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BUILDING CURRICULAR STRUCTURES FOR SCIENCE WITH SPECIAL REFERENCE TO THE JUNIOR HIGH SCHOOL.

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SINCE JUNIOR HIGH SCHOOL STUDENTS REPRESENT A WIDE RANGE OF ABILITIES AND EXPERIENCES, THE SCIENCE CURRICULUM MUST BE BOTH CORRECTIVE OF IMPOVERISHED EXPERIENCE AND ADAPTIVE TO A VARIETY OF ABILITIES. THE PROGRAM SHOULD REFLECT THE NATURE OF SCIENCE AS AN ENTERPRISE OF INTELLIGENCE AND SHOULD USE THE METHODS OF INTELLIGENCE. THE PURPOSES OF THE SCIENCE TEACHER SHOULD BE IN HARMONY WITH THOSE OF THE SCIENTIST. THUS TEACHERS SHOULD CREATE SITUATIONS THROUGH WHICH CHILDREN ENGAGE IN THE INVESTIGATION OF THE MATERIAL UNIVERSE TO SEEK ORDERLY EXPLANATIONS OF PHENOMENA AND TO TEST THESE EXPLANATIONS. THE CURRICULUM STRUCTURE WHICH PROVIDES SUPPORT AND OPPORTUNITY FOR THESE "INGREDIENT PROCESSES" MUST POSSESS STABILITY. A CURRICULUM BASED ON CONCEPTS PROVIDES A MEANS THROUGH WHICH CHILDREN CAN DEVELOP THE ABILITY TO CLASSIFY OR CATEGORIZE INFORMATION IN THE LEARNING PROCESS. CONCEPTS ARE DEVELOPED OVER LONG PERIODS OF ACTIVITY AND THOUGHT (DISCRIMINATING EXPERIENCE) AND INVOLVE (1) OLD COMPREHENSION, (2) CONFRONTATION, (3) INVESTIGATION, AND (4) NEW COMPREHENSION. DIFFERENT LEVELS OF EXPERIENCE INTRODUCED AT DIFFERENT GRADE LEVELS, OR LEVELS OF MATURATION, RESULT IN CONTINUOUS DEVELOPMENT AND INCREASED SOPHISTICATION IN CONCEPT ATTAINMENT. COURSE CONTENT SHOULD BE STRUCTURED BOTH VERTICALLY AND HORIZONTALLY SO THAT STUDENTS ARE CONFRONTED WITH PROBLEMS THAT ARE BASED ON PRIOR EXPERIENCES. THIS DOCUMENT IS ALSO AVAILABLE FOR $1.00 FROM NEA PUBLICATIONS SALES, 1201 SIXTEENTH STREET, N.W., WASHINGTON, D.C. 20036. (AG)

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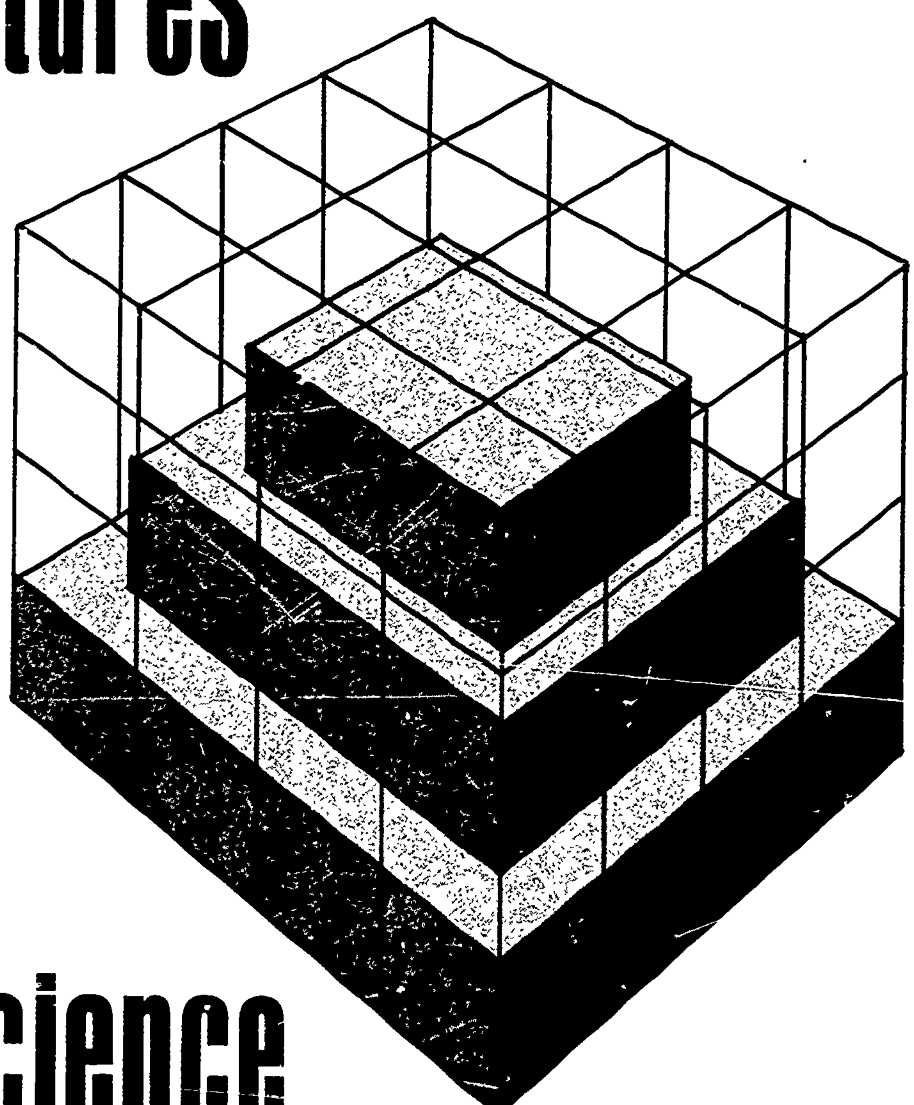

