another serious problem in more advanced instances of meaningful learning is that the learner must possess the necessary cognitive equipment to process complex abstract propositions meaningfully on a purely verbal basis, that is, to relate them to his/her cognitive structure in nonarbitrary and nonverbatim fashion without making use of concrete-empirical props. The existence of this capability, in turn, depends upon certain minimal levels of intellectual maturity and subject matter sophistication which, generally speaking, cannot be assumed to be present among typical elementary school pupils, older intellectually retarded pupils, or complete neophytes in a given discipline regardless of their degree of general intellectual maturity. In the meaningful reception learning of highly abstract concepts and principles, such learners are therefore dependent upon the concurrent or recent prior availability of concrete and specific exemplars. Teachers who overlook this fact are clearly open to the charge of encouraging pupils to acquire rotely memorized and empty verbalisms.

THE ROLE OF COGNITIVE STRUCTURE VARIABLES IN MEANINGFUL VERBAL LEARNING

Since, as already suggested, the potential meaningfulness of a learning task depends on its relatability to a particular learner's structure of knowledge in a given subject matter area or subarea, it follows that *cognitive structure itself*, that is, both its substantive content and its major organizational properties, should be the principal factor influencing meaningful reception learning and retention in a classroom setting. According to this reasoning, it is largely by strengthening salient aspects of cognitive structure in the course of prior learning that new subject matter learning can be facilitated. In principle, such deliberate manipulation of crucial cognitive structure variables--by shaping the content and arrangement of antecedent learning experience--should not meet with undue difficulty. It could be accomplished (1) *substantively*, by using for organizational and integrative purposes those unifying concepts and principles in a given discipline that have the greatest inclusiveness, generalizability, and explanatory power, and (2) *programmatically*, by employing optimally effective methods of ordering the sequence of subject matter, constructing its internal logic and organization, and arranging practice sessions.

Both for research and for practical pedagogic purposes it is important to identify those manipulable properties or variables of existing cognitive structure that influence the meaningful reception learning of subject-matter knowledge. On logical grounds, three such variables seem self-evidently significant: (1) the *availability* in the learner's cognitive structure of appropriately relevant ideas to which the new learning material can be nonarbitrarily and substantively related, so as to provide the kind of anchorage necessary for the incorporation and long-term retention of subject matter; (2) the extent to which such relevant ideas are *discriminable* from similar-appearing but different new ideas to be learned, so that these new ideas can be incorporated and retained as separately identifiable entities in their own right; and (3) the *stability* and *clarity* of relevant anchoring ideas in cognitive structure, which affects both the strength of the anchorage they provide for new learning material and their degree of discriminability from similar new ideas in the learning task.

AVAILABILITY OF RELEVANT ANCHORING IDEAS IN COGNITIVE STRUCTURE

One of the principal reasons for rote or inadequately meaningful learning of subject matter is that pupils are frequently required to learn the specifics of an unfamiliar discipline before they have acquired an adequate foundation of relevant, inclusive and explanatory anchoring ideas. Because of the unavailability of such ideas in cognitive structure to which the specifics can be nonarbitrarily and substantively related, the more specific material tends to lack potential meaningfulness. But this difficulty can largely be avoided if the more general and inclusive ideas of the discipline, that is, those which typically have the most explanatory potential, are presented first and are then progressively differentiated in terms of detail and specificity. When adequately inclusive context is available, new ideas can be assimilated into cognitive structure much more efficiently, thereby facilitating both comprehension and retention of the new material (Bransford and Johnson, 1972).

In other words, meaningful reception learning and retention occur most readily and efficiently if, by virtue of prior learning, general and inclusive ideas are already available in cognitive structure to play a subsuming role relative to the more differentiated learning material that follows. This is the case because such knowledge (1) have maximally specific and direct relevance for subsequent learning tasks, (2) possess enough explanatory power to render otherwise arbitrary factual detail potentially meaningful (i.e., relatable to cognitive structure on a non-arbitrary basis), (3) possess sufficient inherent stability to provide the firmest type of anchorage for detailed learning material, and (4) organize related new facts around a common theme, thereby integrating the component elements of new knowledge both with each other and with existing knowledge.

This proposition simply restates the principle that subsumptive learning is easier than superordinate learning. The argument for using organizers rests on the same principle. It is appreciated, however, that the learning of certain propositions requires the synthesis of previously acquired subordinate concepts or propositions, that is, superordinate learning (Gagne, 1977). Nevertheless, the need for periodic superordinate learnings does not negate the proposition that both the psychological organization of knowledge and the optimal acquisition of subject matter generally conform to the pattern of subsumptive learning.

ADVANCE ORGANIZERS

One of the more effective strategies, in my opinion, that can be used for implementing the principle of progressive differentiation in the arrangement of subject matter content involves the use of special introductory materials called "advance organizers." A given organizer is introduced in advance of the new learning task per se; is formulated in terms that, among other things, relate it to and take account of generally relevant background ideas already established in cognitive structure; and is presented at an appropriate level of abstraction, generality, and inclusiveness to provide specifically relevant anchoring ideas for the more differentiated and detailed material that is subsequently presented. An additional advantage of the organizer, besides guaranteeing the availability of specifically relevant anchoring ideas in cognitive structure, is that it makes explicit both its own relevance and that of the existing background ideas for the new learning materials. This is important because the mere availability of relevant anchoring ideas in cognitive structure does not assure the potential meaningfulness of a learning task unless this relevance is appreciated by the learner.

In short, the principal function of the organizer is to bridge the gap between what the learner already knows and what he needs to know before he can learn the task at hand more efficiently.

IS MEANINGFUL RECEPTION LEARNING PASSIVE?

The acquisition of meanings through meaningful reception learning is far from being a passive kind of cognitive process. Much activity is obviously involved, but not the kind of activity characterizing discovery. Activity and discovery are not synonymous in the realm of cognitive functioning. Merely because potential meanings are presented, we cannot assume that they are necessarily *acquired* and that all subsequent loss is reflective of forgetting.

Before meanings can be retained they must first be acquired, and *the process of acquisition is necessarily active.* Neither can we assume that reception learning is more passive and mechanical than independent data-gathering and interpretation. The unmotivated student who gathers and interprets data manifests no greater intellectual activity than the unmotivated student who receives expository instruction. Collection of data and perfunctory compilation of charts, tables or graphs, and similar activities, are among the strategies that students employ to "look busy," while in fact very little meaningful learning is occurring. The motivated student, on the other hand, reflectively considers, reworks, and integrates new material into his/her cognitive structure irrespective of how he/she obtains it.

Thus meaningful reception learning involves more than the simple cataloging of ready-made concepts within existing cognitive structure. In the first place, at least an implicit judgment of relevance is usually required in deciding which established ideas in cognitive structure are most relatable to a new learning task. Second, some degree of reconciliation between them is necessary, particularly if there are discrepancies or conflicts. Third, new propositions are customarily reformulated to blend into a personal frame of reference consonant with the learner's experiential background, vocabulary, and structure of ideas. Lastly, if the learner, in the course of meaningful reception learning, cannot find an acceptable basis for reconciling apparently or genuinely contradictory ideas, he/she is sometimes inspired to attempt a degree of synthesis or reorganization of his/her existing knowledge under more inclusive and broadly explanatory principles. He/she may either seek such propositions in more recent or sophisticated expositions of a given topic, or, under certain circumstances, may try to discover them himself/herself.

All of this activity (except for the last-mentioned), however, stops short of actual discovery or problem solving. Since the substance of the learning task is essentially presented, the activity involved is limited to that required for effectively assimilating new meanings and integrating them into existing cognitive structure. This is naturally of a qualitatively different order than that involved in independently discovering solutions to new problems—in autonomously reorganizing new information and existing ideas in cognitive structure in such a way as to satisfy the requirements of a given problem situation.

The extent to which meaningful reception learning is active depends in part on the learner's need for integrative meaning and on the vigorousness of his/her self-critical faculty. He/she may either attempt to integrate a new proposition with *all* of his/her existing relevant knowledge or remain content with establishing its relatedness to a single idea. Similarly, he/she may endeavor to translate the new proposition into terminology consistent with his/her own vocabulary and ideational background, or remain satisfied with incorporating it as presented. Finally, he/she may strive for the acquisition of precise and unambiguous meanings or may be completely satisfied with vague, diffuse notions.

The main danger in meaningful reception learning is not so much that the learner will frankly adopt a rote approach, but rather that he/she will delude himself into believing that he/she has grasped genuine meanings when he/she has *really* grasped only a vague and confused set of empty verbalisms. It is not so much that he/she does not want to understand, but that he/she lacks the necessary self-critical ability and is unwilling to put forth the necessary active effort in struggling with the material, in looking at it from different angles, in reconciling and integrating it with related or contradictory knowledge, and in reformulating it from the standpoint of his own frame of reference. He/she finds it easy enough to manipulate words glibly so as to create a spurious impression of knowledgeability, and thereby to delude himself/herself and others into thinking that he/she truly understands when he/she really does not.

A central task of pedagogy, therefore, is to develop ways of facilitating an active variety of reception learning characterized by an independent and critical approach to the understanding of subject matter. This involves, in part, the encouragement of motivations for and self-critical attitudes toward acquiring precise and integrated meanings, as well as the use of other techniques directed toward the same end. Precise and integrated understandings are, presumably, more likely to develop if the central unifying ideas of a discipline are learned before more peripheral concepts and information are introduced; if the limiting conditions of general developmental readiness are observed; if precise and accurate definition is stressed, and emphasis is placed on delineating similarities and differences between related concepts; and if learners are required to reformulate new propositions in their *own* words. All of these latter devices come under the heading of pedagogic techniques that promote an active type of meaningful reception learning. Teachers can help foster the related objective of assimilating subject matter critically by encouraging students to recognize and challenge the assumptions underlying new propositions, and to distinguish between facts and hypotheses and between warranted and unwarranted inferences. Much good use can also be made of Socratic questioning in exposing pseudo-understanding, in transmitting precise meanings, in reconciling contradictions, and in encouraging a critical attitude toward knowledge.

INTEGRATIVE RECONCILIATION

The principle of integrative reconciliation in programming instructional material may be best described as antithetical in spirit and approach to the ubiquitous practice among textbook writers of compartmentalizing or segregating particular ideas or topics within their respective chapters or subchapters. Implicit in this latter practice are the assumptions (perhaps logically valid but certainly psychologically untenable) that pedagogic considerations are adequately served if overlapping topics are handled in self-contained fashion so that each topic is presented in only *one* of several possible places where treatment is relevant and warranted, and that all necessary cross-referencing of related ideas can be satisfactorily performed, and customarily is, by students.

Hence little serious effort is made explicitly to explore relationships between these ideas, to point out significant similarities and differences, and to reconcile real or apparent inconsistencies. This is what is meant by integrative reconciliation; and it can be done best at a high level of inclusiveness, generality, and abstraction, within the framework of a comparative organizer, before the details and the implications of the new ideas are presented. Integrative reconciliation obviously facilitates meaningful reception learning by enhancing the cognitive structure variable of discriminability.

SEQUENTIAL ORGANIZATION

The availability of relevant anchoring ideas for use in meaningful verbal learning and retention may obviously be maximized by taking advantage of natural sequential dependencies among the component divisions of a discipline--of the fact that the understanding of a given topic often logically presupposes the prior understanding of some related topic. Typically the necessary antecedent knowledge is more inclusive and general than the sequentially dependent material, but this is not always true (for example, superordinate learning). In any case, by arranging the order of topics in a given subject-matter field as far as possible in accordance with these sequential depencencies, the learning of each unit, in turn, not only becomes an achievement in its own right, but also constitutes specifically relevant ideational scaffolding for the next item in the sequence.

In sequential school learning, knowledge of earlier-appearing material in the sequence plays much the same role as an organizer in relation to later-appearing material in the sequence. It constitutes a relevant ideational foundation, and hence a crucial limiting condition, for learning the latter material when the influence of both verbal ability and general background knowledge is held constant (Ausubel and Fitzgerald, 1962; Gubrud and Novak, 1973; Royer and Cable, 1975; West and Fesham, 1976). For maximally effective learning, however, a separate organizer should be provided for each unit of material. Thus, sequential organization of subject matter can be very effective, since each new increment of knowledge serves as an anchoring post for subsequent learning. This presupposes, of course, that the antecedent step is always thoroughly consolidated. Perhaps the chief pedagogic advantage of the teaching machine lies in its ability to control this crucial variable in sequential learning.

Another advantage of programmed instruction is its careful sequential arrangement and gradation of difficulty which insure that each attained increment in learning serves as an appropriate foundation and anchoring post for the learning and retention of subsequent items in the ordered sequence. Adequate programming of materials also presupposes maximum attention to such matters as lucidity, organization, and the explanatory and integrative power of substantive content.

Sequential arrangement of learning tasks relies, in part, on the *general* facilitating effect of the availability of relevant anchoring ideas in cognitive structure on meaningful learning and retention. For any given topic, however, there is the problem of ascertaining what the *particular* most effective sequence is. This involves considerations of logical task analysis, progressive differentiation, developmental level of cognitive functioning, integrative reconciliation, and learning hierarchies. Further, in superordinate learning, it is essential to insure that both subordinate concepts and propositions and the component conceptual elements of each proposition are previously mastered.

CONSOLIDATION

By insisting on consolidation or mastery of ongoing lessons before new material is introduced, we make sure of continued subject-matter readiness and success in sequentially organized learning. This kind of learning presupposes, of course, that the preceding step is always clear, stable, and well-organized. If it is not, the learning of all subsequent steps is jeopardized. Thus, new material in the sequence should never be introduced until all previous steps are thoroughly mastered. This principle also applies to those kinds of intra-task learning in which each component (as well as entire bodies of subject matter) tends to be compound in content and to manifest an internal organization of its own. Consolidation, of course, is achieved through confirmation, correction, clarification, differential practice, and review in the course of repeated exposure, with feedback, to learning material. It is the instructional strategy that is used to implement the cognitive structure variables of stability and clarity.

Abundant experimental research (Duncan, 1959; Morrisett and Hovland, 1959) has confirmed the proposition that prior learnings are not transferable to new learning tasks until they are first overlearned. Overlearning, in turn, requires an adequate number of adequately-spaced repetitions and reviews, sufficient intra-task repetitiveness prior to intra- and inter-task diversification, and opportunity for differential practice of the more difficult components of a task. Fre-̣ent testing and provision of feedback, especially with test items demanding fine discrimination among alternatives varying in degree of correctness, also enhance consolidation by confirming, clarifying, and correcting previous learnings.

In directly sequential tasks, where the learning of Part II materials presupposes understanding of Part I materials (where Part II is *sequentially dependent* on Part I) the stability and clarity of the antecedent material crucially affect the learning and retention of the later-appearing material (Ausubel and Fitzgerald, 1962; Gubrud and Novak, 1973; Kahle and Nordland, 1975).

The stability and clarity of existing cognitive structure are important both for the depth of anchorage they provide for related new learning tasks as well as for their effects on the discriminability of these new tasks. The discriminability of new learning material, as shown by several of the experiments reported above, is in large measure a function of the clarity and stability of existing concepts in the learner's cognitive structure. Even in the learning of controversial ideas contrary to prevailing belief (for instance, the learning by Illinois students of the Southern point of view about the Civil War), the more knowledgeable students, namely, those who know more about the Civil War period, are better able to learn and remember the "other side" arguments (Fitzgerald and Ausubel, 1963), presumably because they find them more discriminable from established ideas than do less knowledgeable subjects. Thus, much of the effect of overlearning--both on retaining a given unit of material and on learning related new material --is probably a reflection of the enhanced discriminability that can be induced by increasing the clarity and stability of either the learning material itself or of its subsumers.

Much additional research is needed to establish both the most economical degree of consolidation and the most efficient ways of effecting it (repetition, distribution of practice, feedback, use of organizers, internal logic of the material) that will optimally facilitate the learning and retention of sequentially and parallelly organized subject matter. Such knowledge will obviously have greater pedagogic utility if the effects of these latter variables are tested together with consideration of the pupils' level of cognitive maturity, academic ability, and degree of relevant subject matter sophistication.

NEEDED RESEARCH

Much short-term research has been conducted on the assimilation theory of learning and retention presented above, that is both on such manipulable cognitive structure variables as availability of relevant ideas in cognitive structures, their discriminability, and their stability and clarity. Similar research has also been conducted on such self-evident pedagogic principles that follow from this theory as progressive differentiation, integrative reconciliation, the use of organizers, the need for spaced review, sequential organization of subject matter, and consolidation.

The pressing needs in the next decades, insofar as improving expository teaching and reception learning are concerned lie in the area of validating the effects of these variables and instructional principles in terms of long-term learning processes (i.e., entire courses of study and curricula) and of devising instructional materials based on these principles that will be most effective for individualized instruction.

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MEANINGFUL RECEPTION LEARNING AS A BASIS FOR RATIONAL THINKING

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INTRODUCTION: RELEVANT BACKGROUND IDEAS

When the Educational Policies Commission published The Central Purpose of American Education in 1961, I found myself strongly in agreement with their major claim, namely that education should have as its central purpose the development of the human's unique capability of rational thinking. But I was disappointed to see almost nothing in their statement that could be used to guide educators to achieve this "central purpose." In retrospect, the Commission may have done all that was possible in 1961, for the necessary advances in educational psychology, epistemology and curriculum theory needed for augmenting education in rational thinking were to come later. I will argue in this section that Ausubel's (1963, 1968, 1978) assimilation theory for cognitive learning, advances in epistemology by Toulmin (1972), Gowin (1977) and others and new concepts in curriculum and instructional theory by Carroll (1963), Johnson (1967, 1977) and Bloom (1968, 1976), now permit a whole new conception of the nature and promise of education to augment rational thinking. The major claims in this section will summarize and extend the arguments presented in A Theory of Education (Novak, 1977). The central element in these arguments will be toward the facilitation of meaningful reception learning as defined by Ausubel (see pages 178-180).

Gowin's Epistemological "V"

The education of human beings is an exceedingly complex process, so complex that we must begin our attempt to understand this process bit by bit. At least four key elements are involved (1) the learner, (2) knowledge, (3) the teacher or teaching materials (e.g., books), and (4) a social matrix. These interacting elements are shown in Figure 1. The most variable element in this scheme is the social matrix, which is influenced in part by advances in knowledge. For example, birth control technology has advanced substantially in the past half-century, but schools and communities vary widely in the extent to which knowledge of birth control is incorporated into the educational program. Since this is the most variable element, it is in many respects the most difficult to understand rationally and, therefore, I will deal with this minimally. This is not to suggest that social factors are not important; my suggestion is to follow the successful pattern illustrated by the history of science and deal with "easy cases first." If we wish to establish a rational basis for education, our best chance is to begin with an analysis of those variables most likely to come under rational control. Of course, we need not and must not ignore social factors, but this is probably not the best focus of our energies at this time.

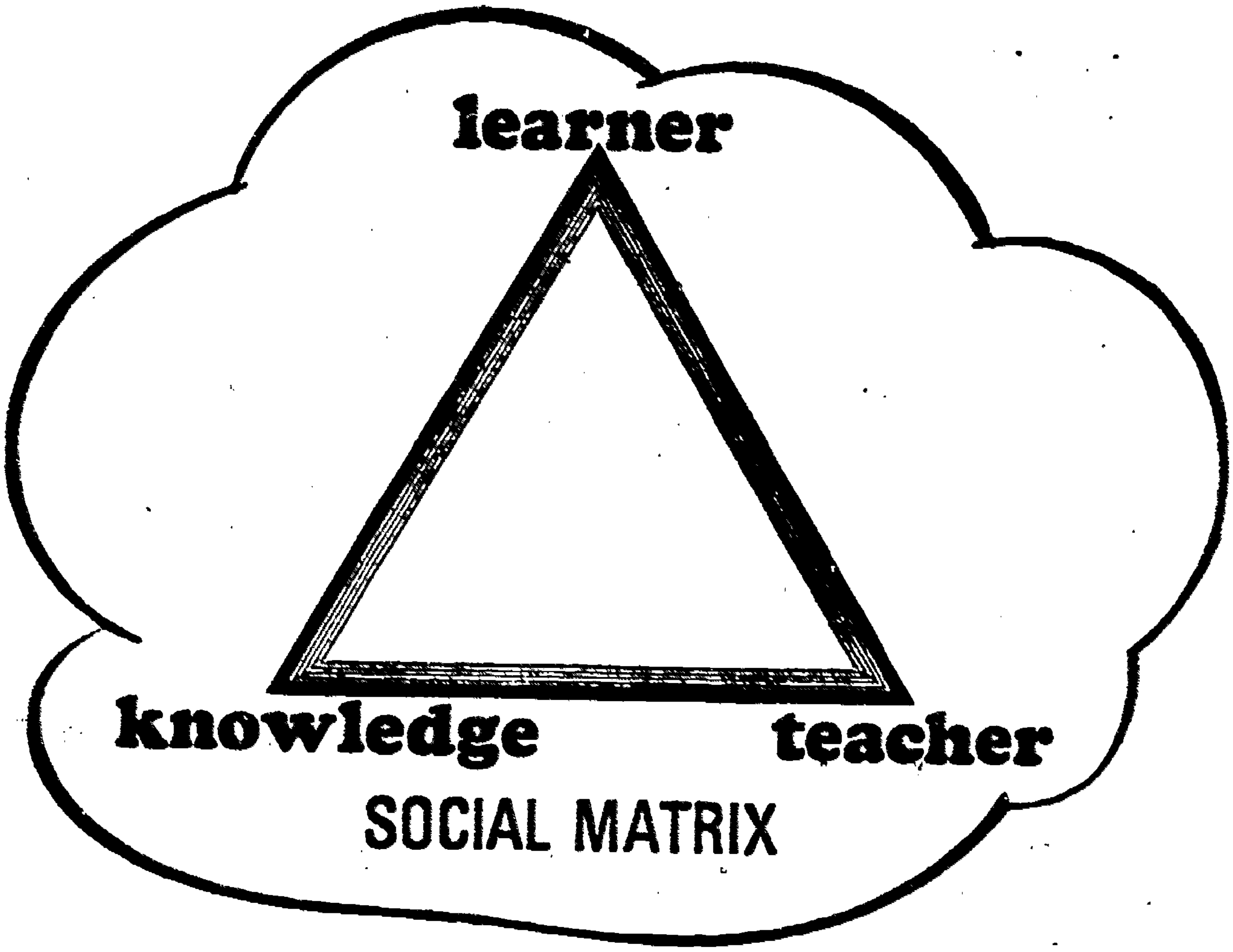

Figure 1. The four key elements involved in learning, with the social matrix, changing over time, influencing the learner, teacher, and the selection of knowledge to be learned.
(Modified from Gowin's (1977) "triad")

We begin with epistemology; how do humans make knowledge and what is the nature of knowledge? First off, we must recognize that knowledge is not discovered, like oil or gold, but it is *made*. Human beings observe events or objects, *make records* of their observations, transform these records and then make *knowledge claims*. How do they do this? One important factor is that they *invent* clever ways to make observations and records, or to transform records (e.g., computers). But the most important factor is that they *invent concepts*.

We will define concepts as *regularities in events or objects* designated by some sign or symbol.* So *cell* is the sign we use to designate the tiny unit structures of living things (which vary widely but also have certain regularities) and *thunder* is the sign for the loud noise events that are heard in stormy weather. Some concepts are invented to describe regularities of a more complex nature and may involve the use of several subordinate concepts, e.g., speciation or atomic energy. Grand conceptual schemes, involving many concepts, can be considered as conceptual systems or as theoretical systems. But all of these things--concepts, conceptual systems and theories--are invented from regularities in events or objects and the records and transformations we make of these events or objects. For these reasons, Gowin places events or objects at the base of his Epistemological "V", shown in Figure 2. The right side of Gowin's Vee represents the methodological side and the left side represents the theoretical-conceptual side. Both sides represent activities or products of rational thinking, and there is an active interplay between operations on the right side and concepts and theories on the left. To make new knowledge, then, involves proceeding with the operations on the right side, guided by concepts and theories on the left side. When the concepts or theories fail in this process, new concepts or theories, or modifications of the old, are necessary. This is what Schwab (1962) has called *fluid* enquiry and what Kuhn (1962) describes as *revolutionary* science. Toulmin (1972) has elaborated these ideas and shows the evolutionary nature of concepts.

We have found Gowin's Vee to be a useful heuristic device to aid students and teachers in understanding the nature of science. For example, both students and teachers are frequently frustrated with laboratory work and this derives in part from their failure to relate concepts and theories to the methodological operations on the right side of the Vee. Most students proceed "cookbook" fashion, making records, transforming the records and trying to decide what claims are "wanted." Without an active, continuous consideration of relevant concepts and theories, students do not understand why they are making

*Most definitions of concept refer to *criterial attributes*, but it is sometimes difficult to identify salient critical attributes. I have found in teaching that asking "What is the regularity in these objects or events" is helpful in concept definition.

the records requested in the laboratory guide, why the specified data transformations are appropriate and useful, and why the knowledge or value claims are legitimate. Technicians become adept at performing data recording and data transforming activities, but the outstanding scientist is one who uses concepts to select what events or objects to observe, what records to make, and what data transformations are meaningful. The Nobel prize winner does this uniquely well, and also usually invents some new concepts or theories. We will return later to the discussion of the importance of Gowin's Vee in the education of students to enhance rational thinking.

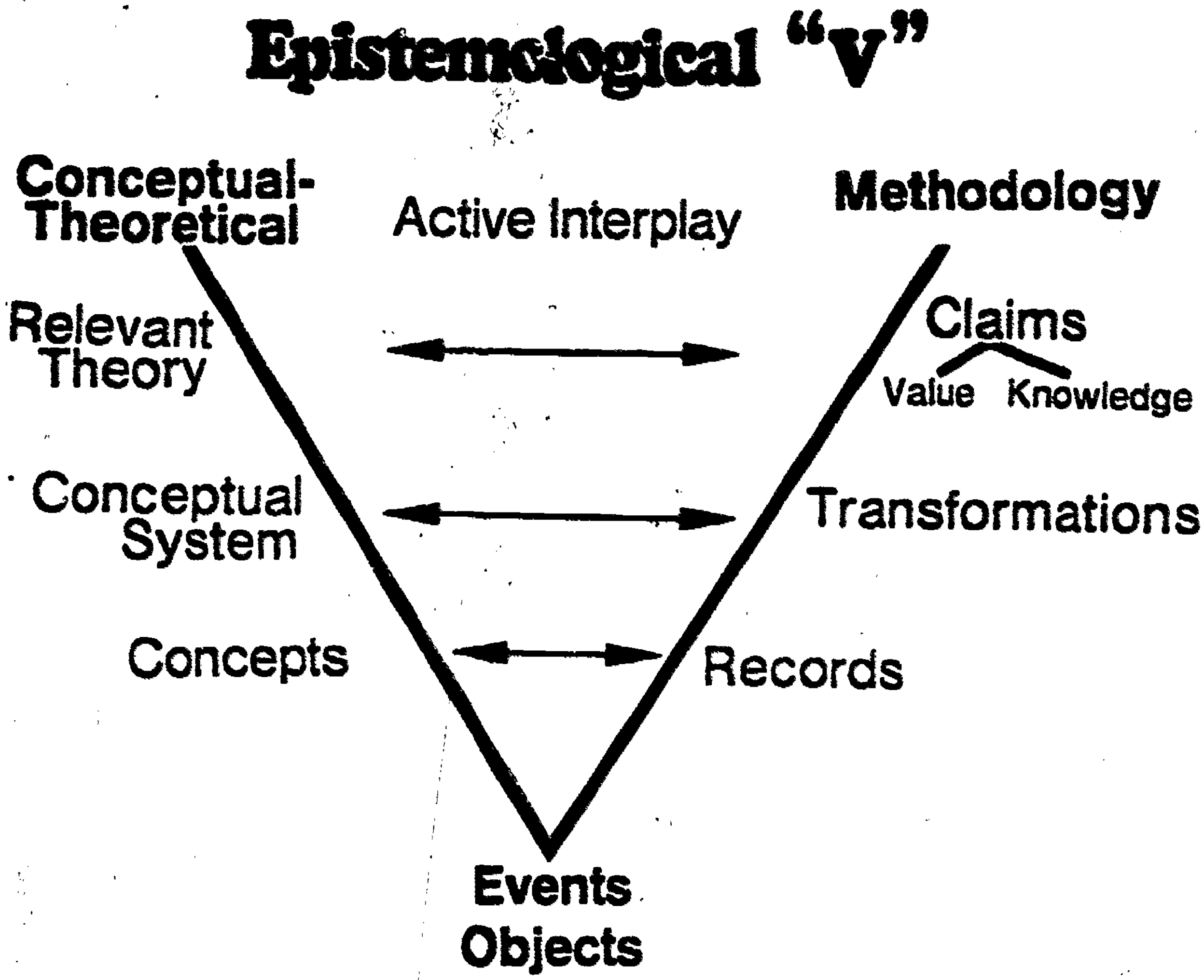

Figure 2. Gowin's Epistemological "Vee".

Rote-Meaningful Versus Reception-Discovery Learning

One of Ausubel's important contributions was to explain the important difference between *rote* learning and *meaningful* learning. (Please refer again to pages 176-178 if you wish to refresh your understanding of this distinction.) In my view, one of the unfortunate aspects of much of the science and mathematics curriculum development projects in the 1950s and 1960s was that the leadership of the programs confused method of *instruction* with mode of learning. *Reception teaching*, where information to be learned is presented more or less in its final form to the learner, does not necessitate *rote* learning. Only when new knowledge is not related to relevant *concepts* already in the learner's cognitive structure is rote learning the result. Only when no attempt is made to assimilate new knowledge into existing relevant concepts does rote learning occur. Unfortunately, most teachers or instructional materials rarely aid the students to identify and use relevant concepts in their cognitive structures to assimilate new knowledge, and the result is that students arbitrarily (rotely) incorporate this new information into their cognitive structure. Furthermore, most school evaluation practices require *verbatim* recall of material taught, and meaningful learning, involving subsumptive assimilation of new information, always results in some modification of the information presented. Meaningful learning allows students to express concepts (that is, describe regularities) "in their own words," but too often true-false or multiple choice questions do not provide adequate scope for expression of the valid but idiosyncratic meanings students acquire when they learn meaningfully. The result is that students soon learn that rote learning pays off, but meaningful learning can get you in trouble (both on examinations and in classroom discussions). Given the fact that most classroom testing favors rote learning over meaningful learning, why do any students try to learn meaningfully at least part of the time? The answer inheres in both the much extended retention students experience when they do learn meaningfully, the "cognitive drive" motivation that comes when they recognize that new knowledge can be related to and assimilated into concepts that already have, and the incomparably enhanced facilitation of future, related learning or extension of the range of novel problems they can solve. Rote learning tends to *inhibit* new, similar learning whereas meaningful learning *facilities* new related learning.

Discovery learning, where students obtain on their own the information to be learned *and* where this information can be related to their existing concepts, does lead to meaningful learning. However, except in the most contrived situations, discovery learning is an exceedingly slow process. Obviously, students cannot discover in school all the concepts (regularities) that generations of geniuses have discovered. It should be patently obvious that *most* school learning must necessarily be reception learning (or at least very carefully guided discovery learning), and, as Ausubel argues, the key issues are how to encourage *meaningful* reception learning.

The degree of meaning that can be expected when a learner is confronted with new knowledge will be dependent upon the degree of development or differentiation of his/her relevant concepts. A botanist's concept of leaf, for example, is enormously more elaborated and differentiated then that held by the layman and new information about gas exchange processes in a leaf will have more meaning to him/her. Therefore, the rote meaningful distinction is a continuum and not a dichotomy. Similarly, reception learning can involve some elements of uncovering unique meaning in new knowledge presented and hence the reception-discovery dimension is also a continuum. Figure 3 illustrates these ideas and also suggests that reception learning can be highly meaningful and discovery learning can be largely rote in character (as when we "discover" a solution to a puzzle by repeated trial-and-error attempts).

A moment's pause to relate the ideas in Gowin's Vee to Ausubel's concept of meaningful learning should show that whether events or objects are observed directly or described in text or pictures, meaningful learning can result if the student is encouraged to use whatever available pertinent concepts they have to "make sense" out of the events or objects. This is one positive aspect of the newer elementary science curricula in that they stress making and/or observing events or objects, and then using whatever concepts the student has to "explain what you think is going on here." Where programs, such as the Elementary Science Study, fall short is that they fail to guide both teachers and students to acquire and use those concepts scientists have invented over the years to make sense out of similar objects or events. The Science Curriculum Improvement Study, on the other hand, specifically recommends supplying an "invention" (concept) to students after an initial exploratory phase of observation and manipulation (Karplus and Thier, 1968). Our audio-tutorial elementary science lessons utilize technology to facilitate instructive manipulation or observation of materials with concomitant reception learning to acquire and elaborate explanatory concepts (Novak, 1972). With this reception teaching and guided discovery approach, we have been able to show that first and second grade children can acquire and meaningfully use concepts of the particulate nature of matter (Hibbard and Novak, 1975), energy and energy transformation (McClelland, 1970; Friedman, 1977), and other concepts.

For the past decade or two, there has been a growing concern for what has been called the "scientific literacy" of the general public. There is a general awareness that most of the adult population cannot read about new scientific discoveries or research programs and understand the implications of this work for their lives or the lives of their children. Some educators have been trying to find simple solutions to this problem, such as offering more seminars or publications targeted at the general public. No doubt there is a continuing need to relate the meaning of concepts scientists are using and/or inventing in a language that will relate to the concepts possessed by the average citizen. However, no satisfactory solution to the scientific literacy problem can occur until elementary schools and secondary schools become much more effective in teaching all or the large

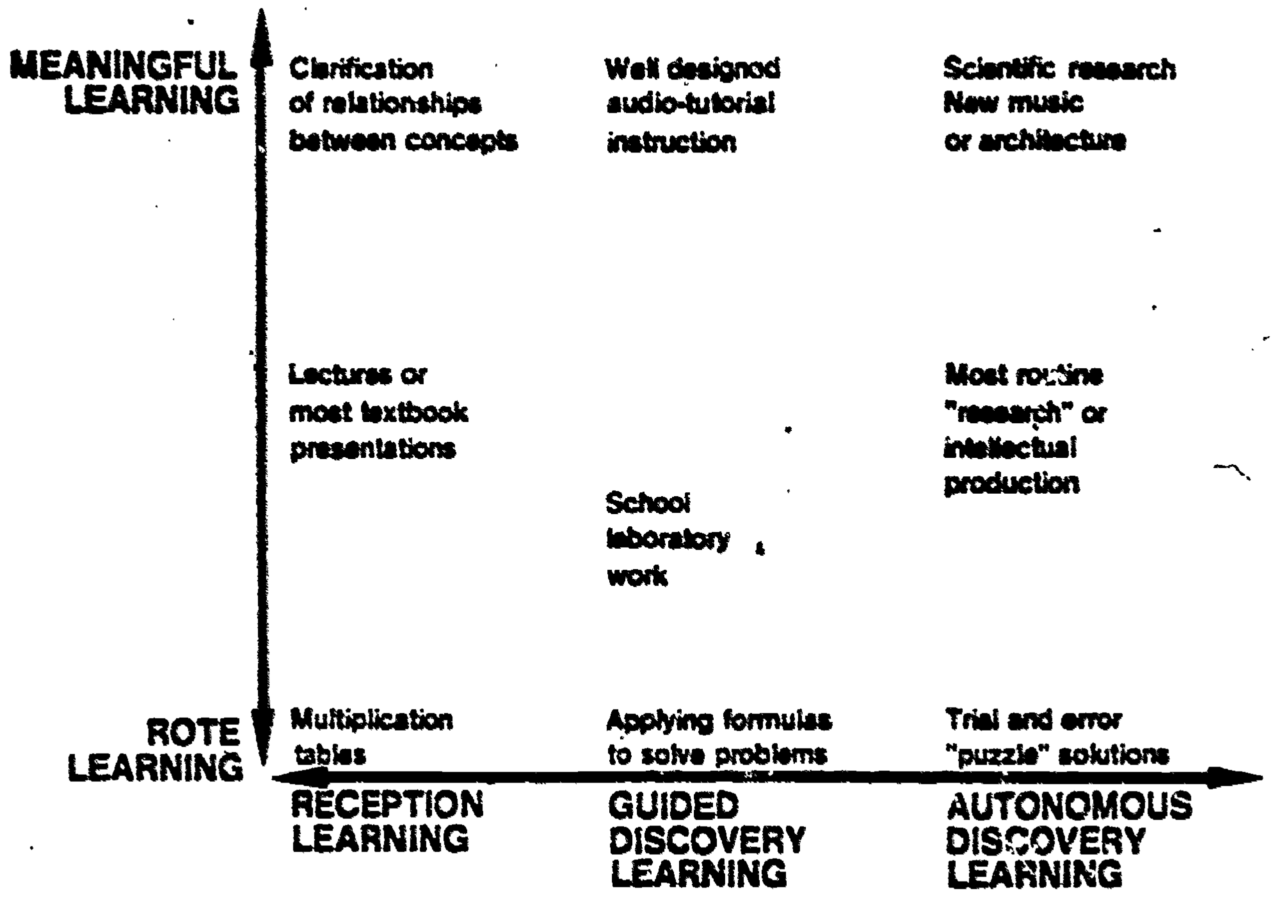

Figure 3. The rote-meaningful, reception-discovery learning continuums.

majority of students those *major* scientific concepts and theories that can be used to serve as a basis for lifelong *meaningful* learning of our citizenry. We believe there is evidence that most students can acquire a functional understanding of basic science concepts (Novak, 1977, Chapter 8), but science instruction in secondary and especially in elementary schools must be improved radically if we are to reach this goal.

The NSTA Conceptual Schemes

In 1963, the National Science Teachers Association's Committee on Curriculum organized a meeting of outstanding scientists, science educators and philosophers with the purpose of identifying "conceptual schemes" of science that could be used as conceptual threads to organize science curriculum programs from kindergarten to college. After two days of deliberations and subsequent criticisms of manuscript drafts, seven major conceptual schemes were identified that were suggested to guide curriculum planners in the development of science programs. Five statements regarding the nature and methodology of science were also prepared. These were published by NSTA in 1964.

Strong disagreement with the published "conceptual schemes" was subsequently reported by some members of the original NSTA Committee (e.g., Glass, 1965) and by others (e.g., Ausubel, 1965). For the most part, however, science educators were at least moderately enthusiastic about the "conceptual schemes" and the rationale presented (NSTA, Theory into Action, 1964). Many science teachers reported that they found the conceptual schemes useful, but that little in their college science training prepared them to understand and use these conceptual schemes in planning their instruction. Two elementary science programs were published based on a similar set of conceptual schemes (Brandwein, et al., 1966; Novak, et al., 1966) but only the first one of these enjoys significant use. To my knowledge, no secondary school science programs were explicitly based on a general set of science concepts.

Over the past decade, I have frequently been asked in classes and seminars why the NSTA science conceptual schemes have not been more widely utilized, since they continue to be well received by students of science and science education. I believe there are several reasons for this. For one thing, the NSTA conceptual schemes were intended to serve as a basic conceptual framework for *all* sciences, but biologists, geologists, anthropologists and others often fail to see the relevance of these conceptual schemes to their disciplines (see, for example, Glass, 1965). Furthermore, the conceptual schemes were intended to guide *expert curriculum planners*, and not the daily lesson planning of elementary or secondary school science teachers, at least not with the existing state of college science instruction for teachers (Novak, 1965). The criticisms of Glass (1965) and Ausubel (1965) were valid in terms of *their* interpretations of the uses of the NSTA conceptual schemes. What became increasingly apparent over the years is that typical secondary and college science courses engage prospective teachers largely in rote learning of what Schwab (1962) has called a "rhetoric of conclusions," and teachers so educated could hardly be expected to relate subordinate concepts of their discipline to the grand conceptual schemes advanced by NSTA. Science teacher education has been and continues to be a victim of instructional practices that favor rote over meaningful learning, and the consequence is elementary and secondary science teaching that usually continues this practice. Some science teaching (at all educational levels) departs dramatically from this norm pattern, but this occurs only where hard working, gifted teachers have learned how to transcend the limitations of most of their formal education and to use practices that result in an emphasis on meaningful learning.

Another difficulty, in my view, has been that the NSTA conceptual schemes were intended to guide *curriculum* planning and needed translation by experts to develop *instructional* activities. We owe a debt to Johnson (1967) for his model that distinguishes curriculum issues from instructional issues, as he defines these.

Johnson's Model for Curriculum and Instruction

Johnson (1967) defines *curriculum* as a structured series of intended learning outcomes (the ILO's). The curriculum is established by selecting and ordering knowledge, skills, values and procedures from our accumulated cultural heritage. Although skills (by this I mean primarily psychomotor skills such as using a balance or microscope), values and procedures are necessary to consider, the overriding task of schooling is the transmission of knowledge, as Ausubel argues in his chapter. And our epistemology tells us that concepts and systems of concepts are the primary basis of our knowledge structure. So more than anything else, *curriculum* planning means selecting and ordering the *concepts* we intend to teach (the primary, but not all inclusive ILO's).

Instructional planning involves selecting teaching strategies and choosing examples or learning tasks that will result in learning. Evaluation serves to assess the actual learning outcomes (the ALO's) that result from the student engaged in the instructional program. Evaluation serves to apprise the students of their progress, provide feedback on the effectiveness of the instructional program and indirectly to indicate whether or not the ILO's were realistic and attainable. Regarding the last point, failure of students to achieve ILO's, such as an understanding of the NSTA conceptual schemes may not mean that these cannot be learned meaningfully. We may have failed to use appropriate examples (for the students at this level of cognitive development), employed inadequate teaching strategies or failed to evaluate the real conceptual gains of the student. Most instruction is faulty at least to some degree on all three of these elements. Bruner (1960, p. 33) went too far when he stated that "any subject can be taught effectively to any child at any stage of development." However, my view is that Bruner was more right than wrong, and that our major problems lie both in poor curriculum planning and poor instructional and evaluation practices. I will try to suggest later how we might do better and how we may move further toward the Educational Policies Commission (1961) goals of improving rational thinking.

Mastery Learning: Criterion Referenced Evaluation

In past millennia, education was either for the privileged few who had tutors, like Plato, or involved a master teaching the apprentice. The most important factor in this form of education is that the progress of the *learner* determined when new topics or skills were to be introduced. The instruction carefully abided by Ausubel's (1968, p. vi) dictum, "The most important factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly." But as *schooling* became the practice, instruction moved to rote memorization from copybooks with the rate of introduction of new material determined by the teacher. In 1963, Carroll suggested that most students could master most learning tasks if they were given varying amounts of time to learn. Schooling, he contended, should offer more opportunity for varying rates of learning. This idea was later expanded by Bloom (1968, 1976) in his concept of *mastery learning*.

Bloom has extended the ideas in Carroll's (1963) earlier paper and has conducted research to show that when effective instructional strategies are used and students are provided with both clearly stated learning objectives and varying amount of time for study, most students can achieve "mastery" of any relevant subject matter. Most previous school programs, however, assume that some students will perform well, some modestly well, and some will fail.

New evaluation practices are needed when instruction is designed so that most students can achieve most of the ILO's. Instead of writing tests whose purpose is to discriminate among students for the purpose of assigning grades (norm-referenced evaluation), educators following a mastery learning strategy are encouraged to write tests that reveal, in absolute terms, proficiency on the ILO's (criterion-referenced evaluation). (See Millman, 1974, for a further discussion of these ideas.)

The most common examples of criterion-referenced evaluation are the written and performance tests to obtain a driver's license, where some persons find they must continue to study and/or practice between repeated attempts to "pass" the exam(s). Criterion-referenced evaluation, especially if the criterion is not easy for most subjects to reach, does not mean that no differences in aptitude will be demonstrated. What is demonstrated is that some learners need *more time* to reach criterion. Unfortunately, there has been much too little educational research dealing with variables that influence the time required to learn specified tasks. From Ausubel's theory, we would expect learning time to vary widely depending on the adequacy of relevant concepts a learner brings to a learning task and/or his motivation to learn meaningfully.

In practice, instructional programs designed to encourage mastery learning seldom expect all learners to reach the same goals. For a variety of practical reasons, most courses employing mastery learning strategies have a set of scale expectations where lesser accomplishment results in lower grades. However, each of the component tasks usually has a defined criterion level of satisfactory performance (such as the exam score needed to get credit for any given unit of study) and what may vary is the number of units of study students choose to complete. There continues to be debate as to whether or not students who get high grades under most mastery learning regimens really know as much as students who do well (i.e., get high grades) under more traditional instructional practices using norm referenced-evaluation (sometimes described as "grading on a curve"). I know of no research on this question that does not have substantial methodological flaws. Our own work, using criterion-referenced test items of equal or greater difficulty than used in previous traditional instruction showed a substantial increase in high performing students.

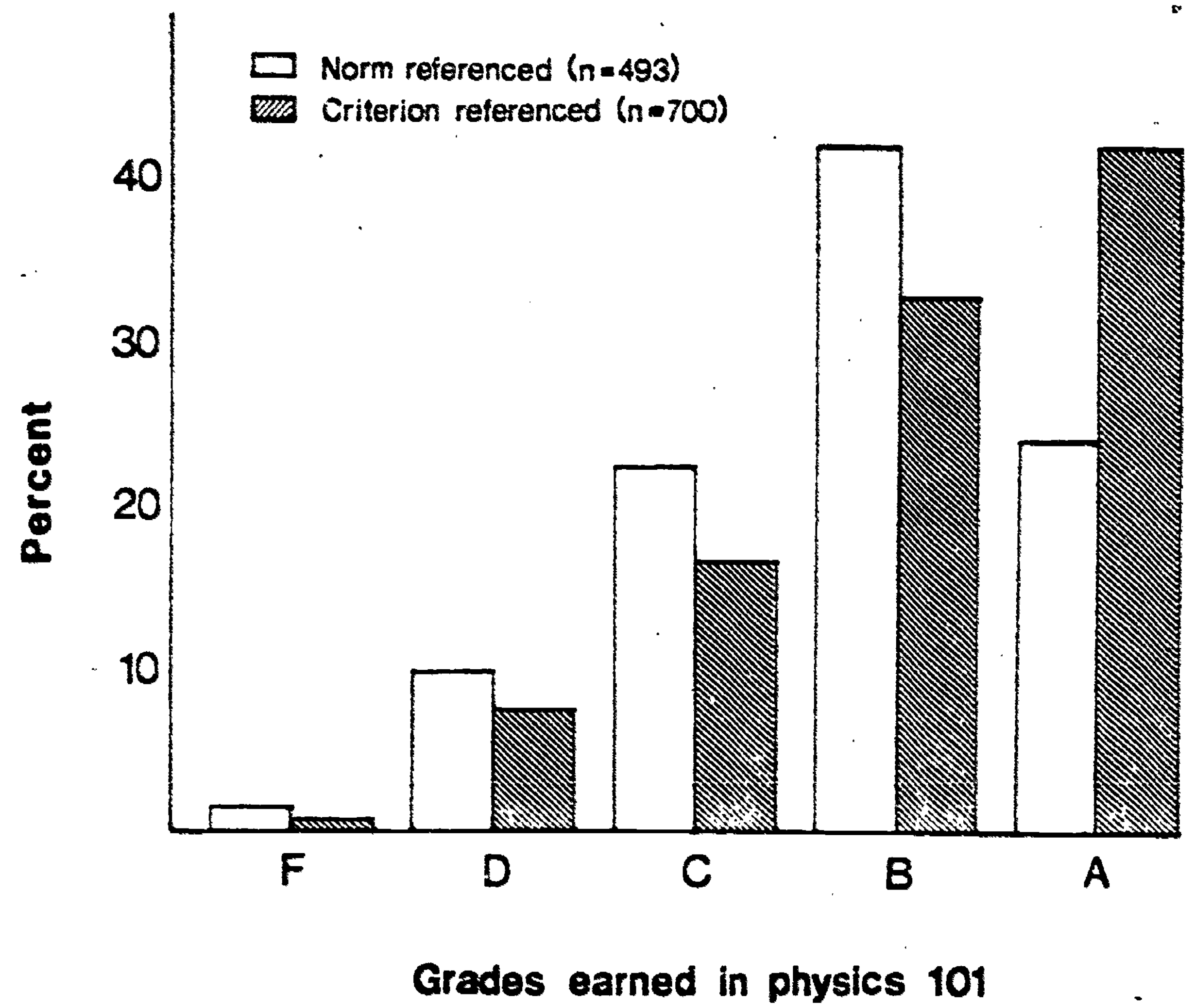

Figure 4. Norm-referenced vs. criterion referenced achievement in college physics (Naegele, 1974).

The Definition of Rational Thinking

In the Commission's statement (1961, p. 5) ten rational powers were identified: (1) recalling, (2) imagining, (3) classifying, (4) generalizing, (5) comparing, (6) evaluating, (7) analyzing, (8) synthesizing, (9) deducing, and (10) inferring. The Commission did not define these rational powers and the meanings of the words used is certainly not universal among educators. Therefore, it may be useful to define these words in accordance with the epistemological and psychological concepts presented above.

Recalling, as we have noted, can vary depending on the nature of the antecedent learning. Rote learning can result in little more than verbatim recall of information previously learned. Since this kind of information is of little value in the many problem solving contexts that the Commission identifies as *fundamental processes* (e.g., health and effective citizenship), we could assume that the Commission was hopeful that meaningful learning would be encouraged, and that the idiosyncratic, transferable meanings that are acquired by individuals could be recalled and used in novel contexts.

Imagining connotes an ability for generating new forms of knowledge or artistic expression. My guess is that the Commission meant something close to what generally goes under the label of creative ability (such as in the writings of Getzels and Jackson, 1962; Torrance, 1962; and Koester, 1964). In Ausubel's learning theory, we define *integrative reconciliation* as part of the process of meaningful learning that results in explicit delineation of similarities and differences between related concepts. My own view is that creative ability combines the cognitive ability to form "higher order" integrative reconciliations (to be discussed further later) between concepts and the emotional proclivity to do so autonomously. Ausubel (1968) sees creative ability as primarily genetically determined and present only in very gifted individuals. My own view is that although inheritance may play the predominant role in creative ability, teaching strategies that encourage and reward autonomous integrative reconciliation of concepts, in all subjects matter areas, can substantially augment the creative expression of most students (see Novak, 1977, Chapter 8). So if imagining is similar to creative expression, once again I see the need for teaching practices that encourage and reward *meaningful learning*.

Classifying involves grouping or categorizing according to some set of criterial attributes. For classification activities to be more than ritualistic "pigeon holing," the criterial attributes must be seen by a person as not arbitrary but rather as defining some *regularity* in the objects or events being classified. Returning to Gowin's definition of concepts, we see that to classify things meaningfully, we must acquire the concept that represents both our own idiosyncratic meaning of the regularity and also corresponds to the culturally accepted meaning. A child may sort (classify) triangles and rectangles without having internalized the meaning (three-sided figure) or the concept label (i.e., triangle). But in time, the child will come to recognize the regularities that make triangles triangles and rectangles rectangles. To classify, then, requires that we *acquire concepts*, and that we also proceed to acquire concepts about concepts. For example, mammal is the concept label we use for a variety of warm-blooded, furry animals that may be familiar to children. To become more proficient at classifying, therefore, requires that we become more proficient at concept formation, and this derives from meaningful learning.

Generalizing involves recognition that some individual object or event is an instance of some defined larger group of objects or events. It involves recognition that the regularity observed in one or more individual things is the same regularity observed in one or more individual things is the same regularity already defined by some concept label. For example, a student may recognize that every equation such as $x + 2 = y$ is an equation which defines a straight line; it is a *linear* equation. We cannot generalize in subject areas where we have no functional (i.e., meaningfully learned) concepts.

Comparing, like generalizing, involves recognition that some individual thing or group of things has regularity and that this regularity differs from that of another thing or group of things. In short, we must use our concepts to see regularities in things and to compare and contrast these things. Concepts are our "windows to reality," and the spectacles by which we can compare objects and events in the world around us.

Evaluating involves the decision process: is $\underline{x}$ a good case of $\underline{y}$? In psychomotor or skill evaluation $\underline{y}$ is our model or criterion of expert performance against which we judge performance $\underline{x}$. In cognitive evaluation, the performance usually required is one of generalizing or comparing. Problem solving usually involves a sequence of comparisons and generalization(s). Except for evaluation that involves rote (verbatim) recall, most evaluation of cognitive learning will be a measure of an individual's ability to recognize regularity in some set of objects or events or group of objects or events. This, as we have noted above, requires that a person must possess and use relevant concepts.

Analyzing is one of the things we must do to classify, to compare or to generalize. To analyze data, for example means to search out regularities, to relate the regularities in these data to more general cases and to compare the observed regularities with other relevant regularities (sometimes using statistical tests).

Synthesizing may involve classifying, generalizing, comparing and evaluation. In Bloom's (1956) Taxonomy of Educational Objectives, synthesis is one of the most inclusive performance tasks. Synthesis may also involve imagination or creativity. This is always the case when the synthesis points to some new regularity, when the new regularity is defined and perhaps given a new concept label. Good synthesis may require one or more instances of integrative reconciliation of concepts, and the more broad and inclusive this new integrative reconciliation, the more likely that unique creative ability will be demonstrated (although it may take a decade or two to be recognized by others).

Deducing would usually be a case of classifying or generalizing, but some deductions might involve a unique synthesis, as in the case of Sherlock Holmes who identifies, classifies and synthesizes a solution to a murder mystery. The deduction may not appear "elementary" to Mr. Watson or to us at first, but as the component regularities (or anomalies that depart from expected regularities) are pieced together for us by Holmes, the ideas involved do become transparent. Creative people may make brilliant deductions, but most people can follow these deductions once they are made, if they are students of the subject. Ausubel (1968) points out that *intelligent* people can learn new relationships or solutions quickly, but only *creative* people can deduce (invent) the solution.

Inferring, last in the list of rational powers given by the Commission, may involve all of the above processes. However, in its most elementary form, inferring is hardly more than recognition that some object or event is another instance of some more inclusive class of objects or events that possess the same regularities. We can *infer* cats have mammary glands because cats fit the attributes of mammals and all mammals have mammary glands. So once again it is evident that the "rational powers" the Commission would like to see augmented in schools place focus on what is the theme of this chapter: concepts are what humans think with and most concepts are acquired through *meaningful* reception learning. Our "central task" as educators is to seek ways to enhance meaningful learning in schools to achieve what the Commission identified as the "central purpose" of education. However, helping students to single out the most relevant and most inclusive concepts in a given learning task at least helps to alert them to some of the concept meanings they lack or that may be inadequate. In the following section, I will discuss in more detail methods by which we can enhance the rational thinking powers of our students

EDUCATION TO ENHANCE RATIONAL THINKING

Getting Your Conceptual House in Order; Concept Mapping

If concepts are central to rational thought, it would logically follow that to enhance rational thinking a teacher should begin by "getting his own conceptual house in order." By this I mean that the teacher should begin planning for a unit of instruction by first identifying those major concepts and subordinate concepts that will define the major regularities he/she wants the students to recognize in the objects or events to be studied. For example, if our unit of study in biology is diffusion and osmosis, the following are some concepts (regularities) that need to be considered: particle size, molecules, ions, random motion, kinetic energy, temperature (as an index of kinetic energy), diffusion barrier, membrane, solute, solvent, concentration, diffusion, osmosis. Concepts are usually easy to find in a test or other material because these are usually the words that are defined (and sometimes printed in bold type). However, some important, relevant concepts for a given unit are found in earlier lesson materials (and unfortunately, sometimes in later lessons) and some concepts must be "imported" from other sources or fields of study (e.g., temperature as a measure of the average kinetic energy of atoms or molecules). This latter task is often difficult for most students to do by themselves, so here is where the well prepared teacher can be of great help.

Once the key concepts are identified, it should be useful to construct a "concept map." Concept maps can serve to suggest relationships between concepts and possible instructional sequences as we proceed from one concept focus to another (refer again to Johnson's ILO's and the need for structure and sequence). There is no perfect concept map, and equally knowledgeable people might produce substantially different concept maps. A "sample" map for the concepts listed above might be as shown in Figure 5.

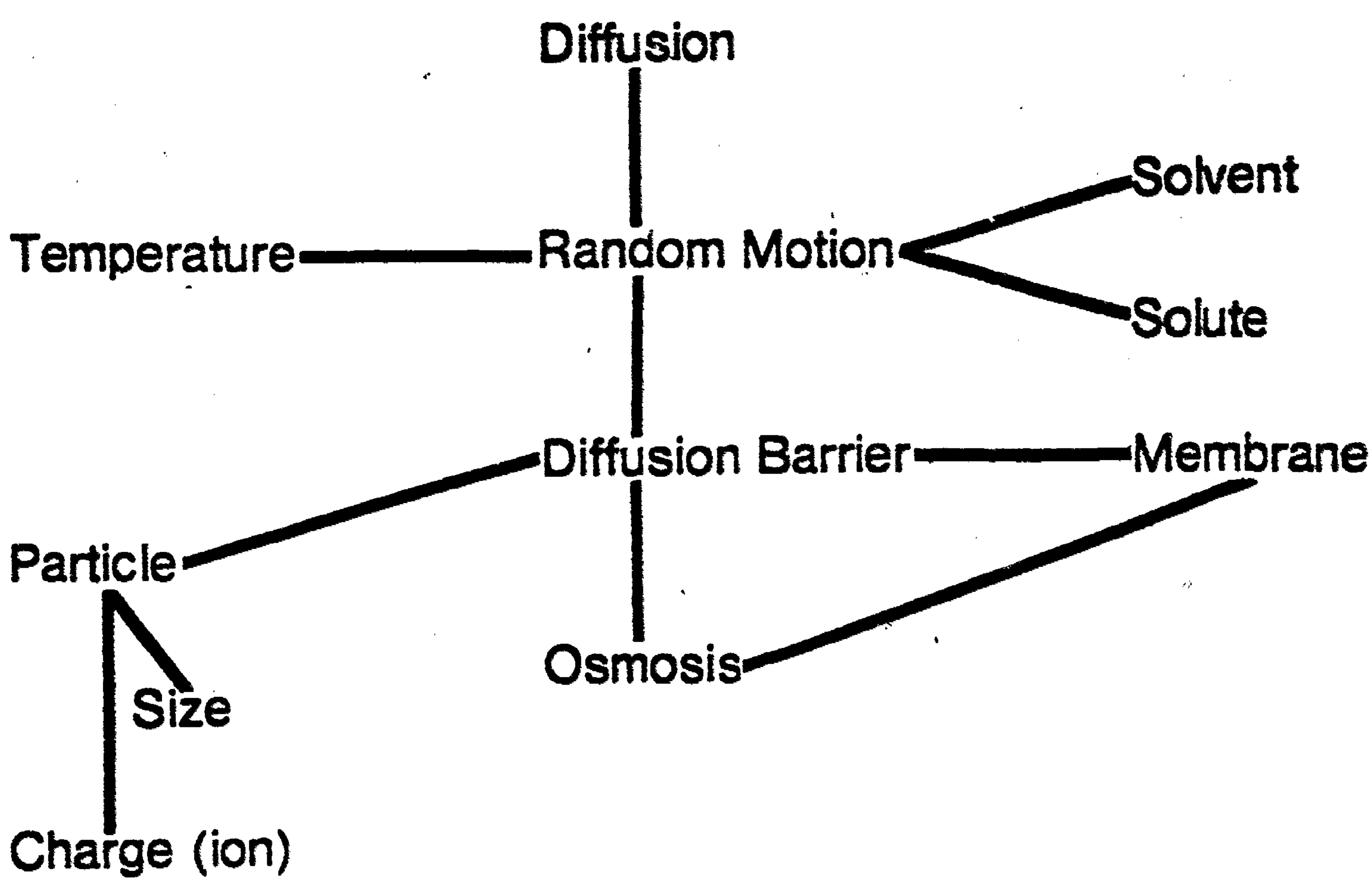

Figure 5. A sample concept map.

I drew this map with *diffusion* as the uppermost concept to suggest that this is the most inclusive (superordinate) concept for *this* unit of instruction. A physics unit might place kinetic energy at the "top" of the map. We could have placed osmosis at the top of the map, but I chose not to, since osmosis is a special case of diffusion. The lines indicate some of the major relationships between concepts. However, since every concept is related to every other concept we know, we could draw lines between each and every concept, but this becomes confusing. By *related*, I mean that the regularities designated by any concept label are at least in some small way defined by the concepts we hold for molecule, atom, protein, lipid, structure, energy, bonding and many others. Take any one of these, structure for example, and it is evident that concepts such as house, brick, frame, girder and many others help to define the regularity coded in the idiosyncratic meaning we have for the concept *structure*. One of the reasons it is difficult to "remediate" students who come from homes poor in the kind of concept usage valuable in schools is that they lack a whole web of interlocking, interacting concepts and there is no simple "crash course" that will help them acquire the concept meanings held by children who fall into the category of "advantaged."

The research we have done to date suggests that concept maps are not particularly useful and may even be confusing when they are given "ready made" to students (Bogden, 1976; Moreira, 1977; Stewart, et al., 1978). Concept maps seem to derive much of their value for both teachers and students from the kind of thought processes necessary to construct a map. Therefore, it has been our experience that provision of opportunities to students to construct concept maps of their own, with opportunities for constructive criticism from their peers and/or teacher, is a useful way to help students understand the complex, interdependent nature of concepts and the web of concepts that needs to be applied to "make sense" out of an experiment, demonstration or segment of instructional material. Needless to say, a teacher cannot be a helpful critic to students constructing concept maps unless the teacher first gets his/her conceptual house in or order.

Understanding Meaningful Learning

Concept mapping is an exercise that helps both teacher and students to gain an understanding of *meaningful* learning. It necessitates an active search by the individual of his cognitive structure with questions such as: what concepts are pertinent to the learning task; what concepts do I lack or understand inadequately; how are the concepts related to one another, or how do I see them related; what are the specific regularities described by the concepts in this specific learning task; what events or objects am I concerned with that don't seem to be encompassed by the concepts (regularities) I am dealing with; and what "higher order" concepts do I know that seem to be most pertinent here? These searching questions help both the teacher and student to focus on the central element necessary for meaningful learning: What do I already know that can be used to subsume new information to be learned?

Meaningful learning requires three elements: (1) meaningful learning *set*; (2) relevant subsuming concepts; and (3) meaningful learning material. Learning *set* is an individual's emotional disposition to want to learn, and a meaningful learning set is the emotional disposition to want to relate new knowledge to relevant concepts the learner already has. There is almost nothing we wish to teach in schools for which any student does not have *some* relevant concept(s). The problem is that many students fail to actively search their minds for relevant concepts. It should be apparent that "concept mapping exercises" give practice and encouragement to develop a meaningful learning set and to search out relevant concepts the learner already knows. Almost everything we teach in schools is "meaningful" learning material, since all knowledge is the product of somebody's meaningful learning effort. As we indicated in our earlier discussion, this is not to suggest that all meaningful knowledge is of equal value or that there are no preferred sequences in the study of a discipline.

Most of us are motivated at least in part by "external" rewards such as high marks, praise, special recognition, etc. Therefore, the evaluation procedures and reward structure established can influence a student's desire to employ a meaningful learning strategy. When verbatim answers or recall of specific facts (records of events or objects) are the main core of evaluation measures, meaningful learning is discouraged and rote learning rewarded.

Psychological Contract

Students quickly learn that some teachers do not mean what they say and do not say what they mean. This pertains both in regard to the concern for and commitment to meaningful learning and to the teacher's concern for the student's self image. Some teachers profess a genuine concern for the feelings of their students, and then proceed with sarcasm, putdowns or other strategies that are ego destructive. If a teacher wishes to facilitate any kind of learning, and especially meaningful learning which requires more psychological risk than rote learning, he must be aware of the "psychological contract" that is developed with his students. To the extent possible, this should be done with explicit concern, by the teacher coming to agreement with the students on what will be defined as positive learning experience and positive interpersonal relations. Here again, concept mapping and evaluation practices that point explicitly toward the use of meaningfully learned concepts can be helpful in defining a constructive psychological contract between the teacher and student. Learning objectives, when they are prepared so as to aid in defining the personal expectations, can also be a positive contribution to development of the psychological contract.

In Figure 1, we pointed out that education involved the four elements: (1) teacher, (2) learner, (3) knowledge, and (4) social matrix. Students are often puzzled as to what their relationship as learners should be as regards the other three elements. When this occurs, the psychological contract becomes ambiguous and fails to provide a positive dimension to facilitation of learning. Just as class discussions regarding what concepts are pertinent to a given lesson can be useful, class discussions that are open and honest can help define the psychological contract that exists between a teacher and his students. If both teacher and student are willing to profit from this exchange, the result can be a much more productive learning environment. Figure 1 can be used as a springboard fot the discussion, with both teacher and students describing how they see their relationship to the other elements in the model.

New Evaluation Strategies

Already noted in conjunction with mastery learning strategies, which can lead to a stronger positive psychological contract between teacher and students, was the use of criterion referenced evaluation. However, most courses, whether of the more traditional variety with norm referenced evaluation or in a mastery learning format, still employ predominantly paper and pencil tests, usually comprised of true-false or multiple-choice questions. While these kinds of tests have value as one indicator of learning success, our experience, from elementary school to college, has been that paper and pencil tests fail to reveal much about the cognitive development of the learner. Therefore, we use almost exclusively, in our research on cognitive learning, modified Piagetian clinical interviews. A monograph describing the techniques we employ is available (Pines, et al., 1978).

There are important advantages to clinical interview evaluation as well as the important disadvantage that an hour or so is needed to interview and analyze the transcript of each subject. However, good tests are not easy to devise and the time investment in writing good questions or grading essay responses is just as great for 30 to 100 students as that required for clinical interviews. An additional difficulty is the logistic problem, in that students must be tested one at a time, and not as a whole group during a single class session. Some of the logistic difficulties are reduced in mastery mode instruction, since students are reaching mastery of units of study at different points in time.

The greatest difficulty with the use of clinical interviews is the availability of skilled interviewers. One of the requirements we have found to be essential for good interviewers is a thorough *conceptual* grasp of the subject. Most graduate teaching assistants and many teachers simply do not have their "conceptual house in order." Given a reasonably adequate background in the subject area, training sessions using video tapes of interviews, analysis of interview responses by applying Gowin's Vee and discussion of concept maps representing the interview content, most teachers can become adequate interviewers in 20 to 30 hours of training (far less than the two to three years Piaget recommends).

We have found that clinical interviews have an important psychological impact on the student. Here is a situation where one teacher is focusing his full attention on one student in a manifestly genuine effort to learn what that student understands, or what misconceptions he has, in a given subject. Many students probably never experience such earnest concern with what they know throughout their school career. The oral exam remains at the graduate level as the final criterion of accomplishment, albeit many oral exams are poor substitutes for an effective clinical interview. The one-on-one involvement of teacher and student does much to enhance the meaning in the psychological contract between teacher and student. In my view, schools should seek ways to redeploy their staff resources so that every child can experience a good clinical interview in each subject area at least once per year. This goal is easily within reach of present school budgets, if school administrators and teachers wished to do this. There would undoubtedly follow substantial improvement in instruction, for teachers would have a far better image of the cognitive structures of their students than they now possess.

The affective realm continues to trouble me. In my view we need far more effort to enhance the affective growth of students, both through the positive affective concomitants of successful cognitive learning and through practices that lead directly to positive affective growth. Rogers (1969) and others have provided some insights in this area but they have not provided useful evaluation strategies for affective growth. It is difficult to advance educational practices that engender affective growth when we have no effective, reliable measures of affective gains. For the time being, we must struggle along with questionnaires and Likert-type scales, until better alternatives are conceived. We are currently experimenting with an "affective" clinical interview strategy.