with Special Reference to the Junior High School

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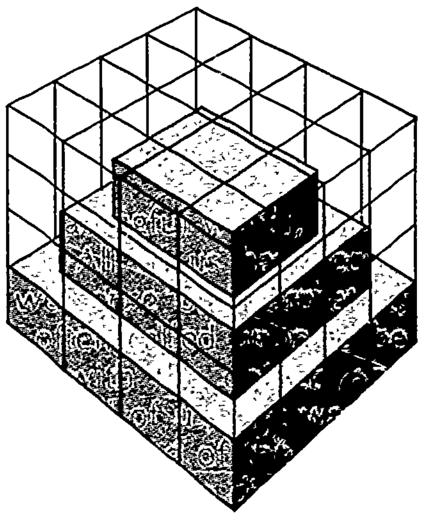

with Special Reference to the Junior High School

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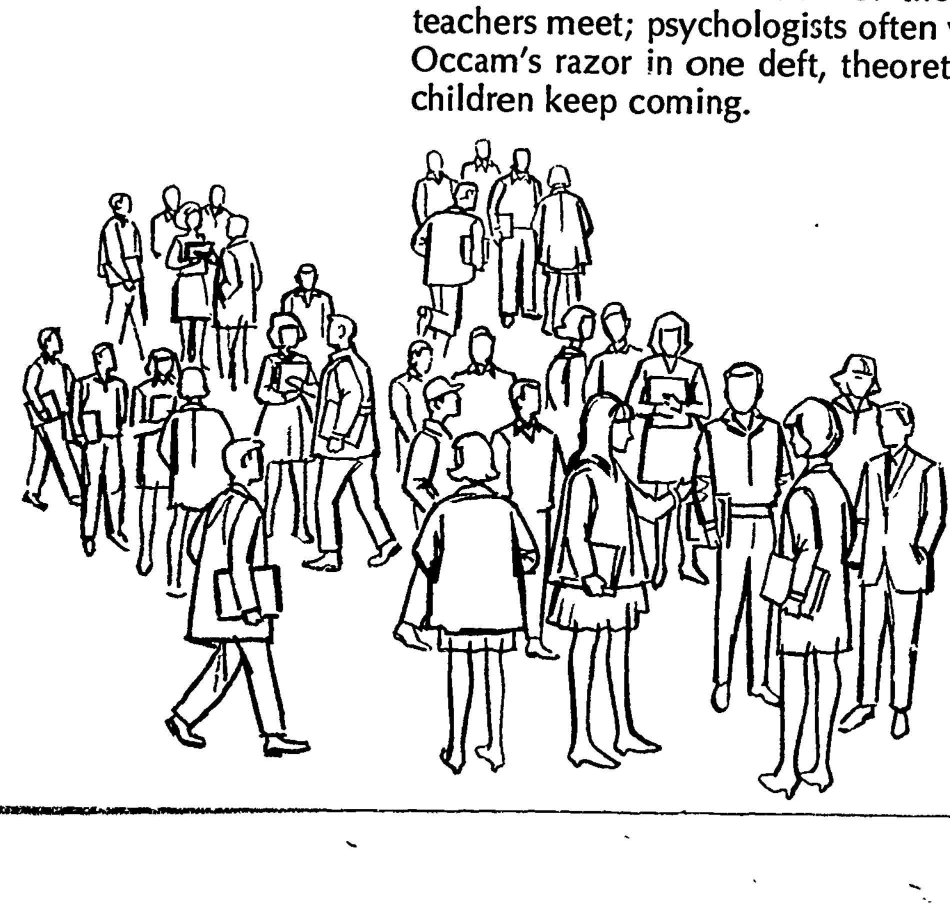
Foreword