AN ATTEMPT TO ADVANCE STUDENTS' RATIONAL THINKING

For several years, we have found that college students guided in the study of epistemology and psychology with a focus on the nature and role of concepts in learning have reported that they believe they have "learned how to learn." They report that classes which seem to lack organization or a coherent conceptual framework can be recast as they review the materials into a much more meaningful structure. Most courses taught by professors competent in their fields do possess inherent "meaningfulness"; they do contain the superordinate and subordinate concepts necessary to link together facts and observations and to identify regularities (concepts) in what at first appears to be a morass of details. Therefore, as students are provided with educational concepts that allow them to see new meaning in their courses, most report a qualitatively important improvement in the study strategies, with attendant improvement in course grades. These experiences have led us to speculate on the potential value of direct, explicit instruction on key ideas from psychology and epistemology as a means to facilitate meaningful learning.

In some of our more recent research studies, we have explored ways in which various learning strategies could be presented to students to facilitate their understanding of the role of concepts in knowledge acquisition and problem solving. Bogden (1977) developed "concept maps" for each lecture in a college genetics course. Figure 6 shows a concept map for the lecture on "Identity of Genes." Concepts are shown in all capital letters, with supporting explanatory examples shown in lower case. These concept maps were handed out prior to lectures and discussed following the lectures in a weekly discussion session conducted by Bogden. Bogden's study did not compare a "treatment group" using concept maps with a "control group" receiving only traditional lectures and laboratory work, due in part to practical limitations imposed by the professors in charge of the course. However, achievement was high (with over 80 percent achieving grades of A) and student reaction to the course (based on questionnaire responses and anecdotal comments) was highly favorable. The use of concept maps in learning was a novel experience for all students in the study and some expressed dissatisfaction with this activity. The dissatisfactions arose from the complexity (hence confusion) inherent in some of the maps and the time investment needed to consider maps for every lecture. In retrospect, Bogden's summary of responses suggested that use of occasional concept maps can be helpful to students, but consideration of all course subject matter in the context of concept maps may not be the most efficient use of a student's time. The concept maps were very useful to the instructors in planning lectures and laboratory activities and in writing and evaluation course exams. For the instructor, preparation of concept maps, although a difficult task at first, appears to be an effective and time-efficient strategy.

Atkin (1977), using ideas from Ausubel's learning theory and information processing theory (Newell and Simon, 1972; Rumelhart, Lindsay and Norman, 1972) developed special instructional guides for organic chemistry to facilitate concept learning and problem solving. Using matched samples of students, Atkin found that students provided with study guides emphasizing key concepts and their role in explaining reaction mechanisms performed better than students using more traditional study guides. The experimental group was not significantly better on test items of factual recall, but on novel problem solving items, this group was much superior ($p < .005$) to the control group (means of 57.4 and 37.7, respectively, on a 68-point test).

Moreira (1977) found that college physics students presented with major organizing concepts (Maxwell's equations) early in a course in electricity and magnetism, and assisted with the use of concept maps, showed superior performance on evaluation requiring understanding of relationships between concept maps, when compared with students using more traditional (Halliday and Resnick, 1966) materials. Moeira's study added confirmation to Bogden's work that the *extensive* use of concept maps for student instruction may not be time-efficient, at least not to the extent that other strategies offer.

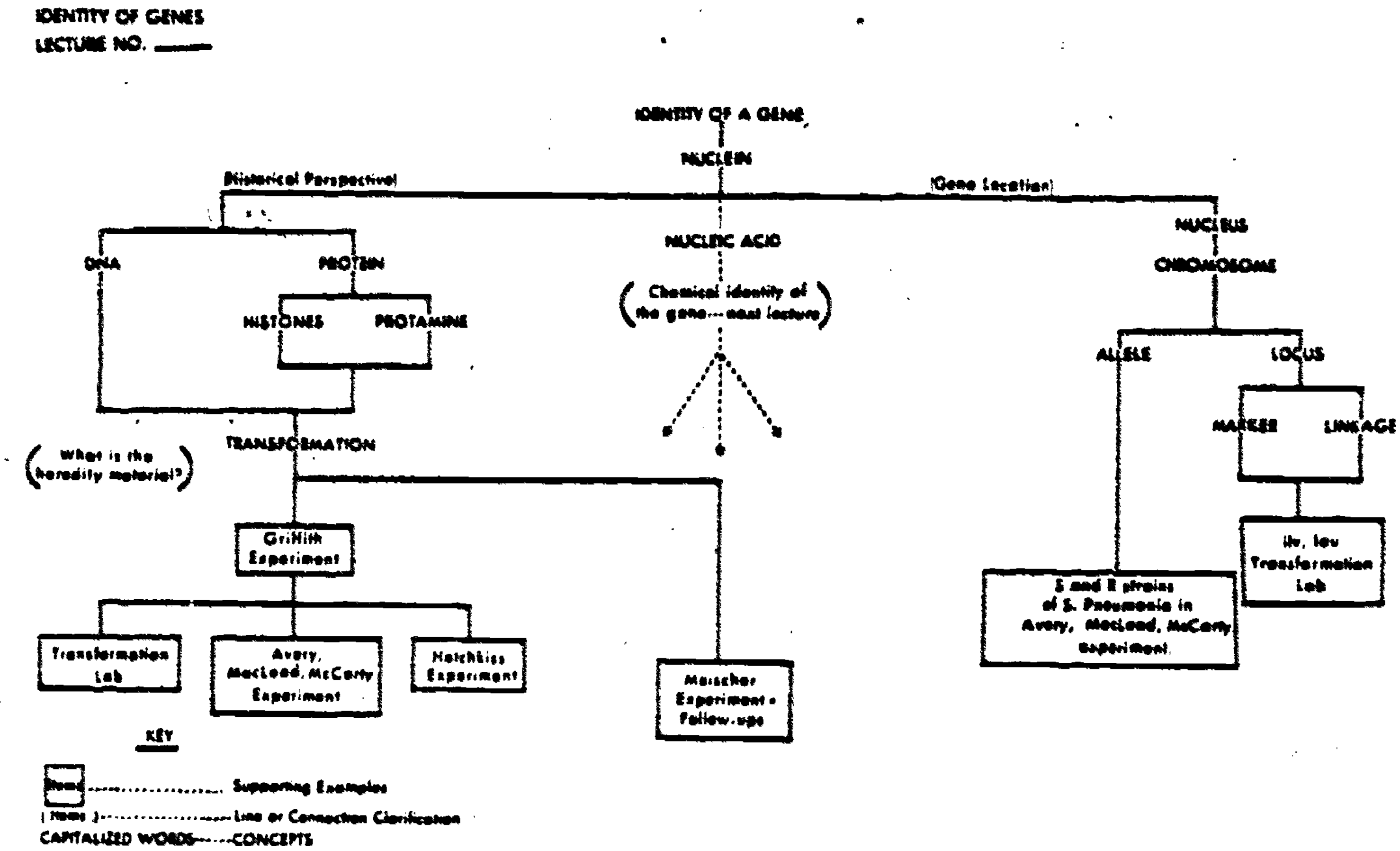

Figure 6. Sample of concept map used in conjunction with lecture and discussion classes in college genetics (from Bogden, 1977).

In another study conducted, as results from Bogden's and Moeira's work was being compiled, Stewart (1978) found that simple concept maps and instructional modules prepared from carefully designed concept maps were well received by students and led to relatively high performance in biology achievement tests. Stewart's study was not experimental in nature but focused instead on strategies for analyzing cognitive structure with techniques such as those employed by Shavelson (1974) and Preese (1976). Stewart's work has added to our understanding of evaluation strategies, applied to analysis of modified Piagetian clinical interviews and specially devised essay questions, to describe qualitative changes in students' cognitive structure.

Research now in progress in a college freshman biology class, a college genetics class, an introductory college chemistry course, and with junior high school science students has combined some of the advantageous elements of the use of concept mapping strategies with new instructional strategies employing Gowin's Epistemological "V".

Our previous findings, together with encouraging preliminary results from our present studies, suggest that the learning strategies used can be effective at the secondary school level. We see the primary factors limiting elementary and secondary school students' performance on cognitive tasks as the lack of adequately developed relevant concepts and the lack of understanding of learning strategies that result in meaningful learning of concepts in contrast to customary rote learning of facts and definitions.

AN EXPERIMENT WITH JUNIOR HIGH SCHOOL STUDENTS

On the basis of our cognitive learning research with elementary, secondary, and college students, considered together with other relevant research studies, we believe there is a reasonable probability that junior high school science students can be taught strategies for "learning how to learn." We plan to conduct an extension of our current research with college students to work with students at the junior high school level employing similar instructional materials that teach (1) an epistemology of science that shows how concepts we possess are both our "spectacles" and our "blinders" in seeing and interpreting scientific events or records of events, (2) a psychology of learning that describes the psychological nature of concepts, the role that previously learned concepts play in acquisition of new knowledge, the role of concepts in problem solving, and the structural relationships between concepts that function in knowledge acquisition and in problem solving, and (3) procedures for recognizing concepts and concept relationships in conventional teaching materials. If we can achieve success in teaching learning strategies at the junior high school level similar to that obtained with college students, the results could have far more impact on the students' future success in science courses and may increase the number of students who continue to enroll in secondary and college science courses.

All of the work we have done in testing instructional procedures that were focused on teaching students learning strategies or "learning how to learn" have been in the context of science classes. It is obvious that to evaluate the value of a learning strategy there must exist some meaningful learning task to which the strategy applies. While our general strategies might be employed in almost any discipline, we have used science classes, since these are most familiar to us. We have done sufficient informal pilot testing of some of our instructional strategies with junior high school students to warrant a conclusion that at least some students at this level can understand and profit from this training.

Experimental Treatment

Our research staff will meet with experimental classes and discuss the nature of the project and the objectives of our work. We will also present in group settings some discussion of the nature of knowledge and the processes scientists use to make knowledge, as well as key ideas from the psychology of cognitive learning. Appropriate printed handout materials will also be provided, and these will be supplemented by use of audio-visual aids, including specially prepared video tapes. Class presentations will be of an illustrated lecture-discussion type followed by small group discussion with each group led by a research staff member or the classroom teacher.

Instructional Materials: Epistemological "V"

We will introduce students to Gowin's (1977) Epistemological "V" first in its general form as shown in Figure 2. Students will have a brief handout with Figure 2 and relevant definitions (e.g., event, concept, epistemology). Within a few minutes, we will move the discussion to an area of science content just studied. For example, if food stored in a seed was studied (Abraham, et al., Interaction of Man and the Biosphere, Unit 3 used by students in Ithaca), we would discuss this experiment. The students would have applied iodine solution to germinating bean seeds and also placed bean cotyledons in a tetrazolium solution. We would assist the students in identifying the relevant *events* in the experiment, *records* of the events (which we define as facts) such as "cotyledon with iodine turned dark red." The data would be shown on a blackboard as in Figure 7. Relevant knowledge claims might be that germinating bean seeds contain sugars (as indicated by the tetrazolium test). It should be easy to show that the *knowledge claims* can only be made by applying other relevant concepts (e.g., starch, sugar, chemical reaction, red, cotyledon, etc.). The knowledge claim does not derive from the *facts* alone but requires that the fact be interpretated through our understanding of relevant concepts.

Our experience has been that students quickly recognize why so much of their previous laboratory work (or demonstrations) has had no meaning to them--they see that either they lacked the necessary relevant concepts to interpret the facts (records) or they failed to see the relevance of concepts they knew (as often occurred in Atkin's 1977 study) or both.

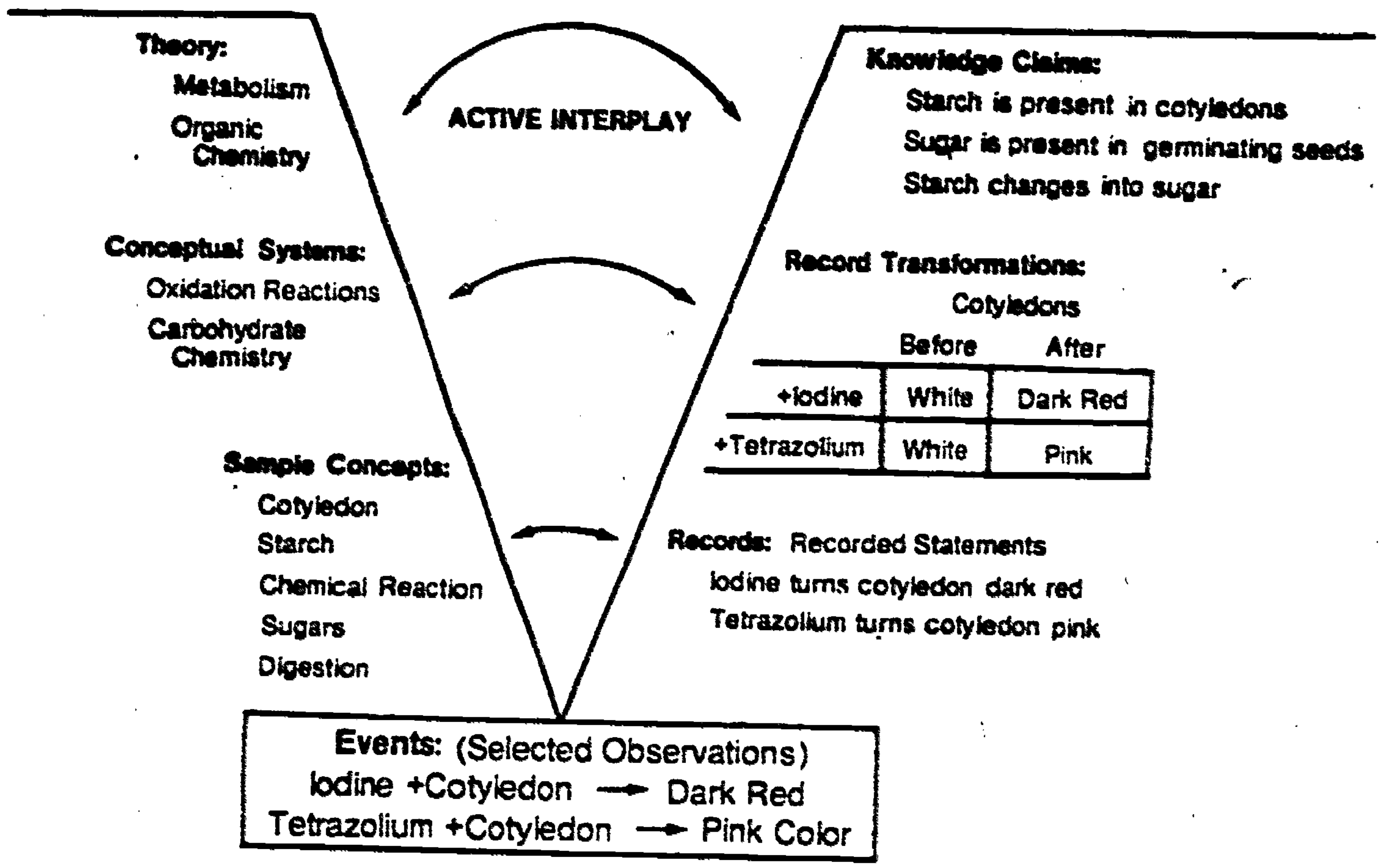

Figure 7. Sample Epistemological "V" constructed on the blackboard through class discussion.

Of course, it is usually a surprise to both students and teachers to see how many previously learned concepts must be brought to bear on even a simple set of events (as in our example). Everyone begins to see why so much of the science laboratory is not integrated into the students' cognitive structure and why the net result is usually rote recall of records and/or knowledge claims with no understanding of what occurred or why.

The discussion naturally leads to questions such as what are concepts and where do they come from (i.e., how do scientists invent or change concepts or what is the *epistemology* of concepts), and what are concepts *psychologically* and how do we learn and modify our concepts? We do not plan extensive instruction dealing with these questions but we will attempt to provide honest answers as time permits, especially in small group sessions or with individual students who press the question(s).

We plan to instruct students in the following key ideas:

Concepts - defined as *regularities* in events or objects designated by some sign or symbol. We will ask students repeatedly "What is the regularity (or regularities) that you see in what you are observing?" They will become aware that concepts are both our spectacles and our blinders, as Kuhn (1962) has pointed out. Concepts we hold help us to recognize certain regularities in a set of events or objects, but blind us (or distract us) from others. This will be clearly illustrated (based on our previous experience) as students are asked to report what regularities are seen in events or objects they will be observing in their science lessons. They will also see that concept labels (i.e., scientific terms) give us a means for communicating our understanding of concepts and relationships between concepts.

Subsumer - The concept each person acquires has idiosyncratic meaning to that person, but still retains the general "regularity" features culturally accepted for the concept label. Ausubel uses the term subsumer or subsuming concept to emphasize two attributes of people's concepts (1) the idiosyncratic nature of the meaning and (2) the fact that new knowledge is linked to and *subsumed into* existing concepts, resulting in some modification of both the new information and the original subsumer.

Meaningful learning - occurs when new information is actively linked to existing subsumers by the learner. This requires (a) meaningful learning material (e.g., most science material and not nonsense syllables), (b) a meaningful learning set (which includes the motivation to try to "make sense" out of the new material), and (c) relevant subsumers for new information which most students possess but they often fail to recognize this. Artful teachers use examples and analogies that help students identify what they already know (subsumers they have) that are relevant to new learning material.

Rote Learning - the common practice in school learning where new knowledge is *arbitrarily* linked to cognitive structure and not incorporated into existing relevant concepts.

Progressive differentiation - the process that occurs with new learning that results in new meanings or refined meanings for a concept (as for example the process by which animal or energy concepts take on new meaning as study of science proceeds).

Integrative reconciliation - the process wherein two or more existing concepts are seen as related through some more inclusive concept, resulting in new (altered) meanings for the existing concepts. We also view this as a *creative* act and unique integrative reconciliations that involve perception of some new high-order regularity are what win people Nobel prizes.

From epistemology we plan to instruct students on the following ideas:

Concepts - their man-made character; the fact that they are invented by creative people (men *and* women, black and white).

Concept evolution - the idea that concepts (like species) change over time, e.g., our concept of gene from 1859 to contemporary ideas on base-pair triplets in DNA.

Competition of concepts - the fact that two or more descriptions of a regularity (concepts) may compete, each with some group of adherents, and eventually one concept wins out or a new concept is invented that displaces the older concepts (e.g., kinetic-molecular theory of heat).

Concept influence - the events or objects we observe and how we observe them (as for example how we design our experiments).

Transformation of records (of events or objects) can clarify or obscure the inherent regularities in events or objects (e.g., statistical analysis).

Instrumentation evolves with our concepts and influences the development of our concepts (e.g., microscopy).

Knowledge claims are rooted in the concepts we hold and in the kind of transformation we perform on records.

Value claims combine knowledge claims with attitudinal or affective valence (e.g., recombinant DNA studies are "good" or "bad").

These psychological and epistemological ideas will not be "dropped" on the students as concepts isolated from their work but rather they will be introduced as they are needed and useful to explain some aspect of the science experiment or demonstration. In other words, we will try to introduce the above concepts so as to practice what we are preaching (meaningful learning) by relating them to concepts students have and at times when the students seem motivated to learn these new concepts.

As our work proceeds, we expect students to handle future experiments or demonstrations with little direct guidance, although we will assist them as questions and problems arise. Another example might be from the area of genetics (Abraham, et al., Unit 11). Students often confuse records or transformed records as events and may say they observed a 3:1 ratio of red to white pea plants. Through discussion, it is possible to show them that the 3:1 ratio is actually an inference or knowledge claim from a transformation of their records (say 28 red and 10 white plants) and their deduction that this is a 3:1 ratio actually involved applying some concepts (monohybrid, cross, dominant gene, recessive gene) to obtain a knowledge claim--that the experiment produced a 3:1 ratio of dominant to recessive peas as would be expected in a single gene, monohybrid cross. We can also illustrate how concepts change over time, from Mendel's day (1859) to our contemporary views on genes, which are also being modified. The discussion can again serve to show in an explicit way that we cannot make sense out of science laboratory experiments or demonstrations *unless* we possess and apply relevant concepts.

Instructional Materials: Concept Maps

For each unit of study, a simple concept map will be developed. For example, in Grade 8, students study the effect of solutes and temperature on the density of water (Abraham, et al., Interaction of Earth and Time, Unit 6). After an experiment or demonstration is discussed in terms of the Epistemological "V", we will construct a concept map, working together with the class in a discussion format. The result could be a map as shown in Figure 8. Students will readily recognize that in some remote way, *hundreds* of concepts have relevance to the interpretation of a set of events, and that we are mapping only a few of the most salient concepts. For example, the fact that the hydrometer sinks as a water solution is heated involves concepts of thermal expansion of materials (glass, water), mean kinetic energy of molecules, heat, etc. Once again, students (and their teachers) will become impressed with the conceptual complexity of interpretation involved in even a "simple" demonstration.

We will ask students to prepare their own concept maps for some demonstrations and experiments not discussed by the class as a whole. Research staff will review each student's concept maps and discuss the maps on an individual basis, assisting the student to see more salient and less relevant concepts and relationships between concepts. This tutoring activity will lead to students' understanding that two or more concepts related in some way describe a scientific *proposition* which is seen as a principle, rule, formula, or law. For example,

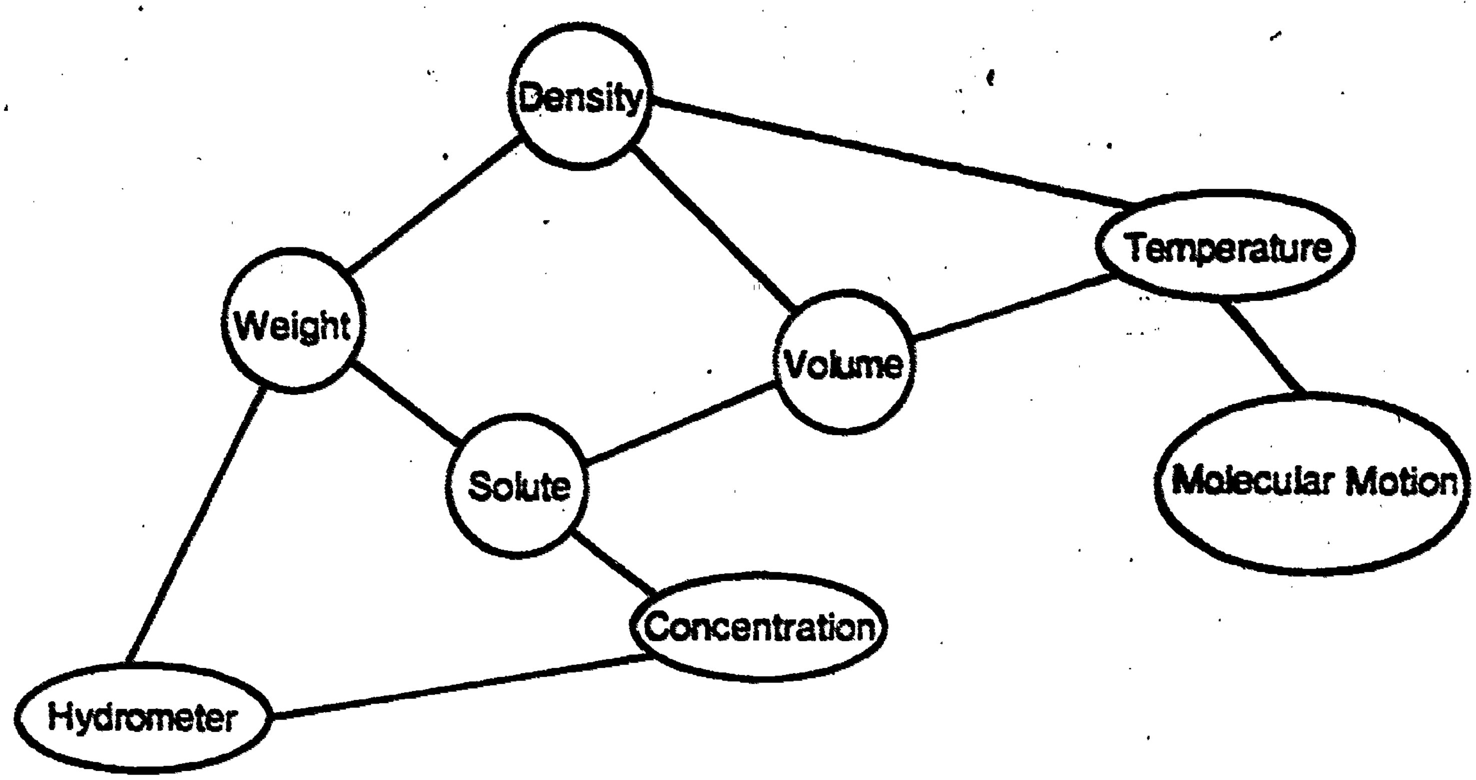

Figure 8. Key concepts involved in understanding experiments and demonstrations in Unit 6.

"hot liquids are less dense than cold liquids," defines a specific relationship between concepts of hot, cold, density, liquid and objects. Much more complex, of course, are the events, records and interpretation of records that lead to the knowledge claim in this example.

Instructional Materials: Videotapes

We have found that students can learn from watching others learn, especially when the teaching-learning episode is carefully analyzed (Carroll, 1976). We will videotape some of the small group discussions, for example, where a staff member is assisting a group to construct an Epistemological "V" for an experiment just completed. The next day, the videotape (perhaps with some editing) will be shown to the class and questions raised such as: "Why did Mark suggest that color blindness may be an important idea in this (iodine test) experiment?"; "Was June confusing records with knowledge claims in her answer?"; "What concept were they missing to explain the record (three of twenty seeds did not react with tetrazolium) they were studying?" On some occasions, we will review videotapes with individual students, especially when there is a problem in understanding what the group is doing.

Instructional Materials: Printed Modules

As we begin to refine strategies and ~~examples~~ for guiding students in understanding the use of concept maps and the Epistemological "V", we will begin to prepare illustrated, printed study modules that can be used by students to minimize the need for research staff tutorial help. Obviously, if our "learning how to learn" strategies are to be implemented in many other schools, we must develop materials that can be successfully employed by ordinary science teachers without the aid of university specialists. We believe this goal can be achieved, although the present study is concerned primarily with whether or not our team approach can succeed in teaching the majority of seventh and/or eighth grade students "how to learn" and whether or not this has transfer value in learning other science units or in later science study.

Evaluation Program

Our primary source of data will derive from clinical interviews with students in experimental and control classes, presenting novel science experiments or demonstrations and seeking explanations for the phenomena observed. Questionnaires, objective tests and anecdotal records will also be analyzed.

SUMMARY

I believe that Ausubel's theory of cognitive learning when employed together with concepts from epistemology and curriculum and instruction theory can lead to substantial enhancement of students' ability to think rationally. This chapter has provided a brief overview of key ideas needed for an experimental program of instruction to enhance rational thinking. A research study with junior high school science students has been described as has the evaluation including assessments of students' ability to think rationally.

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A THREE-STAGE MODEL FOR TEACHING FOR CREATIVE THINKING

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In 1961, the ten rational powers proposed by the Educational Policies Commission (1961) as the central purpose of American education represented frontier thinking. At that time, only two or three of these rational powers (recalling, comparing, and analyzing) were included in the statements of objectives of teachers (Torrance and Ross,1961). Graduate students and other researchers seeking to study problem-solving behavior in classrooms could not find enough such behavior to study. Since that time, all ten of these rational powers have become common in the statements of educational objectives and there have been many studies of classroom problem solving (Torrance and Torrance, 1973). However, it has become clear now that the ten rational powers of the Educational Policies Commission are "not enough" in today's rapidly changing society and in the post-industrial society of the future and that these powers themselves are not always "rational."

Even in 1961, scholars and practitioners interested in creative thinking were insisting that some of man's most important thinking, decisions, and actions require more than rational powers. For example, Alex F. Osborn (1952, 1953) had written and spoken of the creative powers that go beyond what he called absorptive powers, retentive powers, and reasoning powers. He had maintained even that the full functioning of the creative powers requires the temporary suspension of judgment and rational processes. Educator Hughes Mearns (1958) had also written and spoken about the creative powers and described important "new kinds of learning" that went beyond rational processes. William J. J. Gordon (1961) and his associates in the Synectics movement were insisting that in creative thinking "the emotional component is more important than the intellectual, the irrational more important than the rational" (p. 6).

On the basis of seven years of study of survival behavior in emergency and extreme conditions (Torrance,1958, 1959) and three years of study of the creative behavior of children, I had also become convinced that the future would require a type of education that goes beyond the development of rational powers. In 1960 at the Education and Space Age Conference sponsored by the Minnesota Chapter of the Air Force Association, I made a plea for changes in educational objectives, the development of a psychology of thinking (in addition to the psychology of learning), and the invention of teaching methods and materials to implement these new objectives (Torrance, 1963).

NEW LINES OF DEVELOPMENT

Since 1961, several new lines of development have continued to support the burgeoning ideas described above and deepened our understanding and use of them. The work initiated by Alex F. Osborn in advertising has been refined, extended, and researched by Noller, Parnes, and Biondi (1976, 1977) and many others in industry, business, education, and government. William J. J. Gordon's work in Synectics has been extended in industry and business (Prince, 1970) and introduced into education (Gordon, 1973). In education, many writers, researchers, and practitioners have extended the ideas of Hughes Mearns and have described still other new kinds of learning. Some of the strongest assertions of this point of view have been George I. Brown (1971), Robert Samples (Samples, 1975; Samples, Charles and Barnhart, 1977), Frank E. Williams (1972), and E. Paul Torrance and Robert E. Myers (1970). New concepts have been introduced by psychiatrists to describe the "beyond the rational processes." Silvano Arieti (1976) has called it the "magic synthesis" and Rollo May (1975), another psychiatrist, has suggested the term "suprarational" to label the process involved in going beyond the rational to bring something new into being. Edward de Bono (1970, 1975, 1976), a British philosopher and psychiatrist, introduced the concept of lateral thinking to contrast the processes involved in going beyond the rational processes (termed vertical thinking by de Bono). Psychiatrists, psychologists, and educators have identified and described a wide range of states of consciousness other than the rational, wakeful state and have shown that these are important in learning and thinking (White, 1972). Research concerning the specialized cerebral functions of the right and left hemispheres of the brain have deepened our understanding and control of the functions that go beyond the rational process (e.g., Chall and Mirsky, 1978; Dimond and Beaumont, 1974; Eccles, 1973; Ornstein, 1972). To lay the groundwork for the theory of creative thinking and teaching model that I shall present, some of these new developments will be reviewed briefly.

Concepts from Psychiatry

Earlier explanations of creative thinking by psychiatrists and psychologists treated creativity as a regressive thought process. Prior to 1961, Ernest Kris' (1952) concept of "regression in the service of the ego" was accepted by many as an explanation of the creative process. Lawrence Kubie (1958), taking off from Kris' formulation, insisted that the preconscious rather than the unconscious was responsible for creativity. His argument was that only the preconscious has the flexibility necessary for creative thinking, explaining that the unconscious is rigid and stultifying. Thus, he pictured creativity as healthy and adaptive rather than as regressive.

Since Kubie's 1958 formulation, several other psychiatrists have introduced concepts that depart from the regressive view of creativity. Silvano Arieti (1976) described creativity as "the magic synthesis."

The magic synthesis is described as a binding together of the primitive, irrational forces of the unconscious with the logical, rational, and cognitive mechanisms of the conscious mind. He used the term "tertiary process" to differentiate this process from primary (unconscious) and secondary (logical, rational) processes. Rollo May (1975) has maintained that creative processes are not irrational but rather are "suprarational," bringing the intellectual, volitional, and emotional functions into play all together. He believes that creative thinking represents the highest degree of emotional health and is the expression of normal people in the process of actualizing themselves. He sees it as a process involving a realistic encounter with the problem, intense absorption and involvement, heightened consciousness or awareness, and interrelating.

Albert Rothenberg (1976a, 1976b), a Yale University psychiatrist, has introduced two concepts that are definitely nonregressive in nature to explain creativity. One of these, Janusian thinking (Rothenberg, 1976a), consists of actively conceiving two or more opposite, contradictory, or antithetical concepts, images, or ideas simultaneously. He sees this not as a primary process mode of thought, but as an advanced type of abstract thinking. The second of these, homospatial thinking (Rothenberg, 1976b), consists of actively conceiving two or more discrete entities occupying the same space; a conception leading to the articulation of new identities. Although the process involves the visual mode, any of the sensory modalities may be involved. Rothenberg maintains that neither Janusian nor homospatial is primitive nor regressive. He describes them as forms of secondary process thinking that transcend logic and ordinary rational modes of thought. Both of them are seen as important in creative thinking.

Rothenberg maintains that Janusian thinking and homospatial thinking figure prominently in creativity in both the arts and sciences. In educational settings, I have found these concepts especially useful in understanding what happens in the creative solution of problems involving "collision" type conflicts. In my sociodrama class, I have had pairs of students write scenarios about characters representing such opposites as: frugal - spendthrift, moral - immoral, optimistic - pessimistic, clever - stupid, brave - cowardly, and the like. These two-person teams were instructed to write scenarios describing collision conflicts for which they could see no rational solution. These scenarios were then given to another team to use as the basis of sociodramas. Using sociodrama as a creative problem-solving process, creative solutions have developed rather easily.

This concept is not exclusive to psychiatry. It is apparent in creative work in numerous other fields. Robert Adler, in his seminars at the Creative Problem Solving Institute at Buffalo, refers to the phenomenon described by Rothenberg as "the unity of opposites" and illustrates its validity through the construction and enactment of scenarios similar to the ones just described. The use of such conflict in dramatic writing is described by Lajos Egri in his classic, The Art of Dramatic Writing (1960), first published in 1942 and revised and republished in 1969. This concept of the unity of opposites is inherent in the definition of creativity by George M. Prince (1970):

> an arbitrary harmony, an expected astonishment, an habitual revelation, a familiar surprise, a generous selfishness, an unexpected certainty, a formable stubborness, a vital triviality, a disciplined freedom, an intoxicating steadiness, a repeated initiation, a difficult delight, a predictable gamble, an ephimeral solidity, a unifying difference, a demanding satisfier, a miraculous expectation, an accustomed amazement. (p. xiii).

This unity of opposites is also seen in research on the creative personality. This is especially apparent in the research of MacKinnon (1978), Barron (1969) and their associates at the Institute of Personality Assessment and Research at the University of California at Berkeley. They found that highly creative persons were more successful than their less creative counterparts in reconciling the opposites of their nature--masculinity-femininity, independence-dependence, conformity-nonconformity, and the like.

Lateral Thinking

Edward de Bono (1970, 1975) uses the term "lateral thinking" to describe what is involved in generating new ideas and solutions and the term "vertical thinking" to describe the conventional rational processes. He has argued that, since Aristotle, logical thinking has been exalted as the highest use of the human mind, but that useful new ideas do not necessarily come as a result of logical thought. De Bono has always been careful to point out that lateral thinking is not a substitute for traditional logical thinking but is an essential complement. He maintains that there are three basic types of problems (1970, pp. 257-258):

1. Those requiring the processing of available information or the collection of more information.

2. Those where the acceptance of an adequate state of affairs prevents consideration of a change to a better state.

3. Those solved by a restructuring of the information that has already been processed into a pattern.

According to de Bono, the first type of problem can be handled with logical thinking or mathematical thinking, or collecting additional information. The other two types of problem require lateral thinking. Lateral thinking, as conceived by de Bono, processes information quite differently from rational (vertical) thinking. In logical thinking it is absolutely essential to be right at every step; in lateral thinking, this is quite unnecessary. It may sometimes be productive to be wrong; being wrong may dislocate a pattern sufficiently for it to re-form in a new way. With logical thinking, a person makes immediate judgments; with lateral thinking, he may delay judgments to permit new information to interact and generate new ideas. In logical thinking, the processing of information is sequential and linear; in lateral thinking, several kinds of information may be processed simultaneously.

Edward de Bono (1975, 1976) has now developed a variety of instructional materials which are being used rather widely in England and are beginning to be used in the United States. Some of the educational methods will be described and discussed in connection with the implementation of the instructional model presented in this paper.

States of Consciousness

The ten rational powers suggested by the Educational Policies Commission (1961) as central purposes of American education can perhaps be associated with a single state of consciousness, the logical, wakeful state. The past decade has witnessed a great deal of discussion regarding the importance of other states of consciousness (e.g., Orme-Johnson and Farrow, 1977; Ornstein, 1972; Walters, 1977). Stanley Krippner (1972) has identified the following 19 states of consciousness in addition to the ordinary, logical wakeful state:

1. Dreaming State
2. Sleeping State
3. Hypnagogic State
4. Hypnopompic State
5. Hyperalert State
6. Lethargic State
7. States of Rapture
8. States of Hysteria
9. Fragmentation
10. Regressive States
11. Meditative States
12. Trance States
13. Reverie
14. Daydreaming
15. Internal Scanning
16. Stupor
17. Coma
18. Stored Memory (past experiences not available to a person's reflective awareness)
19. Expanded Conscious States.

While some of these states of consciousness offer little promise for facilitating school learning and thinking, several of them do. Yet we lack accepted educational methodologies for inducing and using them productively. However, there has been some experimentation with meditation techniques, some of which have met with controversy and legal action. The legal grounds for forbidding meditation has been its association with religious practices. However, numerous practitioners have gone ahead with practical applications and have avoided religious connotations. The results that I have been shown in confidence have been quite encouraging. Meanwhile, the Maharishi Research Universities in Switzerland and Iowa have gone ahead with rigorous research on "creative intelligence." Rather consistently, meditation training and practice seems to improve creative functioning (Brown, 1971). Recently Jhan Robbins and David Fisher (1973), journalists, made a rather intensive investigation of Transcendental Meditation and presented the following tentative conclusions concerning junior and senior high school students who meditate:

1. Students improve their grades.

2. Students get along better with teachers.

3. Students get along better with parents.

4. Students get along better with other students.

5. Use of drugs lessens.

Experimentation in the United States with Suggestive, Accelerative Learning and Teaching (SALT) based on the Lozanov method has been met with apparently little controversy and has resulted in more hard data in school situations than has been possible in the case of Transcendental Meditation (e.g., Caskey and Flake, 1976; Schuster, 1976; Schuster, Benitez-Bordon and Gritton, 1976).

Georgi Lozanov (1977), the originator of the method, achieved his first phenomenal successes in Bulgaria in the teaching of foreign languages. However, adaptations of the method in the United States have been applied to the teaching of reading (Prichard, 1976), mathematics (Gritton, 1976), naval science (Peterson, 1977), vocational agriculture (Van Lancker, 1975), statistics (Capehart, 1976), and creative thinking (Edwards, 1977). This educational method has at its core a large element of waking state suggestion distributed throughout its classroom application. The first stage of the sequence involves the establishment of a suggestive positive atmosphere for learning, the relaxation of students with optional, mild physical exercises; and the calming of pupils' minds prior to learning. In the intermediate stage, subject matter content is presented in dramatic, dynamic fashion and then is reviewed in time with music. The final phase consists of educational fun and games to activate the material just learned. Thus, such states of consciousness as relaxation, meditation, hyperalertness, and expanded awareness are deliberately used to facilitate learning.

STYLES AND LEARNING AND SPECIALIZED CEREBRAL FUNCTIONS OF THE LEFT AND RIGHT HEMISPHERES OF THE BRAIN

During the past decade there has been increasing interest in education regarding research concerning the brain. One evidence of this is that one of the 1978 yearbooks of the National Society for the Study of Education (Chall and Mirsky, 1978) was devoted to this topic. The present volume also includes a chapter devoted to the educational implications of recent brain research. Other such evidence is the appearance of a large number of books, articles, and workshops on the educational implications of the specialized cerebral functions of the right and left hemispheres of the braining and their attendant learning and thinking styles (e.g., Brandwein and Ornstein, 1977; Eccles, 1973; Reynolds, Reigel and Torrance, 1977). The accumulation of evidence indicates that two different styles of learning result from the specialized functions of the left and right hemispheres of the brain. The left hemisphere processes information linearly, logically, and sequentially and deals primarily with verbal information. The right hemisphere processes information non-linearly, intuitively, and simultaneously and deals with figural, auditory, kinesthetic, and emotional information.

The thinking strategies most characteristic of the left hemisphere are analytical, sequential, and logical. The left hemisphere also specializes in making fine discriminations or differentiations of stimuli (Epinas, 1975). Left hemisphere processing of information seems to be associated with positive emotions when processing data that are orderly and consistent and with emotional irritation when the data are characterized by contradictions and inconsistencies. Among the specialized functions of the right hemisphere are: the analysis of voice intonation, metaphoric expression, the interpretation of complex visual patterns, the recognition of faces, the retention of visual patterns, the perception and retention of complex nonverbal auditory patterns, spatial orientation, the analogical processing of information, and the attainment of a global view or a "Gestalt."

Some educational psychologists (e.g., Dacey, 1976) believe that the right hemisphere style of learning and thinking is becoming increasingly more prevalent among children. Futurist Marshall McLuhan (McLuhan and Fiore, 1967) has maintained that the thinking patterns of the latest generation differ markedly from those of earlier generations. He attributes this to differences in the ways that information has been presented. During the early periods of history, media were virtually non-existent. Information was obtained face-to-face, in a verbal fashion. With the invention of the printing press and the subsequent growth of printed media, the visual processing of information was emphasized. With printed material emotional involvement was low and the processing was sequential and logical. Today's elementary, high school, and college students are the first generation to have known television all their lives. They are accustomed to having information bombard them in non-sequential form, as on television news programs. These students are not as concerned about order and logic, as are their elders. Emotional involvement is greater and many films, television programs, and other media seek to create sense impressions or emotional reactions rather than present information in a linear manner.

DEFINITION OF CREATIVE THINKING

There seems to be little doubt that creative thinking requires all ten of the rational powers identified by the Educational Policies Commission, and probably more. This is apparent in all of the models of creative thinking with which I am familiar (de Bono, 1970; Gordon, 1973; Osborn, 1953; Parnes, Noller, and Biondi, 1977; Torrance, 1978). In this chapter, however, I shall deal almost exclusively with my own definition, theory, and instructional model.

My definition of creativity is much more inclusive than most definitions. I believe that some degree of creative thinking is required any time a person confronts a problem for which he has no learned and practiced solution. There are times when very little creative thinking is required. The mental leap from what is known to the solution of the problem is quite small. There are other times when an enormous leap is required and a disciplined, systematic approach to creative problem solving is required. A number of criteria have been suggested to estimate the degree of creativity required in solving a given problem. Hans Selye (1962) has suggested that a solution is creative to the extent that it is consistent with new data (i.e., generalizable) and surprising in the light of what was known at the time of the discovery. Newell, Shaw, and Simon (1962) have suggested the following criteria for differentiating creative problem solving from ordinary, logical problem solving and assessing the degree to which a solution is creative:

1. Novelty and value (either to the thinker or for his culture)

2. Unconventional in the sense that it requires modification or rejection of previously accepted ideas

3. High motivation and persistence, taking place either over a considerable span of time (continuously or intermittently) or at high intensity

4. The problem as initially posed was vague and ill defined, so that a part of the task was to formulate the problem itself (pp. 65-66).

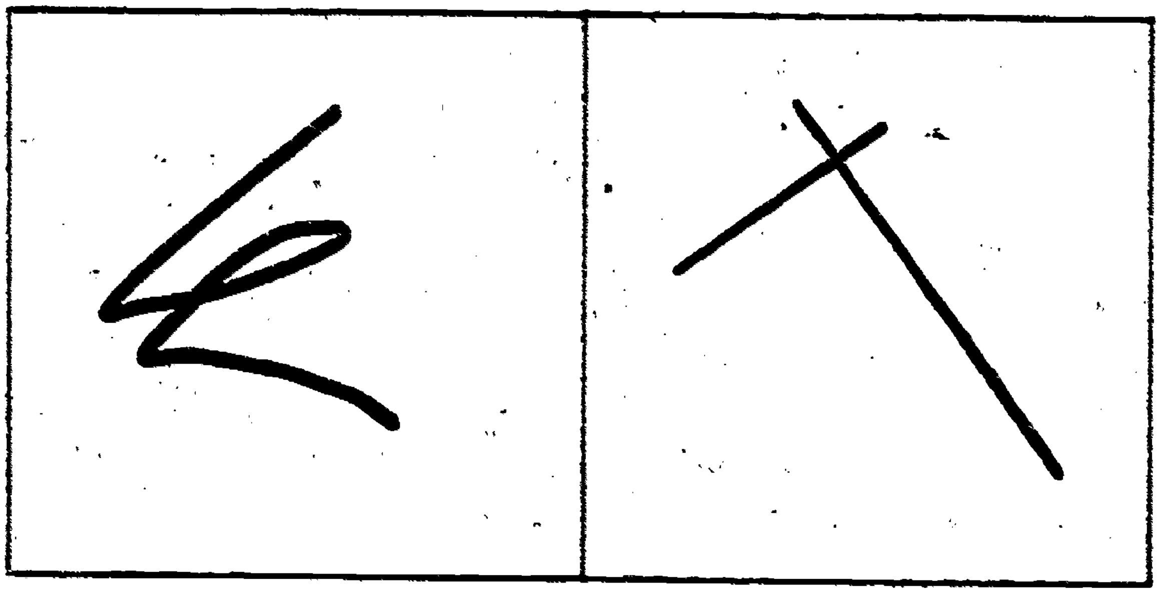
In my research and development work I have chosen to define creativity as a process. I have preferred a process definition because once the process is described, we can then ask what kind of person one must be in order to engage in the process successfully, what kind of environment he needs in order to function in creative ways, and what kinds of products result from the process.

I have defined creative thinking as the process of sensing difficulties, problems, gaps in information, missing elements, and disharmonies; defining the problem clearly; making guesses or formulating hypotheses about these deficiencies; testing these guesses and possibly revising them and retesting them or even redefining the problem; and finally communicating the results (Torrance, 1963, 1965). I prefer this definition for use in education because it describes such a natural process. Strong human needs are at the basis of each stage. If we sense any incompleteness, something missing or out of place, tension is aroused. We are uncomfortable and want to do something to relieve the tension. As a result, we obtain information, ask questions, and try to decide what the problem really is. If the problem has been clearly defined for creative attack, we can formulate alternative hypotheses or make multiple guesses. Until these guesses or hypotheses have been evaluated and tested, we are still uncomfortable. Then, even when this has been done, the tension is usually unrelieved until we tell somebody that we have discovered, produced, or done. Throughout the process there is an element of responding constructively to existing or new situations, rather than merely adapting to them or being destructive. Such a definition places creative thinking in the realm of daily living and does not reserve it entirely for ethereal and rarely achieved heights of creation.

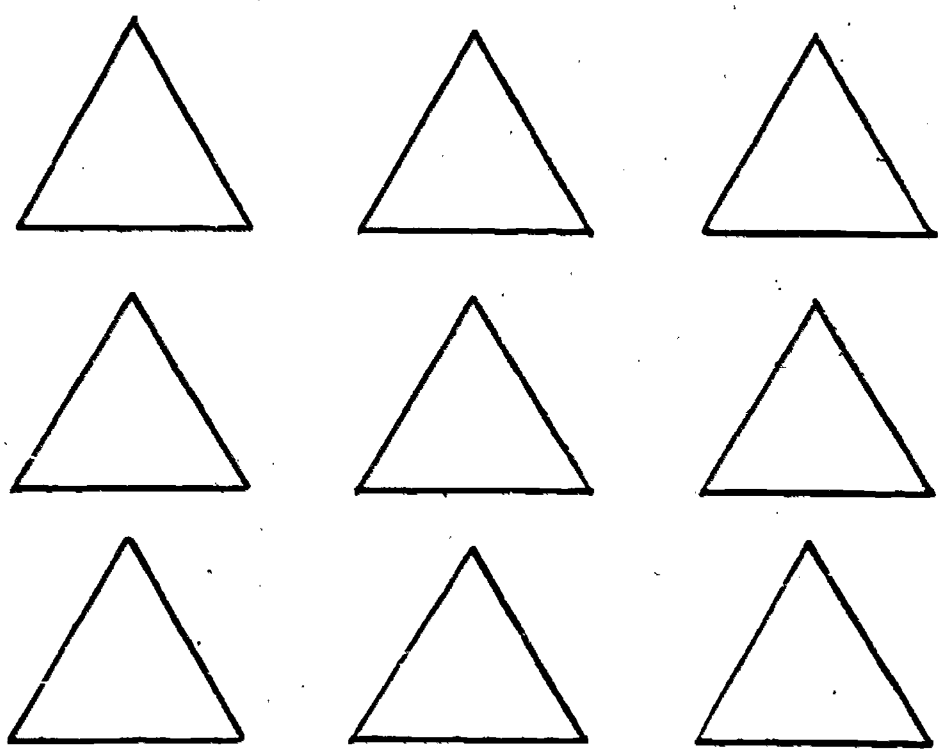
To illustrate this process, I sometimes give a class, seminar group, or workshop group one of the tests I have developed for assessing the creative thinking abilities, usually the Incomplete Figures Test, the Circles Test, or the test task from the Demonstrator Form shown in Figure 1. After a while, I check with them to find out what is happening. With the incomplete figures, they will usually admit that the incompleteness or some other quality of the figures had aroused them to want to complete them. Usually some of them have gone ahead and completed the figures, trying to make some picture that no one else in the group will think of and to add details that will make their pictures tell as interesting and as complete a story as possible. There is usually almost no reluctance, even in the stiffest, most staid, and negativistic group. Rather, there is an obvious atmosphere of relief, increased liveliness and warmth, even smiles and laughter. There is also a spontaneous interest in communicating the results and finding out what everyone else has completed. The closed, completed figures of the circles and triangles test present a somewhat different problem, requiring a person to disrupt a figure that is already completed.

The task of responding to the two kinds of figures shown in Figure 1 illustrates two important kinds of demands for creative thinking. The Incomplete Figures at the top of the figure call into play the tendency toward structuring and integrating. The incomplete figures create tension in the beholder who must control his tension long enough to make a mental leap which is necessary to get away from the obvious and commonplace. Failure to delay gratification usually results in a premature closure of the incomplete figures and an obvious or commonplace response. The invitation to "make the drawing tell a story" is designed to motivate elaboration and further filling in of the gaps. The closed triangles brings into play the tendency toward disruption of structure in order to create something new. The repetitions of a single stimulus require an ability to return to the same stimulus again and again and perceive it in a different way.

Add lines to the incomplete figures to sketch some interesting objects:



See how many objects or pictures you can make from the triangles below.



12-6664-2.2M

Figure 1.--Sample Items from Demonstrator Form of the Torrance Tests of Creative Thinking.

If the thinking of the group is bound to some specific curricular content, such as reading, science, art, or language arts, I try to show how analogous processes operate with that curricular content. For example, let us assume that the group is interested in creative reading as a skill in some discipline such as science. When anyone reads creatively, he must first of all become sensitive to some incompleteness within himself, some problem, or some exciting possibility in whatever he reads. He must want to find out something. He makes himself aware of the gaps in knowledge that might be filled by his reading the material, some unsolved problem, some missing element, or something that is incomplete or out of harmony. To resolve tension, the creative reader sees new relationships, creates new combinations, synthesizes relatively unrelated elements into coherent wholes; redefines or transforms certain pieces of information to discover new uses, and builds on to what he already knew. In this search, the creative reader produces a variety of alternate possibilities, uses a variety of approaches, looks at the information from different perspectives, breaks away from the obvious and commonplace solutions into new directions, and develops his idea by filling in the details and making the idea attractive and exciting to others.

If at this point I want to communicate something about the qualities of the creative products that resulted, I ask the group to discuss the qualities of their drawings. In addition to the divergent thinking qualities (fluency or number of products, flexibility or shifts in thinking, originality or uniqueness of the products, and elaboration or the amount of detail produced in making the drawing "tell a story," we talk about other characteristics of their drawings that illustrate creative behavior. Sometimes I ask, "Who joined two or more of the triangles to make an object or picture?" Then I ask, "Did the instructions tell you that you could join two or more triangles? Was there anything in the instructions that forbid you from joining two or more triangles?" This immediately identifies an important characteristic of the creative person, the ability to make use of the freedom that he has. The psychological set given by the instructions is to make a picture of each triangle and each of the incomplete figures. The ability to break away from such sets is important in creative thinking and a simple measure of this index derived from circles test proved to be one of the best predictors of adult creative achievement in my long-range predictive validity study (Torrance,1972) involving high school students tested in 1959 and followed up in 1971.

Sometimes I even give such groups a checklist of creative characteristics that can be observed in the test responses and which have analogues in creative behavior in a given discipline or in meeting the stresses of daily living. The following is such a checklist:

Abstractness of titles

Resistance to premature closure in incomplete figures

Expression of feelings and emotions

Articulateness in telling a story (giving the object an environment or context)

Movement of action (running, dancing, flying, falling, etc.)

Expressiveness of titles

Syntheses (joining two or more incomplete figures or two or more)

Unusual visual perspective (seen from above, below, etc.)

Internal visual perspective (inside, cross section, etc.)

Extending or creating new boundaries, penetrating triangles

Humor in titles, captions, and drawings

Richness of imagery (excitingness, earthiness, etc.).

The rationale, validity, scoring, and developmental characteristics of each of the above characteristics are described in the norms-technical manuals for the streamlined scoring of the figural forms of the Torrance Tests of Creative Thinking (Torrance and Ball, 1978).

In the course of discussing what happened in the process of responding to the Demonstrator Form, I ask them about their skills and motivations. Usually, someone will spontaneously say that they did not perform very well because they have no drawing ability. At this point, I must admit that, although it is not a test of drawing ability, having good skills in drawing makes it easier for them to express emotion, show things in unusual visual perspective, depict movement, and the like. This enables me to make the generalization that it helps to have the skills that are relevant to the problem calling for creative thinking. Similarly, someone will volunteer that they had not been motivated or warmed up to perform well. Again, this permits me to illustrate the importance of motivations and generalize about the role of motivation, commitment, and absorption in creative behavior.

Frequently, I try to summarize and synthesize these discussions by presenting and discussing the three-ring model of creative behavior shown in Figure 2. I use this diagram to help communicate and to some extent simplify the complexity of predicting creative behavior. It is important to communicate the idea that it is too much to expect tests of creative thinking ability to carry the entire burden of predicting creative behavior and identifying creative persons. The skills of creative problem solving and the special skills involved in the problem, as well as motivations, are essential for creative behavior and should be considered in prediction and identification.

When I want to communicate something of the importance of the press of environment and the idea of building into instructional plans or materials some of the facilitating conditions for creative behavior, I ask the group to take the Sounds and Images Test (Khatena and Torrance, 1973). This is a test of originality in producing word pictures or verbal images in response to recorded sound effects. It has built into it several research-based facilitating and motivating devices.

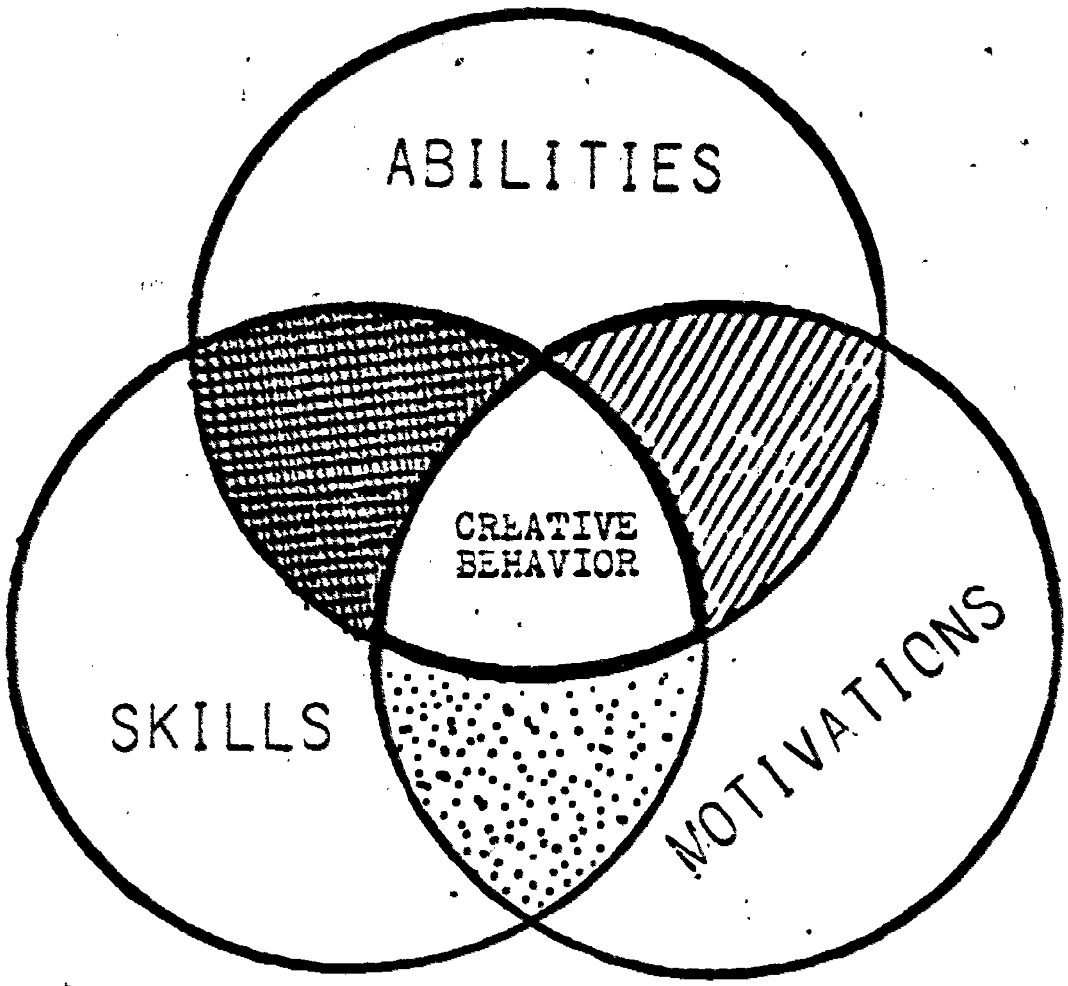


Figure 2.--Model for Predicting Creative Behavior.

The recording consists of four different sound effects, ranging from a coherent and easily recognized one, having few "missing elements," to a strange one made up of six relatively unrelated sounds. This set of four sound effects is presented with a slight pause between each with instructions to the listener to write down a word picture of the image generated by the sound effect. The sound effects are then repeated with instructions to let the imagination roam more widely and depart from the most obvious images. After this, the sound effects are repeated again with instructions to let the imagination swing free, soar. An attempt is made to free the group from threats of evaluation and to encourage it to "have fun." An attempt is also made to help respondents to break the "set" between each of the repetitions of the sound effects. Finally, the group is asked to select its favorite image or word picture and translate it into a drawing or story.

I then ask members of the group to describe what they had experienced, trying to identify what features of the environment (the recorded exercises, the situation, etc.) facilitated or inhibited their efforts to think of original images. They quickly identify such things as the warm-up processes, going from the familiar to the strange and from the easy to the difficult, the legitimacy of thinking divergently, freedom from the threat of evaluation, the open-endedness of the instructions, and the like.

To illustrate the importance of individual differences in thinking styles and the interaction of these differences with instruction, I identify the features that were deliberately built into the Sounds and Images recording and ask the members of the group to identify those forces within themselves which facilitated or inhibited their making use of these built-in features. This usually results in a list of personality factors (most of which have been found to be related to creative behavior), and, it is hoped, in an increased awareness of the group of their own creative functioning and an increased understanding of the forces in individual personalities which influence their creative functioning and those of their associates. Since the originality scores derived from Sounds and Images tend to be positively correlated with the right hemisphere style of thinking and negatively correlated with the left hemisphere style of thinking (Torrance, Reynolds, and Ball, 1978), it can be anticipated that characteristics listed as inhibiting will be associated with left hemisphere cerebral specialization and those listed as facilitating will be associated with the right hemisphere style.

A THREE-STAGE MODEL FOR TEACHING FOR CREATIVE THINKING

I began developing a three-stage model for teaching for creative thinking over twelve years ago when I was asked by a textbook publisher to serve as creativity consultant to the editors and authors of two of its programs--one in reading and the other in the social sciences. One of my responsibilities was to prepare materials that would guide the authors and editors in developing instructional materials, suggestions to teachers, and learning activities. Two types of materials seemed essential: (1) information about the hierarchy of creative skills so that they would be aware of the kinds of creative thinking skills that could be expected at the different educational levels for which they were writing the instructional materials, and (2) the kinds of learning activities that might facilitate creative thinking before, during, and after a lesson. This three-stage model seemed to me to reflect the natural way for bringing into play the creative thinking abilities. During the first stage, before the creative thinking abilities can be activated, something has to be done to heighten ancitipation and expectation and to prepare the learner for seeing clear connections between what he/she was expected to learn and his/her future career (the next minute or hour, the next day, the next year, or 20 years from now). After this arousal has been attained, it is then necessary to help the learner to dig into the problem, acquire more information, encounter the unexpected and continue deepening expectations. This is the second stage. Finally, in the third stage there must be practice in doing something with the new information, either at the time it is being acquired or afterwards.

The creative process as already described embodies the tension of anticipation or expectation. It has variously been described as the warming-up process; rising to the occasion; or attraction to the unknown, the strange, and the puzzling. The arousal of anticipation involves the elicitation of reactions to the information to be presented (in whatever manner--reading, lecture, demonstration, film, etc.) before, during, and after the presentation of the information. A major problem is to use this arousal to help the learner see fundamental relationships among the facts, ideas, and events that constitute the lesson and the past experiences, present problems, and images of the future of the learner.

Underlying Rationale for the Model

Before presenting examples of learning activities to implement each of the three stages, it is important to keep in mind some of the underlying assumptions that pervade the model.

There has long been a fairly general recognition that people prefer to learn creatively--by exploring, questioning, experimenting, manipulating, rearranging things, testing, and modifying ideas or solutions. Generally, however, education has insisted that people learn by authority --by being told. Teachers have maintained that it is more economical to teach by authority than to foster the more natural ways of learning.

I have taken the rather controversial position that many things can be learned more economically and effectively if they are learned in creative ways rather than by authority (Torrance, 1963, 1969, 1970). I have also maintained that some individuals have a strong preference for learning creatively, learn a great deal if allowed to use their creative thinking abilities and their creative ways of processing information to acquire knowledge and educational skills, and make little progress when teachers insist that they learn by authority. Such ideas have opened up exciting possibilities for doing a more effective job of individualizing instruction and for educating some children who do not respond favorably to the usual educational program. From new information already reviewed herein it seems that some of the students who do not respond to teaching by authority may be those who prefer a right hemisphere style of learning and thinking.

Most importantly, creative ways of learning have a built-in motivation for educational achievements that make unnecessary the application and reapplication of rewards and punishment. Even when rewards and punishment succeed temporarily in motivating learning, they may not supply the inner stimulation necessary for continued effort and achievement. Such motivation is usually short-lived and requires continuous reapplication to sustain effort on the part of the learner. The inner stimulation from creative learning makes this unnecessary.

To learn creatively, a person must first become aware of gaps in knowledge, disharmonies, or problems calling for new or better solutions. He must then search for information about the missing elements or difficulties, trying to identify the difficulty or gap in information. Next he must search for alternative solutions, making guesses or approximations, formulating hypotheses, thinking of possibilities, and predicting. Then comes the testing, modifying, retesting, and perfecting of the hypotheses or other creative products. Finally, there is the communication of the results and the interactions that this sets in motion. Strong human motivations are at work at each stage. Once such a process is set in motion, it is difficult to stop it.

People are inquisitive, exploring, searching kinds of beings. They are also self-acting and cannot keep their restless minds inactive even when there are no problems pressing for solution. They continue to find problems and cannot keep from digging into things, turning ideas over in their minds, trying out new combinations, searching for new relationships, and struggling for new relationships, and struggling for new insights—ahas and hahas. This comes from people's cognitive needs—their wanting to know and to encounter things more deeply. People's esthetic needs—their needs for beauty, balanced relationships, graceful and certain movements—are almost as relentless. Cognitive and esthetic needs are served by creative ways of learning which develop the motivations and skills for continued learning.

Any skill must be practiced to be developed and perfected and this applies to thinking skills as well. Thinking is a skill just like playing tennis, driving an automobile, playing the piano, dancing, bricklaying, and the like. Throughout my work with teachers in helping them to teach for creative thinking, I have always been interested to note their surprise to discover that some students who had hitherto seemed to be slow learners suddenly showed remarkable achievement. Edward de Bono (1976) has made a similar observation in connection with his work with teachers in England. He has reported that many of the teachers involved in teaching the CORT Thinking Lessons that he has developed have been surprised to find that some pupils who had previously seemed to be quite dull suddenly turned out to be quite effective thinkers. De Bono commented that these pupils surprise the teacher, their peers, and sometimes even themselves. He believes that this observation fits the experience that children who do well academically do not necessarily continue to do well in later life when thinking is required for success.

Stage 1: Heightening Anticipation

The fundamental purpose of the first stage of the model of instruction that I have proposed is to heighten anticipation and expectations and to prepare the learners to make clear connections between what they are expected to learn and something meaningful in their lives.

Essential to any creative behavior is the warm-up process. Warm-up is highly dependent upon the kind and degree of the novelty to be met. Consequently, whatever is done to heighten anticipation before presenting information should facilitate the warm-up process and this encourages creative behavior in responding to the information to be presented.

Moreno (1946), through his work with psychodrama, sociodrama, and role playing, has provided some very provocative ideas about the warm-up process in relation to creativity and spontaneity (Moreno,1946). He used the novelty of the situation as one feature of the warm-up. The plots, the persons, the objects in the situation, its time and space, and so forth are all novel to the actor entering the psychodramatic or sociodramatic situation. He deals with two kinds of self-starters: physical starters and mental starters. According to him, the infant makes use only of physical starters and thus physical starters continue to be the "rescue starters" in all warming-up processes throughout the life span. This perhaps is the reason that my students and I have consistently found that physical warm-up activities are especially helpful in facilitating creativity among young children, especially disadvantaged children (e.g., White,1976). Moreno points out that adults use physical starters in emergencies and when taken by surprise. This is one reason why creative movement and dance can be a good supplementary technique in almost any subject matter under the direction of an imaginative teacher (Joyce,1973). A background of experience in creative movement and dance also provides an excellent reservoir from which children can draw in mastering creative thinking skills. Through creative movement and dance children discover a great deal about their bodies, minds, language, thoughts, imagination, and ideas. They learn what their bodies can do, how they are put together, what strengths they have, and what energy. They become aware also of time, rhythm, tempo, space, direction, size, and level.

As a person matures, he acquires a variety of mental, social, and psychochemical starters. These may independently initiate a person's warming-up, or they may interact with physical starters. Even the infant is capable of a considerable degree of self-starting but some infants need more help than others. In psychodrama, Moreno used "auxiliary egos" (other actors playing supporting roles) to help the actor warm-up and to achieve higher levels of creative and constructive behavior and go beyond the rational processes. The co-action between the actor and the auxiliary ego or egos facilitates learning. In my work with sociodrama I have developed a number of production techniques and audience techniques for use in school situations and designed to facilitate warm-up (Torrance,1975).

Generally, the importance of warm-up in classroom learning has been neglected. It has been interesting to note the great importance that has been given to this stage of the creative teaching process by Suggestive-Accelerative Learning and Teaching and the methods of Georgi Lozanov, already described. It will be recalled that these methodologies rely upon relaxation and breathing exercises, music, and mind-calming exercises. Sociodrama or role playing is used in later stages for somewhat different purposes. I have developed a list of learning activities which I believe will achieve much the same purpose as Moreno's warm-up techniques and those of Lazanov and his adherents. Each of them has been described and illustrated in considerable detail in other sources (Torrance, 1969, 1970). However, the following list will communicate something of the nature of the learning activities required for implementing the first stage of the model I have proposed:

1. Confronting ambiguities and uncertainties.
2. Questioning to heighten expectation and anticipation.
3. Creating awareness of a problem to be solved, a possible future need, or a difficulty to be faced.
4. Building onto the learners' existing knowledge.
5. Heightening concern about a problem or future need.
6. Stimulating curiosity and desire to know.
7. Making the strange familiar or the familiar strange.
8. Freeing from inhibiting sets.
9. Looking at the same information from different viewpoints.
10. Provocative questioning to make the learner think of information in new ways.
11. Predicting from limited information.
12. Purposefulness of the lesson made clear, showing the connection between the expected learning and present problems or future career.
13. Only enough structure to give clues and direction.
14. Taking the next step beyond what is known.
15. Physical or bodily warm-up to the information to be presented.

In using activities of the kind listed above, the teacher must keep in mind the purpose of such experiences. In essence, they are:

-- to create the desire to know

-- to heighten anticipation and expectation

-- to get attention

-- to arouse curiosity

-- to tickle the imagination

-- to give purpose and motivation

Stage 2: Encountering the Expected and Unexpected and Deepening Expectations

For creative thinking, it is not enough to heighten anticipation. Warm-up is necessary, but it is not enough! The surprise of the unanticipated must be encountered! New information must be assimilated. Otherwise, previously learned responses are adequate and creative thinking is not required. As the lesson unfolds, the heightened anticipation must find fulfillment. The warm-up must be sustained. Heightened anticipation must turn into deepened expectations. I have found several different techniques for the creative processing of information to be facilitative during this stage. I know of no accepted names for them so I shall use analogies that seem appropriate to me.

The first creative processing technique is called *digging deeper*. Edward de Bono (1970) has used a somewhat similar analogy to describe vertical thinking. He has likened vertical thinking to digging a deep hole. In using the technique I have in mind, one may dig several holes and may dig some of them deeper. Essentially, however, an effort is made to get beyond the surface or cover and to find out what is glossed over or hidden. The mind diagnoses difficulties, integrates the information available, checks information against hunches, synthesizes diverse kinds of information, elaborates, and diverges.

I like to think of a second technique of creative information processing as being like *looking twice*. To really look twice at information, a person must defer judgment following the first look and keep open to new information and insights. There is a search for more information. Information is evaluated and re-evaluated. Children do this naturally and spontaneously. Frequently, they ask that a book be read a second or third time. For the first reading, they seem to want to go through the book speedily. During the second and/or third readings, they want to pause and ask questions, make new associations, make personal associations, and the like. To practice this technique with graduate students, I use a brief poem. I read it first, asking them simply to listen. Then I ask them to try to visualize what the poem describes. Next I ask them to move their fingers to interpret what is described. Finally I ask them to move creatively to what is described. I never cease to be amazed at the deepened understandings of the poem that result.

A third technique is termed *listening for smells*. Sometimes I feel that I do not really *know* something unless I have a feeling of congruence between two kinds of experiences. This technique may make use of any or all of the senses--moving, visualizing, imagining sounds, making sounds, smelling, feeling textures, and the like.

A fourth technique useful during this second stage is like *listening/talking to a cat* or *crossing out mistakes.* In using this technique, the learner must let the information presented "talk to him" and he must "talk to the information." In other words, there is a need for developing skills of reading one's own feelings in response to the information encountered. Mistakes will be made in "listening/talking with a cat" and in reading one's feedback about the information encountered, so there must be freedom to "cross out mistakes." Thus, this technique involves making guesses, checking, correcting, modifying, re-examining, discarding unpromising facts or solutions, refining, and making the best solutions better.

A fifth technique is like *cutting holes to see through.* This is accomplished through summarizing, getting the essence, simplifying, and discarding useless and erroneous information. This pattern is especially useful in targeting the problem to be considered or the solution to be implemented. There is always a problem of directing or focusing attention on the specific information that is to be the subject of the thinking.

A sixth technique is like *cutting corners.* This is done by avoiding useless and irrelevant information and making mental leaps to new insights, "solutions to the mystery or puzzle," and the like. Cutting corners is perhaps most useful in making the best solution better, deciding on the statement of the problem, or in determining a plan of implementation.

A seventh technique is like *getting in deep water.* This involves searching for unanswered questions, dealing with taboo topics, confronting the unimaginable, being overwhelmed by complexity, or becoming so deeply absorbed as to be unaware of surrounding events.

An eighth and similar technique is like *getting out of locked doors.* This involves solving the unsolvable, going beyond those "more and better of the same" solutions that make matters worse, and opening up new vistas, new worlds.

The following is a list of some of the kinds of learning activities that I have suggested for development of the creative information processing techniques described above:

1. Heightening awareness of problems and difficulties.

2. Accepting limitations constructively as a challenge rather than cynically, improvising with what is available.

3. Encouraging creative personality characteristics or predispositions.

4. Practicing the creative problem solving process in a disciplined systematic manner in dealing with the problem and information at hand.

5. Deliberately and systematically elaborating upon the information presented.

6. Presenting information as incomplete and having learners ask questions to fill gaps.

7. Juxtaposing apparently irrelevant elements.

8. Exploring and examining mysteries and trying to solve them.

9. Preserving open-endedness.

10. Making outcomes not completely predictable.

11. Predicting from limited information.

12. Search for honesty and realism.

13. Identifying and encouraging the acquisition of new skills for finding out information.

14. Heightening and deliberately using surprises.

15. Encouraging visualization.

Stage 3: Going Beyond and "Keeping It Going"

For creative thinking to occur and to continue to occur, there must be ample opportunity for one thing to lead to another and to do something with the information encountered. Therefore, it is inevitable that any genuine encouragement of creative thinking in schools must take students beyond the classroom, textbook, and the teacher. Ideas stimulated in a science class or any other part of the curriculum might motivate a student to consult other people, to delve into other kinds of literature or sources of information, to get out into the community, to conduct an original experiment, to write an essay or a poem, to paint an original picture, to solve a problem, or to engage in almost any other kind of investigative or creative behavior.

As in the case of the second stage, there are several techniques for the creative processing of information that I think are particularly useful in accomplishing the objectives of this third phase of the model, e.g., going beyond the lesson and keeping the learning and thinking processes working on the information presented.

The first of these information processing techniques is like *having a ball*. Schools, in my opinion, give too little attention to the fun uses of the mind--humor, laughter, and fantasy. This technique can also be used in the second stage to deepen expectations but it is probably even more useful in encouraging students to go beyond the textbook and to keep learning and thinking processes functioning. It is interesting to note that the *having a ball* technique is an established part of the Lozanov method as the final phase of a lesson. The final phase consists of educational fun and games to activate the materials learned during the earlier phases.

A second technique is like *singing in one's own key.* This involves giving the information personal meaning, relating personal experiences to the information, making associations to the information, seeing implications of the information for present problems or future career róles, using it to solve personal problems, and the like.

A third technique that facilitates the goals of the third stage of the model is like *building sand castles.* It consists of using the information as the basis for imagining, fantasying, searching for ideal solutions, or otherwise "taking off" from what is read, heard, or otherwise encountered.

A fourth technique that is especially useful in the third stage is like *plugging in the sun.* This may be interpreted either as "hard work" or as "plugging into" available sources of energy or inspiration. Creative thinking does take expensive energy but it may also be self-renewing and invigorating. This energy source may be new library resources, people resources, place resources, spiritual resources, or the like.

A final technique is like *shaking hands with tomorrow.* It consists of relating the information to one's projected future career; using the information to enlarge, enrich, and make more accurate one's images of the future; storing alternative solutions for possible future use; or using the information to propose a solution of a future problem. I am convinced that schools must begin to devote considerable time to doing things that will enlarge, enrich, and make more accurate images of the future. There is considerable evidence to indicate that a person's image of the future determines in a large measure what he is motivated to learn and do and that the images of the future held by today's young people will determine what the future will be like (Torrance, 1976, 1978).

The following is a list of some of the kinds of learning activities that seem to facilitate the achievement of the goals of the third stage of the model presented here:

1. Playing with ambiguities.
2. Deepening awareness of a problem, difficulty, or gap in information.
3. Acknowledging a pupil's unique potentiality.
4. Heightening concern about a problem.
5. Challenging a constructive response or solution.
6. Seeing a clear relationship between the new information and future careers.
7. Seeing a clear connection between the new information and future careers.
8. Accepting limitations creatively and constructively.
9. Digging still more deeply, going beneath the obvious and accepted.

10. Making divergent thinking legitimate.

11. Elaborating the information given.

12. Encouraging elegant solution, the solution of collision conflicts, unsolved mysteries.

13. Requiring experimentation.

14. Making the familiar strange or the strange familiar.

15. Examining fantasies to find solutions of real problems.

16. Encouraging future projections.

17. Entertaining improbabilities.

18. Creating humor and seeing the humorous in the information presented.

19. Encouraging deferred judgment and the use of some disciplined procedures of problem solving.

20. Relating information to information in another discipline.

21. Looking at the same information in different ways.

22. Encouraging the manipulation of ideas and/or objects.

23. Encouraging multiple hypotheses.

24. Confronting and examining paradoxes.

CONCLUSION

The development of the ten rational powers proposed by the Educational Policies Commission as the central purpose of American Education is a worthwhile goal. However, in the light of present-day information and the requirements of the future post industrial society, the ten rational powers are not enough. The ten rational powers must be complemented by processes that go beyond the rational powers and result in creative thinking and the solution of problems that cannot be solved by traditional logical thinking. Since the proposal of the Educational Policies Commission in 1961, there have been many important developments in this area and these should be considered in today's science education. The author has proposed a three-stage model of instruction which may be used as a guide in planning courses, planning lessons, developing instructional materials, and in making instruction more effective.

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A HUMANIST'S PERCEPTION OF THINKING AND CREATIVITY

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It is a pleasure to have an opportunity to address some comments to a group of natural scientists and science teachers. This is particularly true since I was a high school science teacher for six years and secondly because most of my audiences have been people from the Humanities and Social Sciences. It was surprising and refreshing to learn of your interest in including a Humanist's point of view in your yearbook. Therefore, I am approaching this subject enthusiastically with a hope of communicating some ideas about a Humanist's concepts of thinking and creativity.

WHAT IS A HUMANIST?

Perhaps you are curious about the Humanistic point of view, or more basically--What is a Humanist? That is, it may help our communications if I try to clarify my perception of where the Humanist is "coming from." You should know that this question has been the subject of many hours of discussion among Humanists and is answered unanimously by them only momentarily, if ever. Thus, the word Humanist is a generic rather than specific term, and it includes a broad range of people with different kinds of commitments.

The foregoing means that we can deal only in general trends or threads which constitute a type of matrix which holds Humanists together. This matrix is very elastic and has endured for a long time and it ebbs and flows in relation to its counter force, dehumanism. Their relationship has been one in which the growth of one promotes increase in the other and vice versa. For example, when Humanists perceive that some dehumanizing force is about to devastate the human race the Humanistic movement increases its activity to re-establish an equilibrium. One of the most recent examples of this synergistic-like effect occurred when the space race seemed to push our society toward a technocracy which many Humanists considered dehumanizing. As our society rose to meet the Space Age challenge and the dangers of "Big Brother" looked overwhelming, Humanists achieved some of their finest hours in writings, civil activism, and organization. When it appeared that the emerging technocracy was stopped the Humanistic movement receded in each of these areas. This also illustrates that, because of its reactive quality, Humanism tends to follow rather than precede changes in dehumanism. It seems that Humanists prefer to "do their own thing" rather than conquer others through offensive or aggressive tactics.

Humanists hold to their beliefs tenaciously and prefer to live their life style rather than proselytize for it. This accounts for their seeming passivity in many situations and why they nearly have been obliterated several times. On the other hand, their survival across many centuries may be one of the strongest testimonials to the efficacy of their guerrilla-like tactics. One of the great modern Humanists, Earl Kelley, said it this way, "As I travel across America, I find men and women of good will everywhere I go." As this shows, Humanism is a very pervasive force in our society and its headquarters are very difficult to locate. In most cases its "temples" are not imposing when compared to IBM or other corporate giants. Yet, it is safe to predict that Humanism will endure beyond these monuments to our modern society.

The previous statements add up to something like this. Humanism is a non-institutionalized way of life, and its proponents are volunteers who have a sense of commitment to it.

The next question is, What is the central tenet of Humanism? From all that is written and said, *the central theme appears to be that the personal experience of each human being is the most important thing about this world.* This may seem to differentiate Humanism from organized religion and even cast them in antagonistic roles. It is difficult to support this seeming dichotomy, and much more tenable to hold that some Humanists are atheistic, while others are religious or agnostic. They come from all persuasions and attitudes and coalesce periodically out of a common necessity to counteract dehumanism. When this task is accomplished they disperse into small groups and seem to disappear.

The primacy of human experience may not seem like much of a distinction to hold a group together, but its practical functioning is somewhat more important. By way of illustration we might examine how the Humanistic position would affect a person's vocational choice. A Humanist would be most interested in how a person experiences his work --what it does for him internally. Thus, it makes good sense to a Humanist when a graduate of the Harvard Law School decides to become a farmer, because he wants to understand and experience the growth process. Conversely, this kind of choice might seem weird to another person who felt that professional status was the most important thing in the world. This is not to say that every Humanist is selfish and concerned only with whether or not they feel "good." In fact, some choose to undertake a task which causes them to suffer a great deal for others. The salient point is that they seek to understand how their living processes make them feel. Humanists might say that the important thing about work is that it is meaningful. Others can hold that everyone wants their work to be meaningful, but the question is where personal meaning is located on their values hierarchy. If it is below things like money, prestige, power, etc., then those persons are not functional Humanists even though they may espouse a Humanistic position.

A logical extension of this valuing of personal experience is defending each person's right to pursue life within the limits of the well-being of society at large. There is a concern for both, but because of the overwhelming inertia of public opinion the Humanist is seen more frequently in the role of "defender of individual human rights" than of protector of society's mores. Of course this frequently results in a seeming iconoclastic posture, but as Earl Kelley said, "Most of the rights Humanists defend are as old as the U.S. Constitution."

As defenders of a person's rights to pursue his/her individual experience, Humanists are considered kind by minority groups and/or troubled people. The more they defend the rights of others the greater is the perception by others that they are kind. This becomes a problem when the Humanist defends his or her own rights. When this occurs they must frequently fight pretty hard to attain their goal and in this struggle they may not look compassionate. This leads their detractors to point out the seeming discrepancy between their advocacy of decency for others and their behavior when their own personal rights are infringed upon. An illustration seems helpful in communicating this point.

I once ran a series of quasi-therapy sessions for a group of dorm mothers at a large university. They were quite defensive about their interpersonal functioning which everyone else wanted to improve. As the sessions progressed one of the members continued to insult me and the entire training program. I responded as empathically as I could for several weeks. Finally this lady tried to break up the whole group by suggesting it was worthless. The group discussed her view and decided to continue the training. After the discussion I suggested to the dissenter that she might want to leave the group since it was unprofitable to her. She said that she guessed she would stay. To my surprise, the next day I was called to the office of the director of housing and told that this same lady had told him of my statement that she might want to leave. He said that this constituted cruel and inhumane treatment and that he was disbanding the group. He never asked about the context of that remark, but he did tell me that he did not understand how a Humanist could pick on a sweet little lady like her. This incident is not unusual. It is just turning a person's virtue back upon them. It happens when a parent or teacher tells a child, "I do not see how a nice little boy (girl) like you could say something like that."

In the preceding I have tried to present some of the characteristics of Humanists by various examples and explanations which explored the Humanistic frame of reference. This seemed necessary, because it probably is somewhat different from that of most of you who are the primary audience for this yearbook. It did not seem sufficient to define a Humanistic position in short terminology which simply does not explain it adequately. Again, I would hold that Humanism is a way of life whose major tenets are (a) respect for personal experience and meaning, (b) conflict with dehumanizing forces, and (c) humane treatment of all people. These are not all of the threads in the fabric of Humanism, but they are some of the main ones.

The reader must remember that the remainder of this writing comes through the lens of Humanism as herein defined. It will be easier for you to understand the processes set forth in this writing if you can enter the Humanist's way of seeing the world. Lastly, by the nature of the Humanist philosophy it is impossible for me to speak for all Humanists. No one does that. Therefore, this writing is the thinking of one Humanist who has spent a lot of time with others who call themselves Humanists. To the degree that I have integrated the thinking of other Humanists it represents an extended view of Humanism.

THINKING

Thinking is only one of the multitude of cognitive activities a human being can do. He can smell, feel, taste, hear, and see himself and the world around him. After receiving sensory inputs he can do many things with them. He can enjoy them for their own quality, as when the wind blows lightly on the face. He can wonder what causes the events which are registered by his senses. He can explore new ways to use those events to alter his world. All of these and other possibilities are equally valid ways of responding and using one's sensory input. Some are initiative upon the world while others are receptive to it, but each of them is a legitimate, human activity. In fact, to do nothing with them is also acceptable, because there are times when it is good to just do nothing--to just let the entire body relax and not feel compelled to do anything. As the kids say, "Just hang loose."

On the other hand, there are times when the information received by our sensory input creates questions that our total being yearns to answer. These are consuming questions that demand the full attention of all the senses including the areas of our mind which combine and/or search the new information as well as our stored data to produce an answer to the puzzle. During this procedure the mind employs a variety of processes which may organize and reorganize the information many times until an acceptable answer is found. From a Humanist's point of view this type of thinking is exciting and meaningful because it grows from questions which arise within the person. In this sense they might be called significant questions.

In contrast to the foregoing type of question and cognitive process a person may receive sensory input to which others demand an answer which does not interest the person himself. When this happens there is usually a loss of cognitive efficiency because the problem or question is not real to that person. It is as if the question exists in a world detached from the individual's experience. It might be that, for most of us, completing our income tax forms is such a non-meaningful problem. It has to be done, but it is non-significant and not a source of much learning. In fact, there is extensive evidence to indicate that this is an aversive activity which most people avoid until the last minute. Thus, we can see that answering a lot of non-meaningful questions can create so much aversive conditioning that when thinking is forced upon a person it becomes a painful process we avoid.

For Humanists, questions exist along a continuum whose extremes are meaningful and non-meaningful. This continuum fluctuates in that a question which is somewhat meaningful at a given point in time may become irrelevant at another and vice-versa. Another thing we know about thinking is that it is possible to control a person's attention through a variety of techniques such as selective reward or punishment and this is one of the procedures used in human engineering projects. Generally, this is what you do when it seem necessary to create a particular type of mental activity. It may occur in times of national crisis or similar events. It may also happen when some enterprise decides to direct the attention of its workers toward a particular problem. In other words, it is possible to direct the focus of a person's thinking processes toward a particular problem. Whether or not it is possible to control meaningful problem-solving has yet to be answered.

The overriding issue for Humanists is that of personal meaning and the notion of directing another person's attention to a problem which, if non-meaningful to them, is anathema. This appears to make sense from two points of view: (a) individual freedom, and (b) efficiency. The first of these seems self evident. That is, except in emergencies which endanger the very fabric of mankind, it is contradictory to advocate both individual freedom and thought control of any type. For the second factor, efficiency, we know that people retain more learning when it is meaningful and that human beings tend to do pleasant tasks more frequently than unpleasant ones. Therefore, if we desire a thinking public, we must create a climate which makes it a pleasant process. Conversely, we must eliminate aversive conditions associated with thinking. Specifically, if we want more thinking we must increase opportunities for meaningful thought and decrease situations which necessitate answers to non-meaningful questions. In summary, it seems that thinking about personally meaningful questions is a pleasant experience, and thus increases the probability it will occur in the behavior of those who are allowed to think about questions of this type.

Humanists concentrate more on the meaningfulness of questions than on the efficiency of learning. However, a wide range of research supports the long-term efficiency of thinking about meaningful questions. Therefore, the Humanist position on thinking is strongly supported by findings about both personal enjoyment and learning efficiency. *The Humanist believes that external manipulation of human thinking is, by and large, a luxury which a democratic society can ill afford, because democracy needs an informed and thinking electorate.*

THE THINKING PROCESS

There are very few differences between the way Humanists and Non-Humanists would describe the thinking process. Many theoreticians would agree with the position enumerated by Bloom (1965) and the cognitive processes he enumerates are probably as satisfactory as any. Some classification systems are more complex and few are simpler, but Bloom's formulations are at least functional from a research point of view. Generally the term thinking describes one of many processes in which a person does something internally to answer a problem or to do something with data beyond storing and retrieving it. Wertheimer's work relating to thinking and creativity is superb as is that of Guilford, Ausubel, Piaget, and Bruner. It seems that each of them explains a piece of the complexity of the thinking processes, but most Humanists believe we are not currently at a level of sophistication which fully explicates it.

There is still room for a holistic approach to the topic, and this is the strength of the Humanists. That is, they still deal primarily with the Gestalt of thinking and those factors which affect it. Thus, to a large degree Humanists have considered the results of detailed research by those in other schools of thought rather than doing their own. It might be appropriate to state that most Humanists seem unconcerned with the "nitty-gritty" elements of thinking. Their contribution is to investigations of the generic aspects of the process, and in this area they have done some rather significant research.

One of the leading Humanistic Psychologists, Carl Rogers, proposed a conceptual framework of the learning process (Rogers, 1961), and many workers have used his formulations to develop and research human learning (e.g., Truax and Carkhuff, 1967). Rogers held that all human learning is facilitated or retarded by the levels of Empathy (understanding), Congruence (genuineness), and Positive Regard (valuing) providing by another person. He began his work in studies of psychotherapeutic relationships and later extended it into education. The research of Rogers, Gendlin, Kiesler, and Truax (1967), Carkhuff (1971), Roebuck and Aspy (1975), supported his hypothesis in psychotherapy by finding that patients who received high levels of Empathy (E), Congruence (C), and Positive Regard (PR) improved while those who received low levels of the same conditions deteriorated (Carkhuff and Berenson, 1967).

The extension of Roger's formulation of human learning into Education has been led by the work of the National Consortium for Humanizing Education (NCHE). The NCHE used the same type of technology as that employed for the work in psychotherapy. This technology consisted of (a) audio tape recordings of normal classroom teaching; (b) rating scales for 5-levels of E, C, and PR; and (c) trained raters who applied the rating scales to the audio tapes reliably (consistently). Using these technologies the NCHE collected samples of classroom teaching from 25 states and seven foreign countries and rated each sample for its levels of E, C, and PR. After rating each of the teaching samples the NCHE obtained student performance indexes, i.e., course grades, achievement test scores, etc., and related them to the levels of E, C, and PR provided by the classroom teacher (Aspy and Roebuck, 1977). The findings of these studies supported Rogers' thesis that there is a positive relationship between (a) students' cognitive growth as measured by standardized achievement tests and (b) the teacher's levels of E, C, and PR. The student's gains on achievement tests were measured by pre- and post-testing across one academic year. Similar results were found in a study of IQ changes among first grade students (Aspy, 1972).

The findings strongly support the general contention that students' gains in performance for standardized tests of cognitive growth are enhanced by classroom teaching which is characterized by high levels of E, C, and PR. Conversely, positive changes in students' performances on standardized tests are retarded when low levels of E, C, and PR are provided by the classroom teacher.

This series of studies was expanded to include secondary and undergraduate college students and again, the positive relationship between (a) the teacher's levels of E, C, and PR and (b) students' gains on test performance was substantiated (Aspy, 1972). Additional studies are being completed in medical schools and in-service training of teachers, nurses, and physicians. The preliminary results suggest a similar relationship between teachers' E, C, and PR and their students' cognitive processes in the classroom.

These studies were completed for all grade levels from first grade through undergraduate education and employed the same technology as the previous studies to obtain the teachers' levels of E, C, and PR. The student outcome, cognitive process, was obtained by trained raters who applied Bloom's Taxonomy of Educational Objectives to the audio recordings of classroom teaching. Bloom's Taxonomy of Educational Objectives divides cognitive activity into six categories listed below:

1. Knowledge
2. Comprehension
3. Application
4. Analysis
5. Synthesis
6. Evaluation

These categories have been used by Metfessel, Michael and Kirsner (1969) to create a scale which can be ~~used for~~ observations of classroom teaching. The NCHE raters were trained to record the level of *cognitive process* occurring in a given classroom every three seconds. This procedure allowed the NCHE to study the relationship between the teachers' levels of E, C, and PR and the students' cognitive processes. The results indicated a positive relationship between the two quantities and an especially strong correlation (.85) between (a) the teachers' level of PR and (b) the students' use of cognitive processes beyond memory or recall of facts (Aspy, 1972). It seems that thinking or problem solving in a classroom is a risk and the teacher must communicate a clear-cut positive regard for the student before he will attempt to use a cognitive process whose outcome is uncertain. Apparently, thinking by students in a classroom is promoted when the teacher creates an atmosphere of acceptance regardless of the student's success or failure in his attempts.

Further analyses of the NCHE data indicated that classroom teachers' levels of E, C, and PR are related positively to many non-cognitive student outcomes, i.e., attendance, discipline problems, self concept, attitudes about school (Aspy and Roebuck, 1975), etc. This seems to lend credence to the Humanist position that cognitive processes are related to holistic measures of the organism's levels of functioning. Thus, *thinking and creativity are promoted by a generalized climate which facilitates physical and emotional aspects of the person's well being.*

To explore the concept of holistic functioning as opposed to atomistic measures, the NCHE conducted a few small studies which related physical and emotional indexes to intellectual performance. The results consistently indicated a positive relationship between physical, emotional, and intellectual functioning. Since the technology for these studies is literally burgeoning, it may be helpful to describe some of the procedures used by the NCHE in its investigations. In a study of classroom teachers' levels of physical functioning and their interpersonal conditions (E, C, and PR) offered to their students, the NCHE used a physiograph to measure the teacher's heart rate while she was teaching. The physiograph was placed outside the room which had a one-way mirror and a sound system. The heart rate was transmitted by telemetry to the physiograph and the rater made assessments of the teacher's levels of Empathy while observing through the one-way mirror. Thus, the measures of the teacher's heart rate and levels of Empathy were made simultaneously. Analyses of the data indicated that as time was extended, the levels of Empathy provided by the teachers with high (120 bpm) heart rates tended to diminish. The opposite was true for teachers with low (70-90 bpm) heart rates (Buhler and Aspy, 1975). Since previous studies revealed that high levels of interpersonal conditions were necessary for student thinking and problem solving, the data relating heart rates and Empathy led to an inference that teachers' levels of physical fitness influenced students' cognitive processes. This would seem to be true particularly across long periods of time, because it is difficult to sustain high levels of interpersonal conditions in a state of physical fatigue. The larger studies (N = 5,000 students) by the NCHE provided evidence to support the contention that interpersonal conditions decrease with physical fatigue when it was found that, in general, teachers' levels of E, C, and PR diminish as the school year progresses (Aspy and Roebuck, 1975).

Studies of the relationships between cognitive, emotional, and physical functioning indicate that there is good reason to believe these three areas are related strongly and positively. This is consistent with the Humanistic position which is based upon the premise that a person's functioning is enhanced by an environment which helps him integrate his own being. The emphasis should be upon "*helps him integrate*" because Humanists tend to have widespread agreement that personal integration is a natural process and does not need to be taught. It needs only facilitation.

Perhaps the Humanistic position on thinking and creativity can be summarized in the following list of things which facilitate those processes.

1. Keep the person physically healthy.

2. Nurture the person's exploration of his/her environment.

3. Nurture the person's exploration of his/her own being.

4. Respond empathically and caringly to the person's attempts to solve his/her problems.

5. Understand that thinking and creativity may use either systematic or intuitive processes. It is not always logical to the other person.

6. Understand that thinking and creativity are ways of responding to a person's world. They are not the only or necessarily the best ways of behaving.

7. Help the person enjoy his/her thinking and creativity. These are part of the *fun* of being alive.

8. Help the person use his/her thinking and creativity constructively. These are parts of the *responsibility* of being a human being.

9. Recognize the conditions which facilitate the person's thinking and creativity and try to include them in the person's life experiences.

10. Let the person's thinking and creativity run their own courses. Do not try to force or control them.

THEORY

Most Humanists are atheoretical in their explanations of human behavior. This is true because they find theories limiting rather than freeing. Their experience has been that once persons become locked into a theoretical framework, they tend to try to fit events into it rather than remaining open to the data. They have found this true in every field of endeavor and are trying to avoid that trap by using theories when they facilitate communication but discarding them when they impinge upon the possibilities of mankind. For example, in the field of psychology many professionals are "hide-bound" theorists and spend much effort in making their clients' experiences fit their conceptual framework. Some psychologists are very comfortable when they can place their clients in some nosological (diagnostic) slot or category and they function as diagnosticians. The problem is that there was little correlation between diagnosis and cure. Some other people entered the helping relationship with their clients and dealt with the behavioral problems as they existed. If they found a client who was debilitated by a fear of something (such as cars), they helped the client to not be frightened by them. They did not employ nosological terms and in many instances helped their clients improve. The problem was that many of those who developed this new approach became dyed-in-the-wool advocates of it, and, then, they stopped growing. This is true of investigations of Space, Art, Energy, etc. The investigators who are fixated in one way of looking at a question become stumbling blocks rather than stepping stones at some point. Thus, Humanists are generally atheoretical because *they believe that human potential is so vast that its many possibilities supercede our theories.*

After having said that Humanists are generally atheoretical it is necessary to explain one of their ways of explaining human behavior. First of all they view each human being as a unique self, because each of us has had some experiences no one else has had. Certainly, there are some similarities among all people, but a great source of our diversity stems from our experiential worlds. The logical extension of this tenet is that each of us literally builds a unique experiential self through our growth processes. That is, the combination or totality of experiences of one person are never replicated exactly by any other human being. Therefore, the Gestalt of each of our experiential worlds is unique. This leads to lots of realities about people. We perceive the world, ourselves, and the events around us somewhat uniquely or idiosyncratically. Without question we can have a great deal of consensus about some things like the grass being green or trees being plants, but beyond this level of content we are hard pushed to build consensus. We are forced to deal with different conclusions drawn from our various apperceptive masses or experiential worlds. This causes much difficulty in our world, because we find that it creates different realities. Some cultures try to maintain order and control over these variations while others try to orchestrate it into a functional democracy and tend to turn toward procedures and demogogues who possess the "true" path. Humanists try to avoid controlling the thought patterns of others and strive to increase their understanding of mankind's differing experiential worlds. In this manner they find joy and excitement in the variety of ways the world can be seen and the different life styles which can evolve from this condition. They hope to encourage the variations within and between men inside the parameters of kindness and respect for individual experience.

In the foregoing we can see that the Humanist holds that people are capable of becoming different both within themselves and between each other. This has produced a diversity which necessitates skilled interpersonal functioning to understand the variety of products which flow from this type of existence. *In this situation something which is "provable or replicable" under a given set of conditions is not the only thing that is known by mankind.* We know many things which never exist under replicable conditions and they certainly enter our thinking processes. For example, a person may feel absolutely thrilled by the birth of a child or by a sunset and these experiences may change their whole way of looking at the world. Yet, those experiences are not replicable, because the conditions cannot be recreated.

The Humanist does not deny the existence of information which can be obtained only under controlled conditions. Indeed, they do not question the profitability of such data. On the other hand, they place primacy upon such questions as (a) was the pursuit of that information meaningful to you and (b) will that information make this a kinder, more facilitative world for people to live and grow? Thus, their hierarchy of values states that human experience is more important than the advancement of a theoretical position. In this way Humanists are free to use theories or other systematic processes when they help clarify human experience but are not compelled to either use or develop them. Humanists appreciate theories and the diversity they develop. They do not get "hung-up" with them.

THE CONTRIBUTIONS OF A HUMANISTIC ATMOSPHERE TO THINKING AND CREATIVITY

What is the Humanistic view of the contribution of a humane climate to thinking and creativity? The answer is that a Humanist believes that thinking and creativity are natural, adaptive processes which are facilitated by a climate which reduces anxiety and risk and rewards freedom of thought. They reject the notion that people must be coerced or forced to think and be creative. Since these are natural processes for most people the major problems are (a) how not to interfere with their emergence, and (b) how to facilitate their growth. By the way, there is substantial evidence to indicate that the brain is working continuously. It may be that it is resting when it produces Alpha waves, but it is also tenable to hold that even then it is doing something. Apparently only physical death stops mental activity.

There are also elaborate data about problem solving in most of our personal experiences. For example, many of us have produced the answer to a long-standing problem while our conscious mind was apparently focused on something else. For example, we may be driving along and suddenly from "nowhere" comes an answer about a problem we thought was forgotten at least for the moment. Perhaps it is necessary to add that people are not always thinking about the things we want, and the Humanist position is that this is desirable.

Another aspect of a Humanistic view of thinking and creativity is that they depend on all the individual's processes and are done most effectively when the person is in harmony with himself. This does not mean that they require a state of perpetual ecstasy but rather that thinking and creativity proceed most effectively when the person is not being forced into a situation which creates threat to their general well-being. This can be observed in schools where children are forced to do tasks beyond their ability and/or readiness. In many of these situations the students are striving for self survival and a great many symptoms interfere with their thinking and creativity. At these times they do not see, hear, taste, smell, or feel much of the available data and obviously their conclusions and their processes are errant. They seem to behave stupidly when in reality they are reacting as anyone would when they are not getting much of the important information required for effective behavior. This does not mean that it requires a state of panic to interfere with thinking and creativity. They can be diminished greatly by seemingly minor events. This is especially true for the sensitive or highly aware person.

The preceding may seem overdrawn but studies at the University of Chicago demonstrate that the pupil of the eye shrinks when the person sees an aversive stimulus. This can be interpreted as the organism's getting ready for action, but when it is accompanied by a tight stomach, shaky hands, and other bodily signs of anxiety it diminishes thinking and creativity. Certainly, one can contend that a little tension is necessary for thinking and creativity, but the preponderance of data simply does not support that either or both of these processes is facilitated by threat and/or anxiety. This is particularly true for a long-range examination of people who do a lot of creative thinking. The learning principle which seems to account for this condition is called retroactive inhibition. In this process all the little and big negative experiences a person has had in a given activity begin to add up. The result is an inability to perform the act. It is what we call being burned out. We simply cannot perform the way we used to, because all the pain of the former experiences culminates into a blocking mechanism. Thus, it is for thinking and creativity. A person who thinks creatively for a life time has either (a) a high threshhold for pain or (b) a relative absence of painful experiences with thinking creatively. Humanists understand they cannot control the former, so they try to optimize the latter.

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TEACHING FOR THINKING AND CREATIVITY: THE RADICAL BEHAVIORIST'S VIEW

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> If we train our children to take orders, to do things simply because they are told to, and fail to give them confidence to act and think for themselves, we are putting an almost insurmountable obstacle in the way of overcoming the present defects of our system and of establishing the truth of democratic ideals. Our State is founded on freedom, but when we train the State of to-morrow, we allow it just as little freedom as possible. Children in school must be allowed freedom so that they will know that its use means when they become the controlling body, and they must be allowed to develop active qualities of initiative, independence, and resourcefulness, before the abuses and failures of democracy will disappear. (Dewey and Dewey, 1915, p. 304).

The viewpoint presented in this chapter is that of the science of behavior known as "Radical Behaviorism" which has its origin in operant psychology. Like any science, the aim of Radical Behaviorism is to find order, so that we can describe, predict, and, ultimately, improve behavior. The dependent variable in our science is behavior, including both actions of people which are easy to see and measure (such as writing answers to problems), and behavior which only the behaver is aware of, such as rational thinking, or feeling angry. The independent variables, or roughly speaking, the "causes" of behavior, lie in two places, first, our genetic endowment, and second, our environment--everything we experience and have experienced since birth. Since our genetic endowment is fixed, those of us who teach must concentrate on environmental influences.

Behavior does not occur in a vacuum, it acts upon the world and changes part of that world. How we affect our world determines how we will behave in the future. To see the functional relationships between behavior and environmental factors, we must look at how behavior changes the stimuli present in the behaver's environment, and this requires a three-term analysis (see Figure 1).

While in a diagram the three parts look distinct and static, in reality there is a continual flow of change and interaction. Consider walking across a room, for example. Each step, in fact each part of a step, slightly changes the stimuli which make up the walker's environment,

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and the new tactile and visual stimuli affect the way in which the walker will take his next step. The process is smooth and continuous. In analyzing walking, and what produces effective walking, we need to look not only at the topography of the behavior (what it looks like) but also at how each movement affects the environment and how it, in turn, affects the probability of future behavior. We must consider what are called the *contingencies of reinforcement*, that is, the relationships between a behavior of interest and those conditions in the environment which have control over it, both antecedent and consequent events.

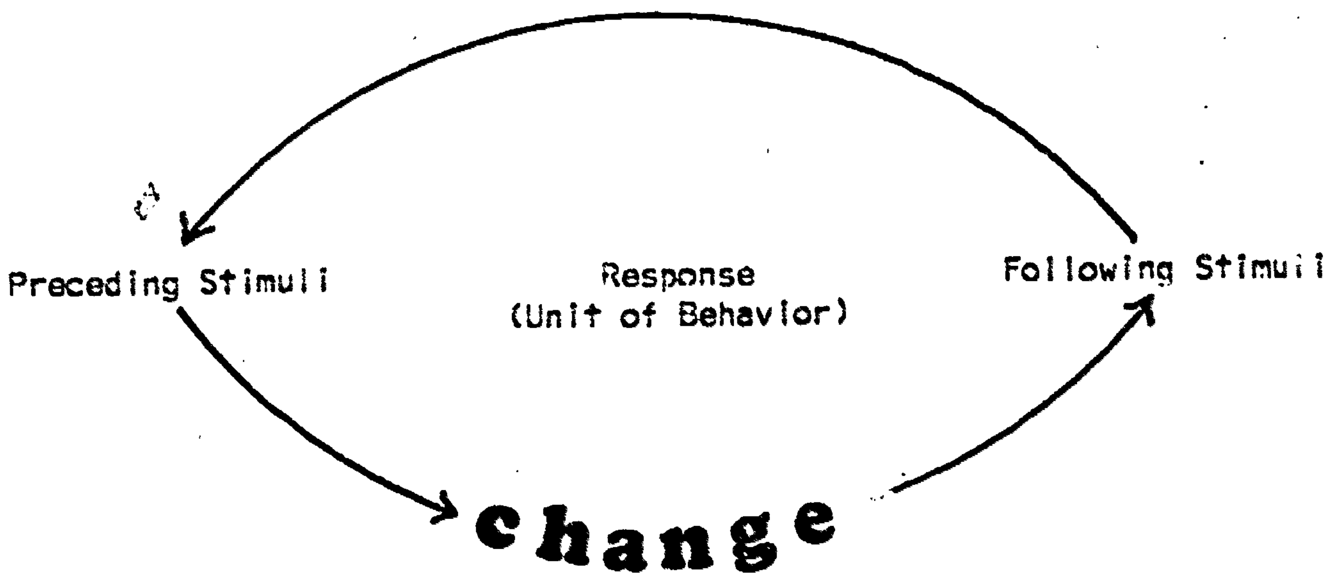

Figure 1. The three-term analysis of behavior.

In learning to walk, for example, nature provides contingencies which shape effective behavior. If a child places a foot correctly, he succeeds in moving forward. If he doesn't pay attention to an object in front of him, he bumps into it. Immediate and consistent consequences follow each miniscule movement. With such effective contingencies, almost every person not physically impaired, learns to walk effectively.

The contingencies for a variety of other behaviors, however, do not occur so directly. Nature does not provide continuous reinforcement for such basic behaviors as reading, writing, or doing arithmetic, nor for the kinds of social behaviors we hope that our young will learn. This is not to say that there aren't natural consequences for behaving well--there are--but rather that we may need to add consequences during the learning stages of new behavior. There is no way, for example, that a youngster could pick up a book in a foreign language and learn to read simply by trying to pronounce each symbol. One role of a teacher, then, is to supply the contingencies for behavior which nature alone does not provide. To do this you must be aware of precisely what behavior is needed and secondly of the contingencies which will bring it about.

Beware of Form Substituting for Function

A person may work at a homework assignment because of an immediate threat of punishment if he or she doesn't. The old stereotype schoolmaster, rod in hand, provided a strong immediate reason for studying. We do not credit such a teacher, however, with teaching *well* even when the student improves in performance. Although the form of the behavior is desirable (that is, the student studies), the functional control depends too much on the teacher's presence. *What* students do in other words, isn't all of the story: We must consider *why* they do it. Students who share may be benefitting others, but we are not satisfied with their generosity if they do so only under the watchful eye of a teacher. Good citizenship may be represented in part by voting, but "voting" doesn't represent good citizenship when the voter marks a ballot for a promised bottle of beer. Those of us who teach are sensitive to this difference in control when we wish students would pursue a subject on their own, not only when it "counts towards a grade." The source of control over a student is as much a part of the goals of American education as the form of their behavior.

Years ago people attributed motion to a *vis viva* because they could not readily identify the variables controlling motion. Today we have exorcised the spirits in the physical sciences, but we still struggle with little homunculi in the behavioral sciences (Skinner, 1971). We still talk of self-control or of motivation as though an internal "self" activates behavior. We speak of creativity as though it were an essence that one possesses in some quantity. We speak of the mind, or the "rational powers of the mind" as though there were a location inside us from which responsible behavior springs. Such formulations ignore the role of the environment in producing and maintaining behavior, pushing some causes into an inaccessible region, and fail to look at contingencies of reinforcement which, though often difficult to pinpoint, actually are responsible for what we do and why we do it. Let us look at some examples of general goals of education.

"Freedom of the Mind"

In a booklet called The Central Purpose of American Education (1961) the Educational Policies Commission recommends as an overall goal for American Education the development of "freedom of the mind." What, behaviorally speaking, is freedom of the mind? What hampers "the mind" to prevent its being free? The answer to the latter question is not easy to find in the document, but on page 8, one finds the statement, "The free individual . . . can escape captivity to his emotions and irrational states." It seems that the enemy of "freedom of the mind" is tyranny by the body.

The mind-body distinction as a framework for explaining behavior has a long history. It can be traced back at least as far as Socrates who was, perhaps, an early behavior analyst in that he was concerned with why we behave the way we do. Since we have only what Plato wrote of him, and, for non-Greek speaking people, only in translation at that, it is difficult to pinpoint the distinction he was drawing. It is reasonable to suggest that he was distinguishing between the kinds of contingencies under which people behave, rather than between locations of controlling centers within our bodies. "Body" refers to the immediately reinforcing effects of food, water, sex, etc., while "mind"--the rational being--could be an attempt to explain behavior which has no easily observed consequences, but which benefits the individual or society in the long run. The "mind-body" dualism, then, describes the distinction between control by immediate conspicuous consequences and control which leads to positive deferred consequences.

Take health, for example. One nation has the technology to produce food for maximum individual health, but so many people are controlled by the immediate pleasures of eating certain foods that we have what could be called an epidemic of obesity, heart disease, and a host of other ills. If the schools are to help students "escape captivity to emotions and irrational states" we need to make students more responsive to the long-term effects of what they eat, "freeing" them from excessive control by sugar, salt, and other detrimental substances. Thus, the struggle to develop "freedom of the mind" is a struggle to free individuals from control by immediate consequences and lead them to behave in ways which take the future into account.

The person exercising self-control has, because of past experience, learned to respond to a variety of subtle stimuli in the past or immediate past which are related to future effects. In refusing a coveted donut, for example, we respond to a variety of subtle stimuli (among which may be such diverse factors as social approval, the current state of our complexion, past admonitions about the dire effects of sugar and fats, yesterday's boast about will power, and so on). In strengthening the power of stimuli related to deferred consequences, we break the control by the single stimulus of the donut.

Civic Responsibility

If we extend our analysis to include the effects of one person's behavior upon the fortunes of others, we can put goals into the two-by-two matrix shown in Figure 2. The long-range effects on others (cell 4) is a part of goals such as "effective citizenship" or "civic responsibility" stressed by the Education Commissions of 1918 and 1935 (NEA Educational Policies Commission, 1961). Human relations goals include conflict between immediate or deferred consequences for oneself (cells 1 and 2) and immediate and deferred consequences for others (cells 3 and 4). To teach someone to be kind and generous, for instance, we must decrease the control over them by conspicuous immediate contingencies or long-range payoffs to themselves (such as having all of something for oneself) and increase the control by contingencies such as seeing others have something too.

		Timing of Consequences	
		Immediate	Deferred
Who Benefits:	Oneself	1	2
	Others	3	4

Figure 2. Gross contingencies of reinforcement for some of the major goals we talk about in education.

Problem Solving

When we cannot immediately solve a problem, we can change our environment or we can add stimuli to it in order to make the problem solving response more probable. We may, for example, take a break and do something different hoping that with the new stimuli a solution will suddenly occur to us. We may discuss the problem with someone or go back and write out our steps so far. Or we may go for a walk and "think" about the problem. Such thinking produces stimuli which may prompt a solution. In any case, we must respond not only to the original stimulus presented by the problem, but to a variety of stimuli, some of which we generate ourselves in the problem-solving process.

Creativity

Creativity, like rational behavior or "self-control" describes not only a form of behavior, but also a certain kind of functional control. Sloan, Della-Piana, and Endo (1976) analyze creativity from a behavioral view. They point out that we cannot judge a work as creative simply by examining the product itself:

> Suppose that two children in different classes both drew identical houses. Let us further assume that we had the means to determine the variables controlling each construction. In one case, suppose we determined that the variables controlling the drawing were analogous to echoic, let us call

them photographic or imitative--the child has seen a similar picture in a book and reproduced it. Let us suppose that we discovered that the second child's drawing was controlled by a prior social studies lesson. In the lesson, the adjustment of men to their physical environment had been discussed, and the second child drew a house controlled by these variables, open walls to let air circulate, and moisture evaporate, raised floor to avoid flooding and insects, locally available materials due to convenience and economy, none of which was explicitly taught in the lesson. Although the two products drawn were identical, the controlling variables were quite different. One was drawn under the formal control which we called photographic, the other was under much less formal control which transposed sensory modalities in a number of ways--it was a visual product under control of basically non-visual variables. Our interest is behavior, and if we look at the two behaviors, rather than the products, I feel we would label one as creative and the other as non-creative (p. 6).

The creative behavior was responsive to broad and multiple sources of control not seen by looking at the product or even by watching the behavior itself.

Summary of Goals

If we are to use the science of behavior to more effectively help students learn to behave for their own long-term benefit and for that of society as a whole, we must look not only at the form of behavior but also at contingencies of reinforcement. In any subject matter, part of education is increasing the range and power of stimuli and environmental changes which are related to future benefits. "Thinking creatively" in its broadest sense means responding to a variety of stimuli, especially those related to future benefits. We seek a balance of power in the stimuli controlling ourselves and our students that parallels the balance of power in democracy itself, which gives up the immediate efficiency of dictatorship for the long-term good of individuals and society as a whole.

LEARNING FROM RULES AND NATURAL CONTINGENCIES

A rule is a special kind of antecedent condition that is often considered as a distinct category from other contingencies. According to Webster's New Collegiate Dictionary, the word *rule* is derived from the Latin *regula* (straightedge, rule) and *regere* (to lead straight). The first definition listed describes a rule as a prescribed guide for conduct or action. The linear property of rules that is shown in the derivation of the word is also brought out in expressions like "toe the line" or "walk the line" to describe close compliance with rules.

Constructing stimuli to guide behavior has had a long and central role in the evolution of our culture. This may well have been an outgrowth of the need to follow the tracks and traces left by prey and predators as well as by other member of the community. Retracing a path, marking a path, or blazing a trail no doubt increased the likelihood of the survival of a culture. Visual guides would help those who were inexperienced to cope in unfamiliar terrain. Marking a path or leaving a trail is a recurrent theme, from Theseus' unwinding of Ariadne's ball of thread as he entered the labyrinth, to Hansel and Gretel's trail of crumbs. Even today we take along a road map for a trip to an unfamiliar place and insist that pilots file a flight plan. Rather than waiting for the natural, but delayed results to teach the young, older members instead give them rules and then reinforce adherence or punish infringements. Warnings, pieces of advice, contracts, regulations, laws, and even proverbs relate behavior to eventual consequences and can make it unnecessary for students to experience natural contingencies in order to behave appropriately.

In thinking, we often engage in verbal behavior that resembles following rules or directions. For example, we may think about or remember what it was we were told to do as we drive to a friend's house for the first time or cook a meal we haven't prepared before, or we may consciously try to follow the rules of logic in life.

Rules have advantages in (1) bridging dangerous and inadequate contingencies, (2) saving time and effort, and (3) leading us away from unpleasantness and toward attractive consequences and new discoveries. Rules also have disadvantages when they (1) exclude relevant contingencies, (2) lead to unnecessary complications and (3) become a barrier to further investigation.

Advantages of Rules

We teach rules to circumvent dangerous contingencies and to help students when immediate contingencies are too weak to control behavior. Through rules, we may learn to drive at a moderate speed or fasten our seat belts without necessarily having experienced the differences that these practices make in a crash. We may stop smoking by following advice before we experience lung cancer. We persevere in our studies without experiencing differences that it will make after we graduate. The natural contingencies in these cases would not have been adequate to shape up the desired behavior in time. Rules are used to bridge the gap between behavior now and benefits later.

We use rules to save time and effort. In order to avoid rush hour traffic, for example, some of us may simply follow the route a friend has advised us to follow. By exploring alternative routes during rush hour, we would have had the direct experiences of contingency-shaped behavior. But it may have required considerably more time and effort before we found a satisfactory route. When we give recommendations we save our students the effort of exploring contingencies directly, even when those contingencies would have been sufficient to produce the desired behavior.

We use rules to make interpolative guesses when we lack direct experience. The search for missing parts in a sequence derived from a rule, for example, may lead to the discovery of hypothesized links. The history of astronomy offers some interesting examples of how people have dealt with a subject matter to which they have limited access through this kind of rule-following behavior.

Johann Bode had been impressed that the distance of the planets from the sun could be correlated with the geometrical series 3, 6, 12, 24, etc. relative to Earth = 10. This gave the calculated distances of Mercury at 4 (0 + 4), Venus at 7 (3 + 4), Earth at 10 (6 + 4), Mars at 16 (12 + 4), etc. The actually observed distances were roughly 3.9 (Mercury), 7.2 (Venus), 10 (Earth), 15.2 (Mars) and so on in a reasonably close fit that the Pythagorean orientation could see as a manifestation of innate form. When Uranus was discovered and found to be in excellent agreement with the next term in Bode's law, a search was undertaken for the "missing planet" between Mars and Jupiter, and the asteroids Ceres and Pallas were discovered in 1801 and 1802. Their distances satisfied astronomers that the "missing" terms in the series had been filled. And this search for "missing links" continued, leading to the discovery of Neptune, which was not nearly in such good agreement as the others. Bode's law was not a good fit for the observation of Neptune even though it may have led to its discovery (Losee, 1972).

Although the extent to which Bode's law actually led to the discovery of new planets may be questioned (Kuhn, 1977), other discoveries, such as those which fitted into the periodic table of chemical elements, seem to have followed rules in which the criteria for recognizing the discovery were determined in advance. This is in contrast to discoveries that were unforeseen surprises, requiring a new or drastically altered paradigm, such as the discovery of x-rays or oxygen (Kuhn, 1977). (The latter may be considered to have been shaped more by contingencies that reinforced responding to a novel consequence than by following a rule.)

Rules have helped people to reach deferred benefits in instructional situations in which responding to immediate natural contingencies alone would have been aversive or inadequate. Possibly because of these advantages, rules play a large role in our educational endeavors.

Disadvantages of Rules

When we substitute rules for natural contingencies, however, we do not promote the variety of control which is so important for effective behavior. Rules may be a simple convenience, but we must look at the long-term effects of relying on them when we teach.

Rules necessarily oversimplify and may be used to substitute for a carefree examination of nature itself. In spending time teaching rules we may lead students to expect that "facts about the world can be certified without the tedium of inspecting Nature to see if the statements expressing them are true" (Harre, 1965, p. 9). Science has run into many dead ends by ignoring Nature. The respected alchemist Geber (A.D. 760-815), for example, found the constitution of metals by inspecting their names, not by inspecting the metals. Using basic numerological axioms, he derived a matrix system. The name of the metal was written down and numbers were assigned to the letters which were then referred to the matrix for determining the external and internal constitution of the metal (Harre, 1965, pp. 11-14).

Geber's view was consistent with mathematical Pythagoreanism which believed that order and harmony are numerical and that idealized forms express conditions to be put upon nature. Looking inward, the formal principles are discovered, e.g., the formal principles of Euclidian geometry. These principles "of the mind" are then imposed upon nature in the conviction that this is how the world must be, that the knowledge obtained is permanent, and that nothing could falsify it. As in Plato's parable of the cave, the ideal forms are considered real and we see in nature but shadowy forms of these ideals in more or less deviation from the ideal norms of our "mind."

But when the ideals are said to be discovered by following rules in our minds, we may overlook important environmental factors. We may, for example, fail to trace geometry to the practical everyday experiences which arose when the Egyptians needed to repeatedly survey (for tax purposes) the lands that were continually reflooded by the Nile.

By their nature, rules are static, and increasingly diverge from natural contingencies if those contingencies change over time. Rules, such as dress codes or proper beach attire, become out of date as customs change. Rules may also increasingly diverge from reality when they are used to generate other rules so that individuals respond to their own verbal behavior rather than to the phenomenon they are trying to explain. Leibnitz illustrates the elaboration to which links-of-a-chain rationality can lead:

> All the different classes of beings which taken together make up the universe are, in the ideas of God who knows distinctly their essential gradations, only so many ordinates of a single curve so closely united that it would be impossible to place others between any two of them, since that would imply disorder and imperfection.... it is necessary that all the orders of natural beings form but a single chain, in which the various classes, like so many rings, are so closely linked one to another that it is impossible for the senses or the imagination to determine precisely the point at which one ends and the next begins. (Lovejoy, 1936, pp. 144-145).

All of the universe can thus be forced into a chain, linking everything tightly together from top to bottom in relationships of simple hierarchical connection.

The Great Chain of Being is a static picture, resistant to change. It is put together like the designed machine which is constructed in tick-tock, click-click fashion. Because such machines work with considerable indifference to alterations in environment, they are attractive models for causal-chain explanations. The movements of the heavenly bodies, the tides, and other products of Divine manufacture have been interpreted in this mechanistic way.

Even today, the chain-like design of laboratory experiments that test out a hypothetico-deductive argument can be compared to the testing of links in a fixed chain. General scientific conclusions are often reported as if they were derived from experiments which were discrete, neatly-designed, single undertakings. The phenomenal contiguity of a specific investigation can be worked into the language of the scientist to impress upon the reader the causal chain image (if the scientist is so disposed), much like a detective's quest or a coroner's inquest which looks for the single link which will explain all. Yet as Hanson (1955) reminds us, "We can treat events as links in a simple chain if we please. But then we must never forget that the 'links' are in reality spider's webs" (p. 311). In actual practice, the topography of a fruitful laboratory design is produced by a skilled experimenter whose behavior has arisen from the control of diverse contingencies (c.f. Hodgkin, 1976; Skinner, 1972).

When we ignore the actual control by diverse webs of contingencies, the structures formed by linear chain reasoning may easily grow, unchecked, link by link until they form a Great Chain of Being or some other hierarchical image. Like the philosophy of Kant, this linear rationality can easily move from categorical imperatives for the mind to ethical imperatives or rules for acting dutifully, with little awareness of the social context within which the rules were formed. In such a case, rules no longer help people respond to broad natural contingencies but instead hinder their sensitivity to the environment.

Rules also have the disadvantage of acting as barriers to further investigation. When an inner pattern or structure is used to explain a performance, further investigation of the environmental variables that control behavior may stop while we attempt to explicate the causality of that inner pattern. We may explain how a child learns to say "dog" in the presence of a dog by saying that he has an image or pattern of dog in his mind which he matches to the dog he sees and exclaims "dog" when the fit is good. But what has this explained? How does the child know which pattern to match? How does he learn to know the correct pattern? By another pattern? Malcolm (1977) points out how appeals to inner structures can easily lead to an infinite regress or leave one with the sort of "mystery" that led to postulating the structure in the first place:

> If we say that the way in which a person knows that something in front of him is a dog is by his seeing that the creature "fits" his idea of a dog, then we need to ask, "How does he know that this is an example of <u>fitting</u>?" What guides his judgment here? Does he not need a second-order idea which

> shows him what it is like for something to fit an idea? That is, will he not need a model of fitting? But then, surely, a third-order idea will be required to guide his use of the model of fitting. And so on. An infinite regress has been generated and nothing has been explained (p. 167).

All of our efforts may be taken up in untangling verbal confusions of our own making. We may become bogged down in a swamp of misdirected effort at the expense of an examination of environmental contingencies.

Once a simple linear causality has been given, it may alleviate any responsibility for further investigation. We may be tempted to explain poverty by saying people are poor because they have no initiative to become rich. We may be tempted to explain mental illness by pointing to hereditary genetic links ("It must run in the family"). We may be tempted to explain ruthless competitive selection in warfare, business, employment or education by saying that conflict is natural to man for the survival of the fittest. We may be tempted to explain a child's problems in school by saying he has dyslexia or a learning disability. And so on. Such explanations frequently support existing practices. They are often used to shut off further examination and discussion. Other alternative explanations and a detailed examination of controlling contingencies are not pursued.

"Blindly" following rules creates more problems than benefits. Rules are useful when they are one variable controlling behavior but not when they take total control.

Interrelationships Between Rules and Contingencies

Behaviors may be learned by responding to natural contingencies. What is learned may be a simple response such as not touching fingers to fire or a complex response that integrates simultaneous stimuli like skiing down hill. Behaviors may also be learned by following rules, e.g., don't put your fingers in the fire, follow these rules for skiing. In whichever way the behavior is initially established, it may be repeated as a rule. For example, whether you learned to keep your fingers away from fire because they had been burned earlier or because you were told to keep them away, your future behavior may conform to the rule to never put your fingers near fire. Subsequently, the rule following behavior may be changed as a result of checking out additional natural contingencies, e.g., you may learn that you can snuff out a candle flame without getting burned by pinching the burning wick from the bottom.

Behavior may also be in response to increasing complexities of relationships between contingencies and rules. Behavior may be in response to merely immediate natural contingencies. Behavior may be in response to assorted rules followed by the consequences a culture arranges to ensure that its members follow rules. And behavior may be in response to both rules and natural contingencies simultaneously, switching to rules when the contingencies are defective or to contingencies when the rules are defective. Behavior may also be in response to a relatively large number of multiple, simultaneous contingencies and rules as well as multiple contingencies and rules extended over time.

If behavioral responsiveness were attuned to the beneficial consequences to other members of our culture, we might describe it as being responsible behavior. Cultures idealistically seek responsible behavior that could effectively control its members and assure future benefits to that culture. Cultures have a vested interest in seeing that their members can achieve future goals such as arriving at distant destinations when the community shares the benefits obtained.

In his discussion of the navigation skills of the natives of Truk Island in the Pacific, Gladwin (1964) illustrates some of the differences between relying on a relatively contingency-shaped strategy or a relatively rule-governed strategy for solving a problem. Voyages of over 100 miles of open ocean have been made by the Trukese in sailing canoes. The destination is often a tiny dot of land less than a mile across and visible from only three or four miles away. To reach their destination, the crew rely on a member who has been trained in traditional techniques that do not include a compass, chronometer, sextant, or star tables. Instead, the navigator relies on "dead reckoning" setting his course by the stars and noting the direction of wind and waves when the stars are not visible. When the prevailing wind does not permit sailing directly to an island, but requires tacking in one direction and then another, the problem becomes considerably more complex. The complexity is such that some observers have stated on *a priori* grounds that tacking against the wind in this fashion on long voyages is impossible in a sailing canoe without European navigation aids. Nevertheless, the Trukese navigator responds to continuous and simultaneous visual, auditory, and kinesthetic stimuli with a slight increase or decrease in pressure on the steering paddle to reach his destination.

The difference between the Trukese response to natural contingencies and the European's response to constructed instruments, rules and plans of navigation are not exclusively contingency-shaped or rule-governed examples. The Trukese navigator may be considered to have followed some rules of guidance in his training, e.g., in being taught which stars to follow and which other stimuli to attend to, while the contingencies of his training have given the European navigator cause to learn to read instruments and make calculations correctly. But the contrasts are rather striking (see Table 1).

The Trukese navigator may be able to respond more quickly to unanticipated changes in conditions, but the further away his destination, the greater the complexity of his task and the greater his vulnerability to drastic changes in conditions such as storms might produce.

TABLE I

Comparisons Between Contingency-shaped and Rule-governed Problem Solving

The Trukese Navigator	The European Navigator
1. Awareness of continuing progress under changing conditions is integrated into a cumulative and changing knowledge of position thus far.	1. Western navigators plan their entire voyage in advance. A course is plotted on a chart which provides the criteria for decisions.
2. Decisions are made on an *ad hoc* basis to assure continued progress toward the goal.	2. The navigator simply follows the overall plan and estimates the amount of this plan which has thus far been accomplished.
3. The navigator needs to know his position in relation to landmarks he cannot "see" before determining how the boat is to be handled.	3. The navigator need never be aware of just where his destination lies as he stands on the helm as long as he can determine where he is relative to his goal by drawing a line on the chart between his on-course position and his destination.
4. The Trukese navigator operates with reference to a beginning point, an ending point, and a present point in between which is constantly being related to an ending point. Each move is successively determined on an *ad hoc* basis in a series of continuous "improvisations."	4. The European navigator has almost all his thinking done in advance with a single unifying plan which is then implemented piecemeal with minimal further reference to the overall goal synthesized within it.
5. When external conditions change, the Trukese navigator simply adds the new dimension to his overall perception of the situation and sails on.	5. When the European navigator is forced to depart from his original plan, he must develop a new plan before he can make a response to the changed conditions.
6. The Trukese can point to his destination over the horizon but he cannot put into words all of the myriad perceptions that have made him sure at that moment where the island lies.	6. The European procedure can be fully described in words that give a logical explanation of what is being done, deducing each step.
7. The Trukese navigator starts with empirical details but does not state any explicit discernible principles. He has learned through training the categories of phenomena he must observe and to which he must apply criteria as to their relative importance based on training and experience. In a continuous process characteristically involving multiple simultaneous operations, he makes decisions relative to handling the canoe and maintains a perception of where the canoe lies relative to its destination.	7. The European navigator proceeds deductively from principles to details. He implements a plan that is a concrete application of basic principles even though he may not understand the theory or how it was derived from the details of a long past history of contingencies. Once the plan has been developed, the navigation can be performed in a step-by-step fashion with a minimum of thought.

Being lost in unfamiliar waters presents a serious problem for the Trukese navigator. As a curious but perhaps not functionally related aside, observers also find that the Trukese are unlikely to consider the long-term consequences of their behavior.

The European navigator has had his task enormously simplified for him. Increased distances add little complexity to his task, and storms that throw him off course need only be of temporary inconvenience. His dependency on plans, however, may deaden his perception of external contingencies and slow his responses in a crisis situation. He may run his ship aground on uncharted shoals. Even the best laid plans are extremely vulnerable when they are not susceptible to empirical feedback and checking with natural contingencies. In addition to their plans, European navigators have supplemental feedback from recognizable landmarks as checks on their progress, and lookouts are posted expressly to respond to unanticipated events among the natural contingencies.

The Traditional Use of Rules in Education

Rules have been used by the schools to educate for "moral virtues and habits." The teaching of moral virtues and habits, in fact, was once the express purpose of the curricular and organizational structure of schools. These habits and virtues function largely to restrain responsiveness to immediate contingencies and to focus on responding to rules. A selection from A Statement of the Theory of Education in the United States, signed in 1874 by 77 college presidents and city and state superintendents of schools, states:

> In order to compensate for lack of family-nurture, the school is obliged to lay more stress upon discipline and to make far more prominent and moral phase of education. It is obliged to train the pupil into habits of prompt obedience to his teachers and the practice of self-control in its various forms, in order that he may be prepared for a life wherein there is little police-restraint on the part of the constituted authorities. (Tyack, 1967, p. 325.)

To meet these ends and the needs of an industrialized society, school practices that led to regularity, standardization, and efficiency were encouraged. As jobs were divided, simplified, and routinized in the quest for efficiency in an industrialized society, so too was school work:

> The large city schools became increasingly mechanized and structured like the large bureaucracies of industry, commerce, and the military that were arising in this age of consolidation. A case in point is A Statement of the Theory of Education in the United States signed by dozens of college presidents and state and city superintendents of schools and issued by the U.S. Office of Education in 1974. "The commercial tone prevalent in the city," said the report, "tends to develop, in its schools, quick, alert habits and readiness to

combine others in their tasks. Military precision is required in the maneuvering of classes. Great stress is laid upon (1) punctuality, (2) regularity, (3) attention and (4) silence, as habits necessary through life for successful combination with one's fellow-men in an industrial and commercial civilization." (Tyack, 1967, pp. 314-315.)

In these and other ways, school practices served to curb desires for immediate gratification in a diverse population and thereby to increase responsiveness to more remote consequences in serving the dominant social order. But the logical rules and means for achieving these goals had become an end unto themselves, as illustrated by many of the absurdly regimented classroom practices recounted by Dr. Joseph M. Rice in the 1890s (Rice, 1893).

The subsequent reaction to the very success of schools in establishing such social controls may well have led to the expression of new mission goals in terms of a progressive personalization of the curriculum for individual development. For instance, "By 1918 the Committee on the Reorganization of Secondary Education could state that 'education in a democracy . . . should develop in each individual the knowledge, interests, ideals, habits and powers whereby he will find his place and use that place to shape both himself and society toward ever nobler ends'" (Vallance, 1977, p. 604). These new goals required a responsiveness to a far more extended range of contingencies than before.

This dramatic shift in the language of justification, however, has not been accompanied with as dramatic a shift in school practices. Contemporary criticism of the "hidden curriculum" testifies that practices which accompanied the earlier expressions of rule-oriented purposes have been maintained, even though the expressed purposes have now been changed. It seems as if these practices may not only fail to reflect reformulated justifications for education and a more extensive responsiveness, but they may also interfere with the achievement of these purposes.

A grasp of the relationships between rules and contingencies is an asset in any situation. A real problem arises when the one form of knowing is not related to the other, as when school learning is too exclusively rule-governed or too exclusively shaped by contingencies that define roles rather than tasks. Rules are a large part of the cultural practices that education must transmit, but just as students become vulnerable in daily life when they have learned to depend too strongly on a teacher, so they may, by dogmatically following a rule, fail to respond to contingencies in their environment.

WHAT TEACHERS CAN DO

Deciding Upon Curriculum

To develop students' problem-solving behaviors it is important for students to respond directly to natural contingencies as well as to rules. A good science activity teaches both general rules and ways of interacting with the environment.

Let us look at three curricula as examples of different approaches. *Hypothetical Curriculum A* is heavily rule-governed, emphasizing following directions for immediate contingencies and following rules for remote contingencies. The curriculum then relies primarily on the printed page. There are scientific facts and scientific laws and directions for performing an illustrative "experiment." The student may find that performing the "experiment" can often be skipped with little loss, since the results are a foregone conclusion anyway, and the criteria for his evaluation depend upon knowing what's in the printed page rather than upon what he does outside the page. In such a curriculum, science becomes a deductive exercise where you can skip the experiment as long as you know the facts, laws, and rules of science.

In *Hypothetical Curriculum B*, a "progressive" alternative might try to focus in on a curriculum that exposes the student to a broad cross-section of immediate experiences. Students plant seeds and care for them. They feed the fish in their aquarium and the gerbil in its cage. They go for nature walks and immerse themselves in "scientific occupation." However, the extension of consequences beyond the immediate may be either slight or adventitious. A discussion or summary may follow. Perhaps a student will make a happy discovery unprompted by the teacher. But follow-ups to the one-shot experiences are conspicuously lacking. In such a curriculum, science is like a novice's search for gold nuggets. He doesn't know exactly what he's looking for or where to look, but he tries to cover a lot of ground in search of lucky discoveries.

Hypothetical Curriculum C brings in all the contingencies, broad and narrow, near and far, and all the relationships between rules and contingencies. Such a curriculum would include tasks like recording the growth of plants by direct observation over their life cycles (e.g., drawing a picture and labelling it at different stages and recording the changes in individual properties over time) with varying conditions (e.g., amounts of water and light). Another example might be to build an aquarium and record the changes in the organisms and their behavior in varying conditions over time (e.g., the amount of space or food). Such a curriculum includes responsiveness to the directions and rules of the printed pages as well as to a broad cross-section of immediate experiences. Its distinguishing feature is the use of records over time that unify repeated immediate experiences and provide an interacting link between both rules and contingencies.

Fortunately, there are some encouraging trends in curricula under way that reflect the procedures of Hypothetical Curriculum C. Science materials, for example, have shifted away from basal-like readers that emphasize memorizing rules to programs like the Science Curriculum Improvement Study (SCIS) and its offspring which emphasize direct experimental experiences over time using a variety of record-keeping methods.

Instructional Methods

In the public schools, few teachers have a choice of textbooks or of curricula. But within a given classroom, most teachers have a great deal of flexibility in not only what they emphasize, but in how they teach. If you teach a class on chemistry, for example, you can decide whether students listen to a lecture, do exercises on balancing equations, create compounds by working with chemicals or some combination of these. If, as we have argued, one of the basic goals of education is for students to come more under the control of a broad range of stimuli, particularly those environmental changes they themselves produce, then they must be given opportunities to actively interact with a subject matter. Involving students in projects is, of course, one way to do this. That projects can have a lasting impact on students is reflected in the comments of several 1977 recipients of the National Science Award, who mentioned an earlier project as the starting point of their interest in science (Cromie, 1978).

What about the content or facts that students need to carry out projects? Where do students learn the basics? In most classes, facts are taught through assignment or class presentations. Most of us give some lecture or lecture-discussion classes. Even within that format we can increase student involvement (see Table II).

TABLE II

Traditional Procedures in a Lecture-Discussion Class and Some Suggestions for Increasing Student Participation and Involvement

Usual Procedure	Suggestions for increasing student participation
1. After lecture for a bit, teacher then asks a question to the class. One student answers.	1. After lecturing for a bit, ask everyone to write down the answer to a question or give a problem for students to work on in groups. Then share answers.
2. At the end of a presentation give an assignment, or announce a test (in the future) or dismiss the class.	2. At the end of a presentation, give a short quiz on the material just covered. (Students respond on index cards and do <u>not</u> write their names on the cards.) Answers are discussed right after cards are handed in.

For example, by giving a quiz immediately after a presentation, you give students a reason for paying attention during class. At the same time, by having quizzes unsigned, you can shift the reason for doing well from grades to getting feedback on understanding. When students turn the cards in, their answers tell you which points they understood and where they still have misconceptions. As an additional bonus, since there are no names on the cards, there is no reason to correct them.

In most schools there is little provision for individual pacing or adjusting the size of steps and even less opportunity for students to become effective managers of their learning and progress. "Copy the model" may be the extent of stimuli before performance. "That's right" or "That's wrong" may be the extent of stimuli after the performance. Such instructional procedures do little to advance the development of complex problem-solving skills and to bring students into extended contact with natural contingencies. They are a sorting and classifying strategy, more than one of teaching.

How are we to individualize when we have 30 or more different students in one class? We individualize when we let students choose a topic for assignment, even when the form or steps they must follow are the same. We individualize, too, when we let students graph their individual performances over time. For problem solving, we can individualize by letting different groups of students work on the same topic, but at different levels of difficulty. One way to organize such an approach is to have problems color-coded for level of difficulty. For example, if you teach experimental design, you can sort your exercises (in which students, say, are asked to set up an experiment to answer a given question) and ~~put~~ those which require only a straightforward application of principles in a red folder, those requiring two steps for design in orange, and those problems which require quite a bit of imagination in yellow. Students can then choose a problem to work in class and can change to another level if they find a problem too easy or too difficult. When problems are taken from published studies, students can read how professionals solved the problem as part of their feedback, though the students may design even better procedures. When we watch students in the process of solving problems, we discover where their strengths and weaknesses in problem solving are, much better than when we only see the product of a problem-solving assignment. Responding to each student's unique strengths and weaknesses is as much a part of individualization as varying assignments.

In courses on teaching, most teachers learn how to design antecedent conditions for student performance, but get very little help in ways of designing feedback and consequences. Yet it is the consequences of behavior that determine the effectiveness of directions and antecedent conditions in the first place. When conspicuous consequences do not flow automatically from performing a task, we must design instruction so that some consequences do occur. A variety of progress records can be used to add consequences or augment natural consequences so that students can evaluate their progress and see what facilitates or hinders that progress.

With adequate feedback over time, a project-based approach to instruction fits in well with extending personal responsibility and problem-solving skill. The responsible person considers long-term contingencies, effects which are likely to occur at a distant time. Instruction based on projects naturally extends over time and necessarily involves spanning an interval of time, with little or great effort, simple or complex skills, and in any combination.

Children acquire early skills in responding to extended contingencies when they look back on the tracks they have made in the mud or sand, showing where they have been over a period of time, step by step. Similarly, charts and collections of products show what was done, the conditions under which it occurred, and the consequences over time.

Just as it is difficult to tell where an individual has gone by looking at a single footprint, so it is difficult to see progress or to be able to project into the future from a single test score. In providing charts, collections, or any kind of visible records of daily performance, we make it possible for students to respond to their own progress--and thus to the future.

Evaluation

The way in which you evaluate your students determines what you see about their learning and thus what aspects of their behavior command your attention. Although our society stresses individual progress even to the point of legislating records of progress for special students (Public Law 94-142), few schools of education teach the kind of continuous measurement techniques required for tracking progress. Most of us have been taught to view measurement as synonomous with testing, and have studied standardized tests and teacher-made tests. But neither kind of test shows the day-to-day variations in performance which let us see student learning in progress. Imagine trying to drive a car along a road with your eyes shut, opening them only now and then to check your progress. Tests *are* eye-openers, but usually they are given at the end of instruction--too late to help the unsuccessful student back on the right path. Even worse for judging progress are standardized tests whose scores tell relative standing--if similar tests were used for driving, they wouldn't tell you whether or not you were on the road, but rather how many other drivers were farther away from the center of the road than you. If, as a teacher, you do not check progress continuously you are in the position of the blind driver--you cannot respond to where your students are headed because you have no data from which you can see progress.

And what about your students? If students don't know, day by day, what is expected of them and how they are progressing, they cannot attend to their own success and effectiveness. So they respond to the only data available--the teacher's approval and grades, which loom increasingly large in the control over their behavior.

One person, the teacher, then has become the source of the controlling contingencies. Dependency on that person may then be based on a combination of contingency-shaped and rule-governed behavior. The student performs because of the rewards and punishments the teacher delivers or "promises" according to how ~~well the teacher's~~ rules and directions are followed.

If we go back to the goals of American Education—a broadening of the stimuli to which students respond—we see how destructive our measurement techniques can be. A system in which students are more tuned in to rewards from their teachers than to their own effectiveness in dealing with a subject matter turns control downward from teacher to student (see Figure 3). One level up, downward flowing control produces teachers overly sensitive to the judgment passed upon them by their principals (Pennypacker and Vargas, 1976).

Ideally, we wish the control to flow the other way. When we succeed in interesting students in science, for example, the control over their behavior flows from their interaction with their environment. Perhaps they just notice and appreciate the quartz in the pavement or the robin's eggs in the tree, happy to be able to name them. Or perhaps they respond to their effectiveness in trying to isolate variables responsible for some aspect of health or pollution. Within the classroom, our motivated students do not constantly glance at the teacher but rather are controlled by problems or by what they find out by reading, or trying out ideas or procedures.

At the next level up, we would like teachers to be controlled by their effectiveness in helping students. They should respond more to their students' progress than to the good will or wrath of their supervisors. The whole educational systems should be set up to serve, and to be responsive to, the progress of students. Control should thus flow upwards (see Figure 4) like that in a grass-roots democracy.

Education is a complex behavioral system in which many people—teachers, learners, administrators, parents, and public officials—interact. An evaluation system should bring all those individuals together working for a common goal. In order to center the control on student progress we must design an evaluation system so that progress can be seen.

A student's behavior may be defined by its effects on his environment. We define talking by the amount and kind of noise produced, writing by marks and so on. Behavior therefore always changes the environment, and these changes in turn, influence subsequent behavior —in a simple, but delicate, feedback arrangement called learning.

The purpose served by evaluation is to *augment* the natural corrective feedback process. When we augment feedback to the student, we are making the results of his behavior more obvious to him. Thus we are making it more likely that he will come under the control of natural (though augmented) consequences of his *own* actions.

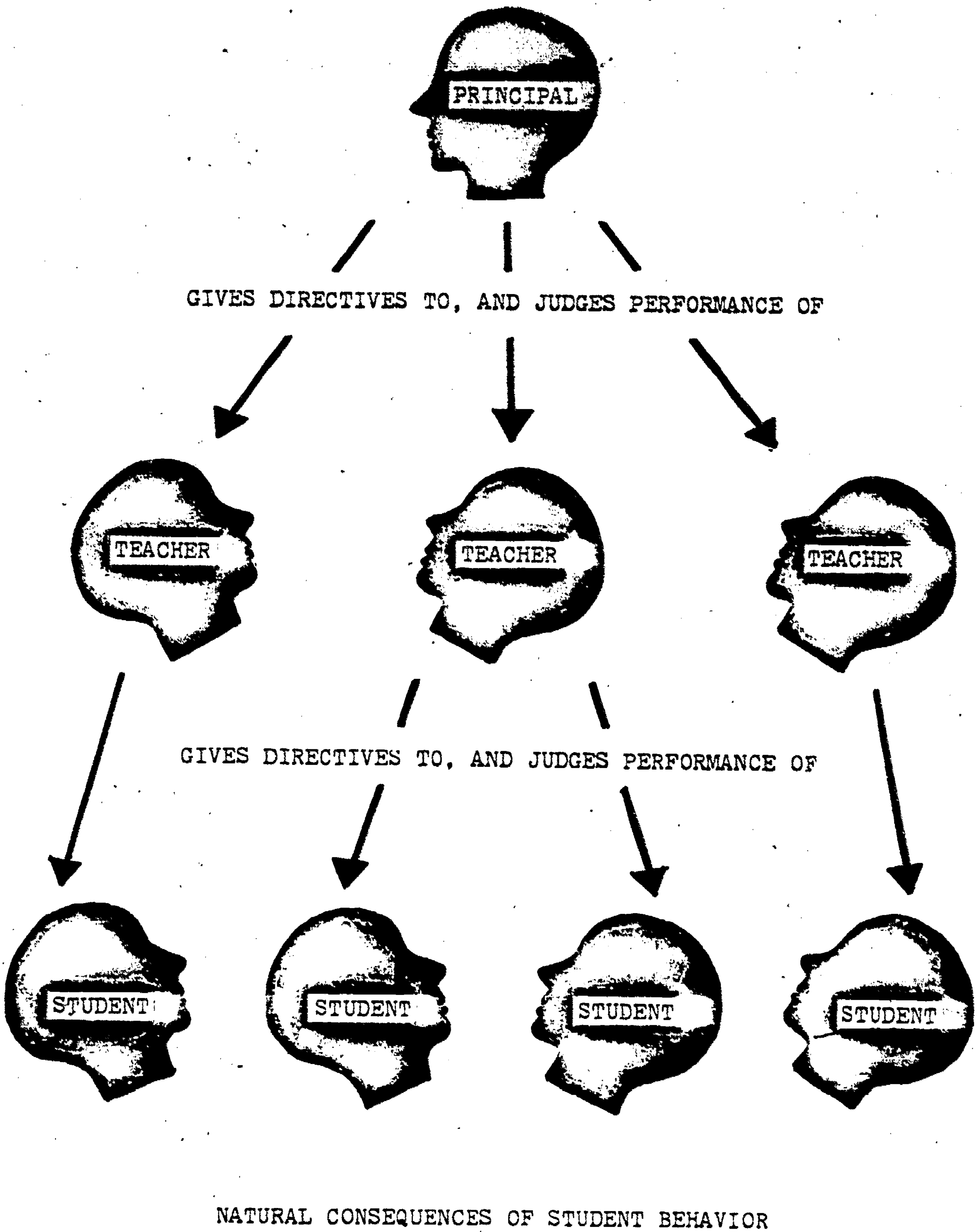

Figure 3. Control when evaluation flows down from authority. (From Vargas and Pennypacker, 1976).

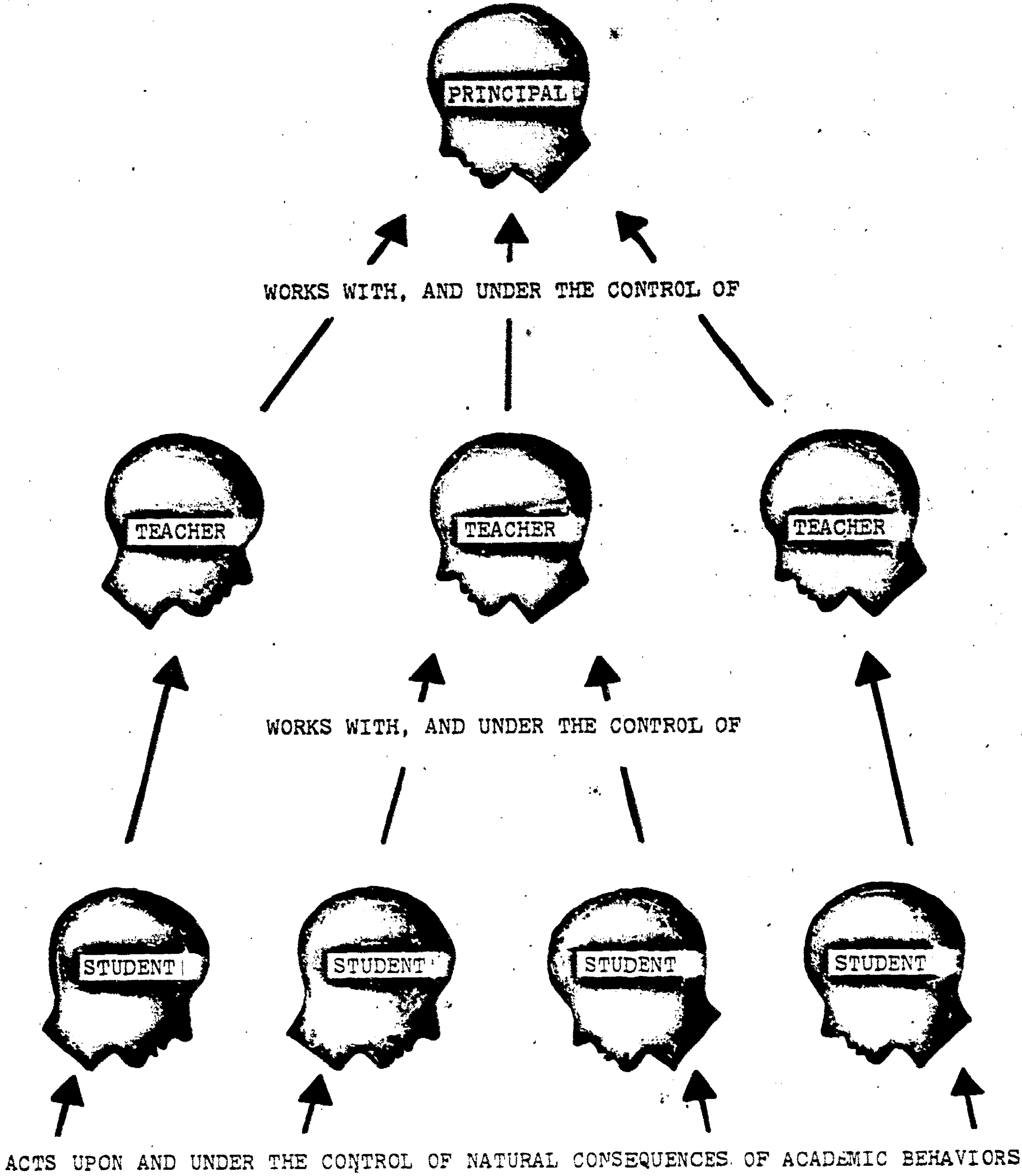

Figure 4. Sources of control when evaluation flows up from natural consequences of behavior. (From Vargas and Pennypacker, 1976).

For the natural consequences of student learning to be the source of control up the educational system the most relevant data are those that best show student progress on course goals. The data, then, must show what students do and can do, and the progress they are making. The most sensitive measure of behavior we have is rate (the number of times a student does something per unit of time). It has been shown to be both universal and absolute. (See Lindsley, 1972; Pennypacker, Koenig, and Seaver, 1974; Pennypacker and Vargas, 1976; and Johnston and Pennypacker, in press, for a discussion of this point.) Students are constantly behaving, but without recording what they do it is difficult, if not impossible, to see the day-to-day changes that are so critical. Even the students themselves may not realize how much progress they are really making. To start, then, we need data on student behavior.

In order to show changes and trends, the data need to be in a form which reveals change. Charts or graphs make progress (or its lack) immediately apparent. Many writers (e.g., Bates and Bates, 1971; Lindsley, 1971; Vargas, 1977) have suggested the use of a standard chart which shows improvement in terms of ratio of change, rather than absolute amount of change. One advantage is that this does not discourage the slow learner. More important, change which is usually a curve on traditional graphs, is linear on the standard behavior chart, thus making prediction easy.

Two of the most powerful aspects of natural feedback are its immediacy and its continuous nature. The way to achieve immediacy and continuity is surprisingly simple: Have students keep their own charts. Students are closer to their behavior than anyone else and are also in the best position to observe it continuously.

Student records of their behavior, or records of their products, then become the primary data base for all subsequent evaluation and decision making within the complex system. It is the student that the system is designed to teach, and it is student progress that needs to be the ultimate source of control all the way up the organizational ladder.

At this point you may be thinking, "But students will cheat. The records won't be accurate." If records are used by teachers, administrators, parents, and so on to reward or punish, students will indeed cheat. But that misuse is turning the control upside down again. In rewarding or punishing students for what the chart shows, teachers are taking control away from the chart and increasing the power of consequences they themselves provide. Even if teachers base consequences on the charts, the control is in the wrong place. Consequences should not come from *teacher* behavior. They should come from *student* behavior. When charts are used only as feedback to see progress, the consequences the data provide are a direct and natural result of the student's own behavior. With nothing "extra" to gain or lose, there is no reason to cheat, any more than there is for a driver to record that he is closer to the center of his lane than he really is.

Many teachers work within a school system which requires a specified testing procedure, but even then they can introduce continuous daily recording of student accomplishment into their teaching procedures. For systems which permit more flexibility, we can design behavioral progress records, such as the Kindergarten record, in Figure 5, part of which is filled out by the children themselves.

Summary

Curricula should emphasize the kind of record keeping skills that characterize the scientist and that can be used to derive rules from contingencies, check contingencies against rules, and to combine the narrow following of steps in rules (largely a motivational problem) with learning different responses to contingencies (a learning problem). This scientific emphasis on recording should extend beyond science into every curriculum area. In mathematics, quantitative skills naturally fit into the charting process itself. In language arts, record keeping, which is, after all, one mode of communication, serves as a check on impressions about progress. In social studies, the science of behavior shares many features with historical analysis and with values clarification, both of which would be enhanced by charting. In expressive arts, collection of works could show the evolution of each student's skills. Within any subject area, charting benefits self-management skills, aids in effective peer teaching, and creates a classroom organizational structure centered around individual progress.

Instruction should include conspicuous consequences for tasks that do not naturally provide them. We do this by adding feedback as well as by changing the activities included in our curriculum. In contrast to the occupational focus of progressive education, we can address both holistic accomplishments and specific subskills by designing feedback into tasks which do not automatically reveal competence. In this way, we do not need to be limited to unreliable, albeit rich, feedback of time-consuming occupational tasks nor to the "correct" and "incorrect" feedback on the limited subskills of memorization and recall. Evaluation should focus on a broad base of consequences the student produces by his progress in performance rather than on the narrow source of approval or disapproval by a higher authority.

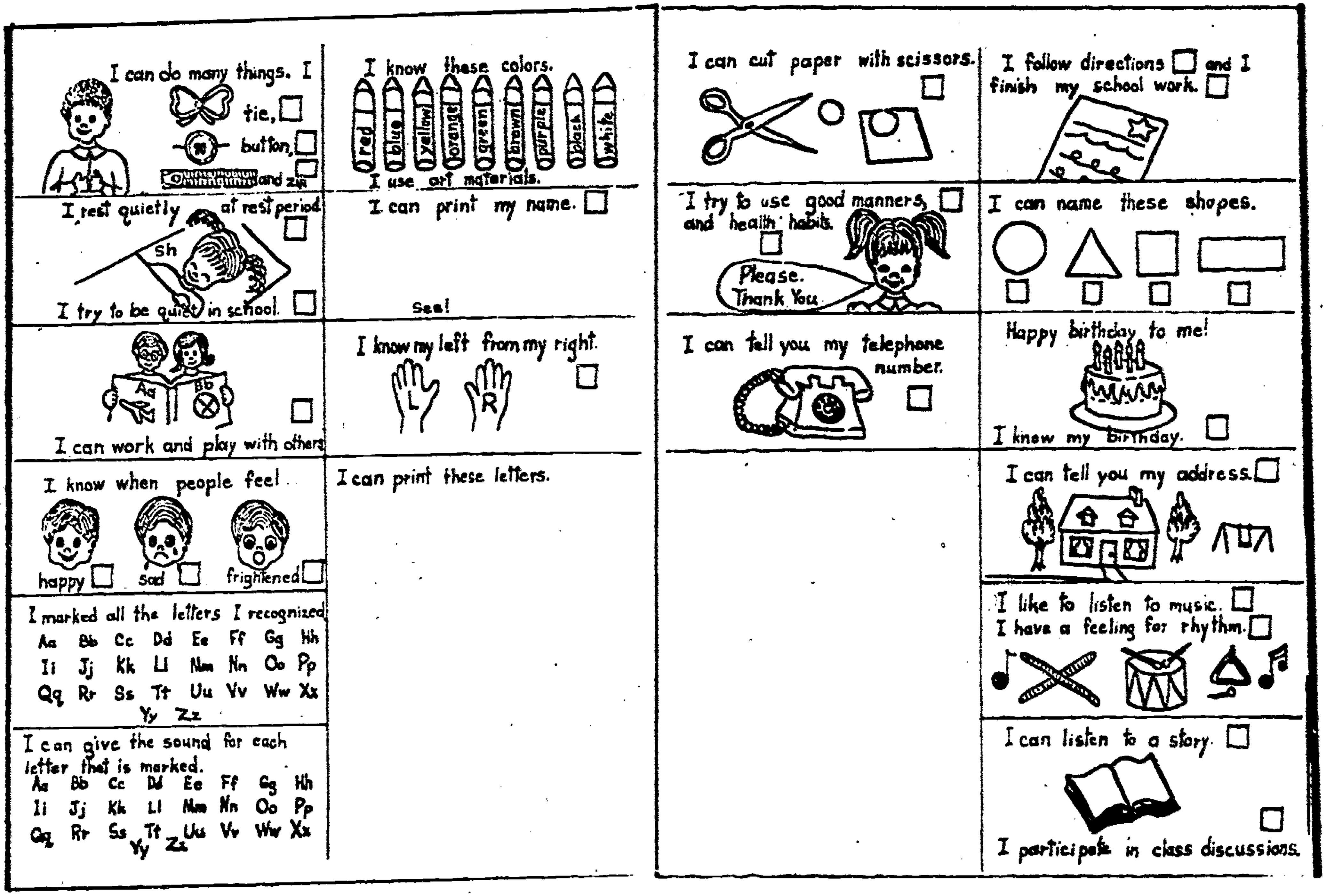

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Figure 5. Inside two pages of a behavioral record. (From Rupich, 1978).

CONCLUSION

We teach for the dual purpose of helping our young learn to interact successfully in the environment they will encounter beyond the school walls and also to help change our country and the world for the better. The world they will enter is complex, requiring sensitivity to a wide range of stimuli. In teaching, we strive to increase the range of stimuli which control the behavior of our students--and thus also to broaden the variety and sources of stimuli which can reinforce them. Where the baby needs only to respond to a very small part of the world, the young child must attend to a broader range of stimuli including properties of objects such as color or shape, and the young adult is expected to respond to still more stimuli. There is no difficulty in getting youngsters to attend to stimuli when there are immediate consequences for doing so. Thus the teenager learns readily to respond to incredibly subtle cues from members of the opposite sex, or to make subtle discriminations between cars, pop singers, and so on. The task of education is to increase the importance of stimuli which are critical for long-term benefits, even if they do not bring immediate payoffs. Both for an individual's future, and for that of others, we must learn to take the future into account.

As a society, we have not been very successful at teaching our young to behave in ways of benefit to the future. The problems which face future generations are largely problems of behavior in which immediate effects dominate long-range considerations. We have not yet, however, attacked behavioral problems with the same kind of rational and scientific persistence that we have used to solve problems in engineering or agriculture. The science of behavior exists and, if we use it consistently, offers hope for the future.

Like most sciences, the science of behavior can look hopeless when challenged with simple daily occurrences. Just as the physicist would be hard put to explain the exact forces over a particular falling leaf, or to predict where it will fall, so the behavioral scientist would have difficulty in explaining the forces controlling the flight of a fly, or predicting where it will land. Compared with such simple processes, the complexity of the classroom may seem an insurmountable obstacle in using behavioral psychology in the classroom.

Not so. Any teacher can become more effective in achieving the long-term goals of education by approaching classroom problems as a scientist approaches a problem in the lab. For science can help us, as teachers, take the future into account by helping us respond to relevant stimuli. Prime among those stimuli are the behaviors we wish to produce in our students, the sources of control over those behaviors, and data on the day-to-day progress of each student in obtaining them. When we concentrate on long-term goals and the kind of data on students that are required for a rational problem-solving approach to teaching, then we are less likely to flip back and forth from giving directions to admonishing or punishing students. By using the science of behavior, then, we are more likely to do what we should be doing in the classroom, namely, teaching for problem solving in the future.

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BRAIN ASYMMETRY: THE POSSIBLE EDUCATIONAL IMPLICATIONS

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INTRODUCTION

In his seminal article on the possible importance of brain asymmetry studies for education, Joseph Bogen (1975) traced the history of two modes of cognitive processing. Educators, psychologists and philosophers have distinguished between two modes of thought one identified as logical, classifying, analyzing and deductive; the other as analogical, generalizing, synthesizing and inductive. Whatever labels given to identify these cognitive modes different types of information processing schemes may be associated with them.

The rational, logical cognitive mode is characterized by a sequential information processing scheme in which temporal differences are important. The intuitive, analogical cognitive mode is characterized by a simultaneous information processing scheme in which temporal differences are not important. Certain areas of study are also assigned to specific cognitive modes. The subjects of science, mathematics, and languages are normally associated with the logical cognitive mode while subjects such as art, music, and dance are normally associated with the intuitive cognitive mode (Bogen, 1975).

While theories on cognitive style and education have incorporated the above concepts, it is only recently that evidence has accumulated suggesting a basis for two distinct modes of information processing in the specialization of the brain's cerebral hemispheres. This specialization in processing provides the substrate from which the different cognitive styles may arise.

The human brain is an intricate and complex structure which houses man's perceptual and cognitive systems. These in turn are associated with the interconnections and interactions of the billions of nerve cells that constitute the brain. What is known about information processing in these systems comes from two avenues of exploration: anatomical studies (interventions due to disease or injury) and psychophysical testing of injured or intact brains. Studies such as these permit the limits of perceptual and cognitive information processing to be defined.

The findings of brain asymmetry studies are exciting in the implications they hold for the future of education. Such implications, however, are not easily assessed. From the extensive literature available on brain asymmetry studies it is possible to draw some conclusions that yield insight into student learning and educational programs. To do this it is first necessary to review that literature.

THE HUMAN BRAIN

The brain may be divided anatomically into three general regions. Each of these regions has certain subdivisions and performs certain information processing functions on the incoming signals. The first region is the brain stem. This includes everything from the medulla (the swelling at the top of the spinal column) to the diencephalon, the last area of integration before signals are sent to the cortex. The second region is the cerebellum, located at the base of the cerebral cortex and connected to the cerebral cortex and brain stem. The third region consists of the cerebral hemispheres which rest upon, and are supported by, the brain stem (Curtis, Jacobson and Marcus, 1972).

Fibers carrying information from sensory and motor areas of the body enter the brain stem. Here information from various sensory and motor inputs is extracted and refined. Within the brain stem individual nuclei that process incoming sensory and motor information have a bilateral representation. The nuclei are symmetric and exist on both the right and left side. Within the brain stem the majority if incoming fibers cross and recross synapsing on nuclei of the opposite (contralateral) side but in most cases retaining a same (ipsilateral) side component. When the fiber tracts reach the upper part of the brain stem, the diencephalon, the tracts of each side carry information concerned mainly with the opposite side of the body. This means that each cerebral hemisphere receives information from, and mainly controls the opposite side of the body. Crossing of fibers in the brain stem thus constitutes the first anatomical step in brain asymmetry.

Within the three major sensory systems (visual, auditory, tactual) the degree of crossing of fibers ascending to the cerebral cortex is different. Within the visual system, vision to the right of a point of fixation is processed by the left half of the brain, and to the left of a point of fixation by the right half of the brain (Kimura, 1973). This occurs since information from the nasal portion of each retina crosses to the opposite hemisphere while information from the temporal portion of each retina remains uncrossed. The crossing of optic fibers results in the right and left visual fields described in the literature (Sperry, 1974).

Extensive interaction occurs between the right and left inputs for the auditory system within the brain stem. Information from both ipsilateral and contralateral inputs is received by both hemispheres. Contralateral (crossed) input, however, is more important than ipsilateral input in determining ear advantage for spoken and melodic patterns in dichotic listening experiments (Kimura, 1973). The extensive crossing of auditory fibers at the level of the brain stem may be responsible for certain asymmetries occurring in dichotic listening tests that appear to be independent of asymmetry of processing in the cerebral hemispheres.

Information carried by the tactual and motor systems is almost completely crossed. Again the contralateral component is more important than the ipsilateral component (Curtis et al., 1972). Asymmetries in anatomy of the descending motor system (fibers carrying information from the cerebral cortex) do occur and the degree of crossing of the fibers varies in any given population. Geschwind (1974) reports some rare cases where no crossing occurs. The degree of crossing of the descending system may have an effect on hemispheric asymmetry especially in relation to language representation (Levy, 1974; Levy and Reid, 1976).

Fibers carrying incoming sensory and motor information ascend to the cerebral cortex. The cerebral cortex consists of two anatomically similar hemispheres divided by a deep fissure. Despite the general anatomical similarity, differences in gross morphology between the hemispheres are present. These differences are greatest between the right and left temporal lobes. Cortical areas involving speech functions are larger on the left temporal lobe. Some differences in cytoarchitecture also occur. Other variations in the macro- and micro-structure of the cerebral hemispheres are reviewed in detail by Geschwind (1974).

When the two hemispheres are slightly separated, a wide band of approximately 200 million fibers, the great cerebral commissure or corpus callosum, may be seen. The fibers of the corpus callosum connect portions of the frontal, parietal, occipital and cingulate cortex in one hemisphere with the same area in the other hemisphere. There is also a secondary fiber tract, the anterior commissure, connecting parts of the right and left temporal lobe and olfactory bulb (Bogen and Bogen, 1969; Curtis et al., 1972). These two fiber tracts permit communication between the cerebral hemispheres. When the corpus callosum and anterior commissure are sectioned, either surgically or due to disease, communication between the cerebral hemispheres is stopped.

HEMISPHERIC ASYMMETRY: ANATOMICAL EVIDENCE

Early Studies

The first knowledge of hemispheric asymmetry in perception and processing of information came from lateralized lesions of the brain due to injury or disease. These type of data have been compiled since the 1800s and are the most extensive and best surveyed. Sections 1 and 2 of Table 1 contain a portion of this material. For more extensive coverage see Gardner (1974) and Geschwind (1965a, b).

Most of the anatomical data comes from individuals whose brains were damaged due to strokes. These patients were studied over a period of years prior to death when post-mortum operations were performed to determine the locations of brain damage (Geschwind, 1970). Early work was carried out by Broca, Dejerine, Wernicke and others (Gardner, 1974). These investigators set the trend of thought toward anatomical localization of function. It became evident from their studies that for the majority of people an intact left hemisphere was necessary for speech production and comprehension. The left hemisphere appeared to control writing, comprehension of written words and forms of mathematical calculations as well (Gardner, 1974; Geschwind, 1965a, b; 1970). Damage to various areas of the left hemisphere resulted in a series of disorders of language, reading or writing termed aphasia, alexia and agraphia respectively (Geschwind, 1970). Since verbal communication was (and is) basic to most cultures, these disturbances were easily noted, recorded and studied. These studies eventually led to the concept of a dominant hemisphere responsible for verbalization, the left, and a 'silent' or non-dominant hemisphere, the right.

Early researchers, however, recorded cases where lesions to the right hemisphere resulted in aphasia and other disturbances normally associated with a left hemisphere. Cases also occurred where damage to the left hemisphere produced only a mild aphasia unlike that seen with similarly damaged regions in other individuals. These cases appeared related to age, sex, and handedness. Such observations led to the idea that reversal of hemispheric language representation might occur in certain individuals while in others bilateral representation of language may be present. The relationship to handedness was examined and the results, then as now, were complex.

Lateralization of the language functions appears to be greatest in right-handed males. The degree of lateralization of language is variable in females and lefthanders with some lefthanders showing a right hemisphere lateralization for language. The handedness relationship is more complex (Levy, 1974; Levy and Reid, 1976).

Because of the importance of verbal communication, left hemisphere damage is easily recognized. However, impairment of right hemisphere function is not so easily recognized. More recently it has been found that damage to portions of the right hemisphere results in defects of varying severity such as the inability to carry a tune (amusia) or the inability to recognize faces (prosopagnosia). Right hemisphere damage also results in loss of abilities such as the ability to copy simple drawings, the ability to orient in space or to find one's way around town (Gardner, 1974). If the site of the lesion occurs in the area of the parietal-occipital lobe, dream disturbance may result. This latter disturbance has been explored in relation to right and left hemisphere functions (Bakan, 1975; Gardner, 1974; Humphrey and Zangwill, 1951).

Surgical Intervention

The view of a dominant left hemisphere which contains language and other rational functions developed from the studies mentioned above. When brain surgery for removal of tumors and for control of epileptic seizures became possible, this view was slowly amended. It became apparent that the issue of dominance was actually one of mode of information processing and specialization.

TABLE 1

RESULTS REPORTED IN THE LITERATURE SUGGESTING HEMISPHERIC SPECIALIZATION FOR INFORMATION PROCESSING*

METHOD		IMPLICATIONS FOR INFORMATION PROCESSING		
GENERAL	SPECIFIC	LEFT HEMISPHERE	RIGHT HEMISPHERE	REFERENCES
1. Injuries	Penetrating brain wounds	Verbal abilities	Imagery, Dreaming	Bakan (1975) Humphrey and Zangwill (1951)
2. Disease	Stroke, Tumors, Epilepsy	Language; reading, writing; mathematics; when focus of epilepsy--sense of personal destiny; paranoia; humorlessness	Music; drawing; fact recognition; spatial orientation; focus of epilepsy--emotionality (elation, sadness); obsession; overconcern with details and orderliness	Gardner (1974) Bear and Fedio (1977) Geschwind (1970) Penfield and Perot (1963)
3. Surgery	Commissurotomy Hemispherectomy	Complex language functions Reading; Mathematics; Memory and emotion; Sequential processing of data: Highly structural inputs, (Euclidean geometry).	Visuospatial functions; Music (melody, pitch); simple language; memory, (nonverbal); Emotion, Wholistic processing of data; Loosely structured inputs (topological tasks)	Bogen (1969a, b) Dimond and Beaumont (1974) Franco and Sperry (1977) Gazzaniga, et al. (in press) Geschwind (1965a, b) LeDoux and Gazzaniga (in press) Milner and Taylor (1972) Sperry (1974) Zaidel (1976, 1977)
4. WADA Test	Cartoid injection Sodium amytol	Rhythm; Words	Melody; Pitch	Bogen and Gordon (1974)

*Data from testing patients with various hemispheric disorders.

Data accumulated from studies involving electrical stimulation of the conscious brain, hemispheric removal (hemispherectomy) and sectioning of the corpus callosum (commissurotomy) which helped clarify hemispheric functions. Major observations on lateralization of function in a conscious brain were made by Penfield and Perot (1963). Their results confirmed those of other researchers and added a dimension associated with memory and complex behavioral sequences seen in pre-seizure states (auras) of some epileptics. Comparison of pre-seizure states in temporal lobe epilepsy to the site of the epileptic focus indicated the type of aura experienced was hemisphere dependent. Pre-seizure atomaton-like behavior was associated with a left temporal lobe focus, while a dreamy feeling or visually hallucinated aura was associated with a right temporal lobe focus. Since the temporal lobe (left) is intimately connected with speech and sequential information processing, it is interesting that in epilepsy, lesions in the left temporal lobe appeared associated with stereotyped and sequenced behavior (Penfield and Perot, 1963).

Recent studies of severe epileptics have expanded the work of Penfield and Perot. These studies indicate different affective and cognitive concerns which depend upon the focus of the lesion in temporal lobe epilepsy. Table 1, Section 2 gives a brief survey of the finding which Bear and Fedio (1977) presented in greater detail. In general, right temporal lobe epileptics were identified with changes in affective drive or behavior and left temporal lobe epileptics with changes in intellectual functions.

The WADA Test and Commissurotomy

When uncertainty as to the degree of speech lateralization is present, a WADA test may be administered. The WADA test consists of injection of sodium amytal into the carotid artery so that a temporary state of paralysis of either hemisphere results. The WADA test again demonstrates the lateralization of speech, certain types of mathematical reasoning and melody perception in a given hemisphere (Geschwind, 1970). Results indicating an expanded function for the right hemisphere have also been observed. For example, a singing dysfunction was observed with a paralyzed right hemisphere. Pitch perception for singing appeared localized in the right hemisphere and was separate from pitch perception in propositional speech which appeared localized in the left hemisphere (Bogen and Gorden, 1974).

For rare cases of intractable epilepsy the corpus callosum and the anterior commisure are cut. The procedure prevents the spread of the epileptic focus to the adjacent hemisphere and permits control of the seizures. It is from individuals having undergone this operation that the most surprising results are obtained. Unlike the cases of brain lesions where the callosum is still intact, commissurotomy results in complete absence of communication between cerebral hemispheres at the level of the cerebral cortex. Recall that there is still bilateral input of sensory and motor data from the lower level of the brain stem.

Commissurotomy was first performed by A. J. Akelaitis and colleagues in Chicago in the 1940s. When patients were tested after the operation they appeared to be no different than before and it was believed the surgery held no risk (Gardner, 1974). Commissurotomy was not attempted again until the early 1960s by neurosurgeons Philip Vogel and Joseph Bogen. Patients were tested before and after the operation and the extent of surgery was known. In discussing these findings, careful note must be made of the tests used and the responses required. It must also be remembered that these patients had severe, intractable epilepsy, many since childhood. And, the number of patients to date is under 100.

Testing Procedures

Investigators Roger Sperry, Michael Gazzaniga and Jerry Levy developed a number of tests to explore the unique processing schemes of each hemisphere in split-brain patients (Gardner, 1974). The material used in testing was usually visual, auditory or tactile. The patient could be asked to respond by pointing or identifying by touch, verbally, writing or drawing. The general tasks were matching, identification, copying and writing (Bogen, 1969a, b; Levy and Trevarthen, 1976; Sperry, 1974). Later, the affective components of presented material were studied (LeDoux and Gazzaniga, 1978; Sperry, 1974). The individual memory of each hemisphere was also studied (Milner, 1972; 1974).

Commissurotomy Results

Table 1, Section 3, gives some of the results obtained from split-brain patients. After commissurotomy the patients appeared as before except had fewer seizures and could not be distinguished from normal individuals until carefully tested when the split-brain syndrome, as it came to be called, was demonstrated. The syndrome revealed that each hemisphere behaved as a distinct whole as to perception, encoding and processing of information. Each half was a whole brain with its own cognitive style (Bogen, 1969a; Milner, 1974; Sperry, 1974). Since each cortex controls (with greater facility) the contralateral side of the body, weakness occurred in tasks requiring ipsilateral control.

The results of testing procedures indicate that the left hemisphere is lateralized for language. It appears to phonetically encode language. Syntax can be processed by this hemisphere but not by the right hemisphere (Bogen, 1969a, b; Zaidel, 1977). Some language representation does occur in the right hemisphere, but this appears limited to vocabulary (Levy, 1974; Zaidel, 1976). Caution must be used in interpretation since the hemispheres involved were damaged; some, from early childhood. The plasticity of the brain during childhood is well known, thus the processing associated with the hemispheres of these patients may be due to the assumption of a task by one hemisphere due to damage in the other hemisphere (Gazzaniga, LeDoux and Wilson, in press). The patient studied by LeDoux, Gazzaniga and Wilson had an extensive vocabulary in the right hemisphere. His right hemisphere could also understand syntax to a limited extent. This patient was 15 years old.

An alternative explanation to assumption of a task by an undamaged hemisphere deals with the initial degree of lateralization of functions in the brain. The LeDoux, Gazzaniga, and Wilson patient may have been less well lateralized initially and this rather than assumption of the verbal processing by the right hemisphere may have resulted in the large verbal component in the right hemisphere.

For most patients in Bogen's group the right hemisphere surpassed the left in performance of spatial functions, shape and face identification and copying drawings of objects. The left hand could copy drawings of geometric shapes very well, but could not write. The right hand could write very well, but could not copy such drawings (Bogen, 1969a, b).

Each hemisphere behaved as a whole and was unaware of the input to and processing in the other. This condition was best illustrated in tasks where the hemispheres were fed simultaneous but different inputs. Such material was presented tachistoscopically. The patient fixated at a point directly in front of him and slides flashed on in durations of 200 milliseconds or less were presented. Because there was no connection between the hemispheres, information in either visual field was effectively perceived by only one hemisphere. For example, if the picture of a banana were shown to the left hemisphere and the picture of a spoon to the right hemisphere, the patient could be asked to identify the object seen. The patient would respond verbally by stating "a banana" while the tactual response with the left hand would be to pick up or point to a spoon. Similar examples are described in detail by Sperry (1974), Milner and Taylor (1972), and Gazzaniga, LeDoux and Wilson (in press).

Both hemispheres have their own emotional component corresponding to the limbic system on each side (Bogen, 1975). However, differences between hemispheres in affective thought do occur. The work of Gazzaniga, LeDoux and Wilson (1978) shows an example of this difference. The patient under study reacted to an emotionally charged word flashed to the right hemisphere and responded verbally. When questioned, the verbally responding hemisphere was puzzled not knowing the reason for the response. Sperry (1974) reports similar, though nonverbal, responses to emotionally charged visual material.

LeDoux and Gazzaniga (in press) also demonstrated that each hemisphere could assign its own subjective value to an event. They found that using the subjective ratings of the patient, the right hemisphere was consistently more negative than the left. Similar results in affective thought wer found by Bear and Fedio (1977) for temporal lobe epileptics. These differences in affective thought also occur in intact brains.

General Results from Anatomical Studies

When the data from the anatomical studies are analyzed, a general picture of hemispheric asymmetry begins to emerge. Each hemisphere appears to function independently as a whole brain with its own specialized mode for processing information, its own perceptual system, affective system, and memory system. The left hemisphere deals best with information presented in a sequential format where temporal differences are unimportant. The right hemisphere surpasses the left in visuospatial abilities where simultaneous processing of information is vital, but temporal differences are unimportant. Tasks requiring analysis (taking the whole apart) are best accomplished by the left hemisphere. Tasks requiring synthesis (reconstruction of wholes from parts) are best accomplished by the right hemisphere.

HEMISPHERIC ASYMMETRY: PSYCHOPHYSICAL EVIDENCE

Since early brain development can alter specialization to some extent, observations of split brain patients may represent a distorted picture. It becomes necessary to look at hemisphere specialization and interaction in people with intact brains and no history of pathology. The task is to "split the brain" without physical intervention. A variety of psychophysical techniques exist to accomplish this task. They rely on various methods of presentation of material and type and rapidity of reply.

Testing Procedures

Visual material is presented tachistoscopically and response time is measured. Depending upon the material presented and the method of reply, the response time can be a measure of the hemisphere activated (Filbey and Gazzaniga, 1969).

Dichotic listening makes use of the simultaneous presentation of signals to both ears. These signals may involve verbal materials (words or nonsense sounds), music, clicks or any combination of these. The ear advantage is measured by which input is heard or deciphered best. If a right ear advantage occurs this may indicate left hemisphere processing of the input. Conversely a left ear advantage may indicate right hemisphere processing of the input (Kimura, 1973). This method is not as reliable as others due to the extensive bilateral interaction of auditory fibers in the brain stem. Hemispheric asymmetries do appear using this method, but care must be taken in interpretation. Movements of the eyes to the right or left when the subject is asked a specific question are known as conjugate lateral eye movements (CLEM). Such eye movements have been related to the degree of hemispheric activation associated with a given task (Bakan, 1975; Gur, 1974; Harnad, 1972). While relative seating arrangements of experimenter and subject affect the data obtained by the CLEM method, it has nevertheless proven fairly reliable (Bakan and Strayer, 1973; Gur, 1974).

Amplitude ratios of EEG measurements have also been used to study hemispheric activation in a subject presented with various tasks. Care must also be taken in interpretation of EEG data, but in general it can be shown to be related to hemispheric activation in a specific task.

Results from Psychophysical Tests

Table 2 gives a summary of selected examples from the results obtained by the above methods. These results appear to support those determined from anatomical studies regarding hemispheric specialization. The left hemisphere is associated with complex verbal processing. Activation of the left hemisphere is seen for processing words, digits and syntactical materials (Cohen, 1971; Krashen, 1977). This hemisphere does well in detecting fine order temporal differences. Melodies can be recognized by the left hemisphere using a time ordering method. The left hemisphere has been shown to be activated to a greater degree than the right in trained musical listening by experienced listeners (Gorden, 1975).

Dimond and Beaumont (1974) have also demonstrated a high level of vigilance performance by the left hemisphere. Left hemisphere vigilance showed the traditional decline over a period of time. The right hemisphere showed a low level of vigilance, but was capable of sustaining this without decrement.

The right hemisphere is associated with visuospatial functions. It is superior in detection of line orientation, depth perception and rapid scanning of a number of stimuli (Kimura and Durnford, 1974). The use of imagery in thinking is also associated with this hemisphere (Bakan, 1975). The right hemisphere is capable of some simple language functions (Zaidel, 1977). Recognition of melodies and nonverbal speech is also associated with the right hemisphere. A right hemisphere superiority in analysis of tonal chords in music has been shown (Cohen, 1971; Kimura, 1973). The right hemisphere also appears to play a special role in emotional arousal and response and tends to view the world in a slightly depressive state (Dimond, Farrington and Johnson, 1976; Schwartz, Davidson and Maer, 1975). The work of Tucker, Roth, Arneson and Buckingham (1977) suggests that during stressful situations the right hemisphere is activated to a greater degree than the left.

General Results from Psychophysical Studies

The literature contains many psychophysical studies assessing the nature of hemispheric asymmetry in normal individuals. Results of these studies confirm those obtained from anatomical studies. The respective hemispheres and consequently the different modes of information processing can be activated by proper presentation of material (Levy and Trevarthen, 1976).

TABLE 2

RESULTS REPORTED IN THE LITERATURE SUGGESTING HEMISPHERE SPECIALIZATION FOR INFORMATION PROCESSING IN THE INTACT BRAIN

GENERAL METHOD PSYCHOLOGICAL TESTING	LEFT HEMISPHERE	RIGHT HEMISPHERE	REFERENCES
Reaction time (tachistoscopic presentation)	Letters and word identification; Vigilance with decrement; Learning, Verbal ability (complex tasks)	Visual location; Shape identification; Line orientation; Low vigilance but no decrement; Learning; Minimal verbal ability; Form, Spatial Location	Day (1977 Dimond and Beaumont (1974) Filbey and Gazzaniga (1969) Kimura (1973)
Dichotic Listening	Rhythm; Structure of sentences (Syntax): Fine order temporal judgments	Tonal chords; Rhythm; Vocal Non-Speech Sounds	Cohen (1971) Krashen (1977) Kimura (1973)
Conjugate Lateral Eye Movements (CLEM)	Score higher on SAT; Faster at concept identification; Tend to major in sciences; Processing verbal material; Overactivation and dysfunctional in schizophrenia	Use of imagery in thinking; Considered more artistically diverse; Rated as more creative; Tend to major in humanities; Special affective control; Greater activation during stress; Processing spatial material	Bakan (1975) Bakan and Strayer (1973) Gur (1975, 1978) Harnad (1972) Schwartz et al. (1977) Tucker et al. (1977)
EEG Data	Activation during NREM-Sleep; Greater initial amplitude for verbal material; Alpha desynchronization greater when listening to English	Activation during REM Sleep; Greater initial amplitude for noise (non-verbal) material; Alpha desynchronization greater when listening to Hopi	Bakan (1975) Cohen (1971)

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HEMISPHERIC ASYMMETRY: MODEL AND APPLICATIONS

The results from anatomical and psychophysical studies may be viewed in terms of cognitive processes. Each cerebral hemisphere has its own perceptual and information processing system which gives rise to a particular cognitive mode. The cognitive mode of the left hemisphere is linear-verbal. This hemisphere is concerned with highly ordered or structured inputs such as those associated with language, complex verbal tasks and certain mathematical systems. Information processing is sequential in nature and temporal order is of great importance. The cognitive mode of the right hemisphere is non-linear-spatial. The right hemisphere is more concerned with loosely ordered or structured inputs associated with visuospatial constructions where the whole or "Gestalt" is of prime importance.

Present Models

If each hemisphere has unique abilities, how do these abilities integrate in a normal brain? Several persons have investigated this problem. They have approached it with studies of both split brain and normal subjects. Levy and Trevarthen (1976) showed that each hemisphere could process information that was normally processed by the other hemisphere. The ability to process this information was increased when such information was presented in a context appropriate to the hemisphere (i.e., sequential or spatial). These same tests demonstrated that control could be exerted by either hemisphere when it was appropriately activated even for a task for which it was not specialized. Levy and Trevarthen (1976) postulated the existence of a meta control system capable of activating the hemisphere appropriate to a task. If the wrong hemisphere was activated (i.e., the hemisphere whose cognitive mode was inappropriate to the task), the task was then performed in a cognitively inappropriate mode.

Does such a system exist in the intact brain? Much of the data on brain asymmetries in normal human beings supports this view. As seen in Table 2, these data indicate that the hemisphere appropriate to the task is the one activated. However, superior performance of one task by a specific hemisphere does not imply the other hemisphere plays no part in the performance of that task. Since the cerebral hemispheres are in contact with each other via the corpus callosum in the intact brain, interaction between them is expected. This interaction, for the most part, is inhibitory in nature. Evidence presented by Dimond and Beaumont (1974) and other experimenters show that when increasing demands are placed on the brain, integration becomes more pronounced. This occurs for complex perceptual tasks and especially for problems demanding creative solutions. These data have been reviewed by Bogen and Bogen (1969) and Dimond and Beaumont (1974). Dimond and Beaumont (1971) demonstrated the use of two hemispheres increased the brain's capicity for performing simultaneous perceptual tasks. Bogen and Bogen (1969) and Dimond and Beaumont (1971, 1974) emphasize the need for such integration to exist for creativity to exist. Bogen terms such integration complementarity and defines it as the integration of the processing modes of each hemisphere (Bogen and Bogen, 1969). The more creative individual may be one for whom complementarity is an easy process. The different information processing modes of each hemisphere can be applied to a problem, resulting in a creative solution.

Research indicates, however, that variations in degree of hemispheric lateralization occur and that these variations are related to cognitive specialties. Both Levy and Bogen have considered the implications of the degree of lateral specialization on cognitive style. Levy (1974, 1978) developed a model based on extremes of lateral specialization resulting in individuals who may be identified as cognitive specialists or cognitive generalists. Cognitive specialists possess a weak degree of functional lateralization and cognitive generalists possess a high degree of functional lateralization. According to this model, well lateralized individuals can use either hemisphere with ease and are at home either cognitive mode. Weakly lateralized individuals have atypical representation of one mode bilaterally. They may be more at home in spatial or verbal modes to a great degree, but show deficits in the other less well represented mode. There is evidence from handedness studies to lend support to this model (Levy and Reid, 1976) and from studies on dyslexics (Witelson, 1977).

Bogen and Gordon (1972) developed a model based on the concept of hemisphericity. Hemisphericity is defined as the preferred use of one hemisphere. This model takes into account functional asymmetry and adds to it the concept of choice of mode of information processing as a first or only approach to a problem. This model does not consider varying degrees of functional asymmetry.

While both models may lack completeness they are the first attempts at a comprehensive explanation of hemispheric asymmetry. Support for both exists in the literature, yet it is their combination that yields the best insight into the application of asymmetry studies to education.

A simplified version of the combined model may be seen as one where varying degrees of functional asymmetry exist in a population. This functional asymmetry would be modified by interaction with the cognitive bias of a given cultural. This cognitive bias would be transmitted by the materials and methods used in formal education.

If a continuum of varying degrees of lateralization exists in individuals, this continuum would range from the well-lateralized cognitive generalists through varying degrees of bilateral representation of functions to the atypically-lateralized cognitive specialists as described by Levy (1974, 1978). Hemispheric integration in atypically lateralized individuals would depend upon what functions were well represented in each hemisphere. An individual with the rational-logical mode bilaterally represented might excel in verbal and mathematical functions that did not require much spatial abilities. Such an individual would have a deficit in visuospatial functions.

imagery might be poor or nonexistent. The opposite would hold for an individual with the intuitive-analogical mode bilaterally represented.

If creativity is viewed in terms of integration, the cognitive specialists would be creative in the regions of their extremes of specialization (verbal or spatial). Such an individual might be a great sculptor or writer, but never both. Exploring this model further, it could be inferred that such an individual would show a hemispheric outlook (a predominant cognitive mode) in accordance with the bilaterally represented function. This may be equated with the concept of hemisphericity introduced by Bogen and Gordon (1972). Within a given population such functional hemisphericity would be found in only a small number of individuals (Levy, 1974). These atypically lateralized individuals could be creative (in their special mode) or learning disabled (in the deficit mode) or both, depending upon the tasks they were called upon to perform.

What of the remaining spectrum of degrees of lateralization? It is here that Bogen and Gordon's (1972) and Bogen's (1975) concepts lead to some interesting ideas. Bogen and Gordon (1972) suggest cultures differ in the degree of emphasis on one cognitive mode relative to another. In particular Bogen (1975) suggests present Western culture emphasizes the logical-rational mode. Cognitive specialists with an atypical cognitive mode opposite that of the prevailing cultural outlook (e.g., spatial versus verbal) might be at a severe disadvantage. Those whose cognitive mode was the same as that of the cultural outlook might be at an advantage even over cognitive generalists. Those with varying degrees of lateralization might acquire by education the prevailing cognitive mode of their particular culture.

Learning Disorders

In a culture with a left hemisphere outlook, learning problems involving left hemisphere functions are easily noticed. Reading becomes the first area to look for evidence. Witelson presents a strong case for atypical representation of functions in developmental dyslexia. Witelson's model (1977) may be seen as a special case of the combined model presented above. She suggests that spatial functions in dyslexics are represented in both hemispheres. Though language also exists in the left hemisphere, the dual representation of spatial function is responsible for a deficit in the sequential mode of information processing. Dyslexics develop a predominantly spatial-holistic reading strategy characteristic of the right hemisphere which encodes information as a "Gestalt." Since the verbal mode is not the major processing mode, in reading dyslexics neglect the phonetic sequential reading strategy. This leads to difficulties in reading phonetically coded languages such as English (Witelson, 1976, 1977).

Learning difficulties associated with a bilateral representation of verbal-logical skills involve deficits in visuospatial skills and are not as easily demonstrated. Sommer (1978) discussed the lack of right hemisphere skills and their effect on learning. The most obvious are the lack of imagery and its use in problem solving and difficulties in subjects requiring spatial manipulations; for example, the uses of cognitive processes in different geometries. This topic has also been studied by Franco and Sperry (1977). They found that the right hemisphere does well with loosely structured topological tasks while the left hemisphere does better with highly structured geometries such as Euclidean Geometry. How these results relate to learning disorders in normals has not as yet been examined.

Conjugate Lateral Eye Movement (CLEM) Studies

Additional evidence for the effect of asymmetry and cognitive mode on problem solving comes from the CLEM (Conjugate Lateral Eye Movement) studies. When an individual is asked a question requiring reflective thought, they will gaze right or left before answering. Consistent looking to the right is associated with left hemisphere activation while consistent left looking is associated with right hemisphere activation (Bakan and Stayer, 1973). The activation of either hemisphere is related to task type (verbal or spatial), task difficulty, personality characteristics of the individual, and cognitive style (Bakan, 1975; Harnad, 1972; Gur, 1974).

Though the hemisphere activated is related to the task, individuals differ in the preferred direction of CLEM and show a preferred direction of looking for most tasks (Bakan and Stayer, 1973). This is associated with activation of a preferred hemisphere and hence a preferred cognitive mode in problem solving.

Relationships with other factors show that right lookers (left hemisphere activation) as a group score higher on the SAT mathematics subtest, are faster at concept identification, and tend to major in the hard sciences. These are just the areas in which the left hemisphere information processing mode excels.

Left lookers (right hemisphere activation) as a group tend to report more vivid imagery, consider themselves more artistic and musical, and tend to major in the humanities. Again these are just the areas in which the right hemisphere information processing mode excels. Still other categories can be obtained from CLEM studies (Gur, 1974; Krashan, 1977).

Functional asymmetry and hemispheric activation may also be related to disorders of mental processes. Recent studies on schizophrenia suggest a relationship of this disorder to a left hemisphere dysfunction. Clinical evidence shows that schizophrenic thought is illogical and irrational and that schizophrenics are characterized by having a flat emotional response. Gur (1978), using the CLEM technique, studied the pattern of eye movements in schizophrenic males and females. These studies relate schizophrenia to functional brain asymmetry and indirectly to preferred activation of the left hemisphere which is seen as dysfunctional.

Normal Development

Application of the combined brain asymmetry model to normal development is hampered by scarcity of asymmetry data for infancy and childhood. Witelson (1976) reviews some of the available material. There is evidence that anatomical asymmetries present in the adult brain are found in the child and infant brain. These asymmetries are associated with the left hemisphere, in particular the speech areas (Geschwind, 1974; Witelson, 1976). Specialization for linguistic processing by the left hemisphere appears to occur by the age of five. Right hemisphere specialization for visuospatial functions also occurs at an early age, but such laterality differences have been shown to be sex related. Witelson (1976) demonstrates right hemisphere superiority for spatial processing in boys at age six. Similar specialization is not present in girls at that age. Evidence from this study and others suggests the right hemisphere in young girls is not specialized for spatial processing and a bilateral representation of such processing may remain until adolescence. The extended plasticity in the female right hemisphere is consistent with data on incidence of verbal deficits following damage to the left hemisphere. When the lesion occurs early in life, women show less verbal impairment than men (Witelson, 1976). Developmental disorders involving language occur more frequently in males than females.

HEMISPHERIC ASYMMETRY: EDUCATIONAL STRATEGIES

While hemispheric asymmetry appears to be the substrate from which cognitive modes arise, the specific relationship to educational strategies has yet to be explored in detail. Clues to some possible applications can be found in the combined model of Levy and Bogen presented above. Varying degrees of functional lateralization exist according to Levy (1974) and Levy and Reid (1976). These presumably can be reinforced or hampered by the prevailing educational strategy (Bogen, 1975). Some subjects lend themselves better to one mode of information processing and hence one hemispheric style. Certain forms of mathematics and science fall into a linear-sequential category while music, dance and art are normally considered subjects in the non-linear-simultaneous category. However, any subject, is most likely bihemispheric to some degree.

The first and most global strategy is to permit all cognitive modes to flourish. The second is to encourage the use and development of both modes. Various authors and educators have attempted to develop new, and/or to expand present, strategies to accomplish these ends. Table 3 illustrates some approaches used and their results. It can be seen that these approaches have met with a certain amount of success. They also have several things in common. The approaches are process specific, that is they rely on certain types of presentation to accomplish their ends. Such methods use a multi-modal technique and concretize the materials presented. This is especially true when materials are presented to children. These approaches are indicative of attempts to stimulate right hemisphere processing. They rely very heavily on presentation of materials in terms of visually depicted relationships, imagery and visualization.

TABLE 3

EXAMPLES OF ATTEMPTS TO EXPLORE AND APPLY CONCEPTS OF HEMISPHERIC ASYMMETRY TO SPECIFIC SUBJECTS AND LEVELS OF EDUCATION

AUTHOR	SUBJECT COVERED	APPROACH USED	GRADE LEVEL	RESULTS
Paul Brandwein (1976)	Sciences and Humanities	Lecture with usually presented materials and music	Primary grades	---
Robert Samples (1976a; b; 1977)	Sciences and Humanities	Non-verbal exploration of technical subjects; Visual imagery	Primary; Adult education	Greater self-confidence; Wider exploration of subject contents; Higher level of creative invention
Robert Sommers (1978)	Engineering drawing; Creative writing	Imagery and visualization	College; Adult education	Better comprehension of material; Ability to produce usable products
M. C. Wittrock (1977)	Science Theory	Pictorial; Concrete examples; Sample verbal text	Kindergarten; Primary grades	Successful learning of concepts; Better retention of subject matter

These methods may be used alone or with a lecture presented in a sequential format. Such an approach would change the relative degree of hemispheric participation in a task primarily by recruiting the right hemisphere since it processes visual materials more efficiently (Kimura and Durnford, 1974).

Paul Brandwein, Director of Research at Harcourt, Brace and Jovanovich, presented a demonstration of such methods (Brandwein, 1976). These were developed for primary grades. Brandwein combined music, visual material and physical demonstrations with material presented verbally or read. Again such methods serve to recruit right hemisphere participation in a left hemisphere task.

Wittrock (1977) described several studies with primary school children. These studies involved teaching the kinetic molecular theory to children in kindergarten and primary school. The concepts of states of matter and molecules in motion were taught by using pictures, concrete examples, and simple verbal text. This approach stimulates both the right and left hemispheres. Since the data available indicate the spatial mode of processing is well developed in primary school boys and bilaterally represented in primary school girls, this procedure should facilitate learning in both modes for both groups.

Samples presented science material to primary and secondary school students using similar methods (Samples, 1976a, 1977). Again there was heavy reliance on visual-pictorial presentation, concrete relationships, and additional tactile and kinetic approaches. Samples has also applied a similar approach to adults (Samples, 1976b).

Sommers (1978) described the work of several educators using imagery and visualization as techniques to improve visual problem solving and perspective drawing in engineering and creative writing. As mentioned, these approaches have in common a greater participation of the right hemisphere in the subject or task. As a result, they are process specific, not material specific. The idea behind such approaches is since each hemisphere "sees" a problem differently, engaging both hemispheres with their unique capabilities might facilitate the solution to a problem and/or contribute to a creative solution. Dimond and Beaumont (1971, 1974) demonstrated an increase in information processing capacity for some perceptual tasks using both hemispheres. Encouraging greater participation of the right hemisphere in left hemisphere tasks appears to lead to better comprehension of material and retention of subject matter as illustrated in Table 3.

The degree of participation of each hemisphere varies to some extent even for language, as has been demonstrated by Rogers, Tenhouten, Kaplan, and Gardner (1978) for bilingual Hopi children. Some of the results of this study are given in Table 2. This study focused on the EEG asymmetry present in bilingual Hopi children when they listened to stories read to them in Hopi and English. Results indicated a greater participation of the left hemisphere when the stories were read in English and a greater participation of the right hemisphere when the stories were read in Hopi (Rogers et al., 1978). Results of this study suggest that language, which appears to be primarily a left hemisphere function, may recruit the hemispheres by varying degrees depending upon the nature of the language. Samples has explored this area for the Japanese Alphabets (Samples, 1976a; 1977).

Some activists may demand equal participation by both hemispheres. Bogen (1975) suggests symphonic orchestration as an example of an activity demanding equal participation by both hemispheres. Some data have been cited that support the idea that the two major modes of information processing are inhibitory to one another. How this inhibition functions in terms of learning specific materials and by specific methods of presentation is an exciting area for future research.

SUMMARY

Two modes of information processing exist in the brain and are associated with the right and left hemispheres. The right hemisphere processes information in a non-linear, simultaneous mode in which spatial relationships are most important. The left hemisphere processes information in a linear, sequential mode in which temporal relationships are most important. The degree of functional asymmetry is related to sex and handedness. This relationship is complex and changes somewhat with age. Atypical functional asymmetry results when bilateral representation of one mode occurs. This may result in certain forms of learning difficulties.

Each hemisphere appears to give rise to a cognitive mode associated with its inherent method of information processing. The cognitive mode predominantly used by an individual can be measured by a variety of psychophysical tests. Such tests indicate most individuals tend to use one mode as the first and/or favored approach to tasks.

Hemispheric asymmetry data have not yet had any appreciable influence on educational practice. The subject is too complex and any application to education is at best tentative. On first analysis, the data reflect what is already intuitively known. Students are individuals and learn in their own manner and bring to any subject matter their own unique cultural and neurological backgrounds. However, the brain asymmetry data can pinpoint some problems, suggest possible solutions, and project future possibilities.

Easily observed problems deal with atypical lateralization of functions. The tentative solution is to recognize the problem and to encourage development of the less well-represented mode while simultaneously aiding the development of the atypical mode. Encouragement of both modes of thinking should be a main aim in educating any individual.

Tentative applications to education rely on various methods of presentation of learning material to encourage participation by both hemispheres. Methods consist primarily of visual presentation of materials, manipulation of the environment, presentation of left hemisphere material in a right hemisphere format, and encouraging imagery and visualization in learning. This likely results in increased participation by the right hemisphere. The results, while of some significance, do not suggest abandoning the use of the left hemisphere mode of processing.

Before any brain asymmetry results or models can be successfuly applied to educational strategies, certain areas must be researched and understood. One area is the relative degree of participation of each hemisphere in different subject matters. The degree of hemispheric participation may be subject dependent. If so, does actively encouraging participation of the other hemisphere aid or hamper learning? What role does inhibition of one hemisphere by the other play in learning? What role does inhibition of one hemisphere by the other play in learning? Both the method of presentation and the material presented will determine the degree of participation by each hemisphere, but what the exact relationship may be is as yet unknown.

Another area where research is needed is in determining the relationship between functional asymmetry and creativity. This area is also related to the degree of hemispheric participation in learning and problem solving. Finally, studies are needed in order to understand how cultural bias may modify the functional asymmetry by encouraging or discouraging one particular cognitive mode.

Within these general areas hemisphere asymmetry data has much to contribute to education. In becoming aware of the present and the possible future data from brain research, education will be enriched and broadened. It may be these results that best give rise to a creative educational strategy for educating the whole brain and the whole individual.

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