IN ALL AREAS of the school curriculum today, teachers, administrators, parents, the public generally, and, indeed, students also, are seeking to answer not only the what and how of teaching but also the why. We attempt to open each area of the curriculum to the influence of all other subjects. We attempt to think in at least global terms, and to look farther and farther into the future. Yet, with it all, it is the child in the classroom today — happy or sad, interested or alienated — that must be our immediate concern; whatever our subject area or grade level. Few educators today have Paul Brandwein's gift of linking present and future, of being practical yet visionary, and of being at the same time compassionate to the learner and rigorously accurate in subject matter. Therefore, the National Science Teachers Association is pleased to present this statement on building curricular structures as an aid to all those who are concerned with introducing the young adolescent or junior high school student to the adventure of lifelong learning in science.

ROBERT H. CARLETON
Executive Secretary
National Science Teachers Association

CHILDREN KEEP COMING to school. Each year teachers meet them and teach them — doing whatever they can. What is taught and how it is taught bears the imprint of various kinds of inventions coming out of the personal-social-psychological-historical-political "mix" we bundle under the euphemism "the teaching situation."

When teachers, supervisors, and administrators turn to those who should be in a position to help them — those scholars who have turned their attention to the field of learning — they find even the theoretical structure in disarray. Indeed, there are a number of theories of learning, "families of theories," if you will, dealing with cognitive, psychomotor, and affective elements. Because scholarship has imposed upon it the strictures of verification and testability, psychologists cannot lend themselves to the solution of the pressing problems teachers meet; psychologists often wish they could use Occam's razor in one deft, theoretical stroke. But the children keep coming.

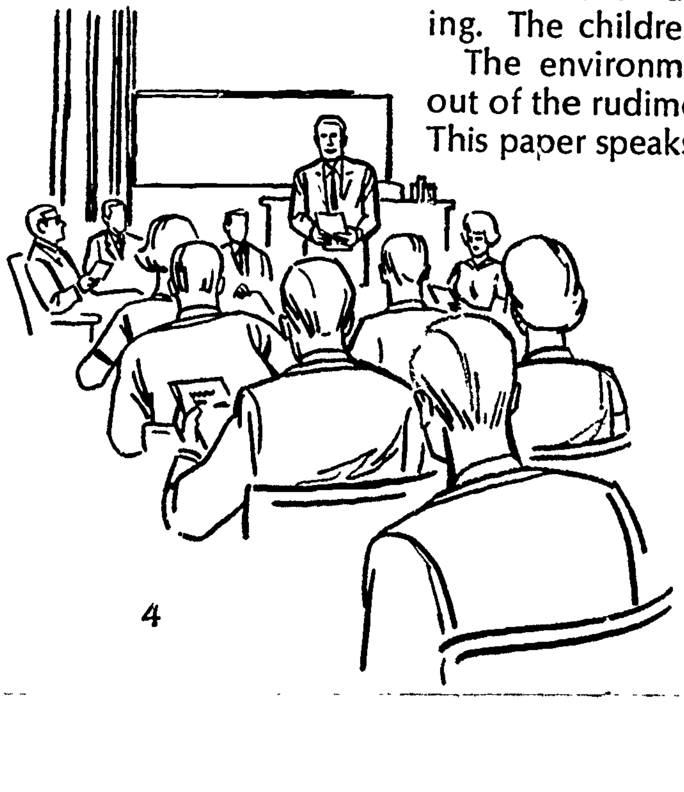


The dichotomy of the simpler problems engineered by the psychologist in the laboratory and the more complex problems in teaching and learning met in the classroom call for a new approach. And, in a sense, there has been a new profession in the building: that of the educational engineer. Simply, the educational engineer engineers (innovates, invents, develops, designs) educational systems or devices — whether they are facilities, curriculum, courses, or instructional devices of any kind. Sometimes he has the time to do it (PSSC and BSCS engineered a curriculum in four to five years); at other times, there is urgency. Sometimes the innovation has solidity; at other times, it is jerry-built. The user asks only that it work — against the time when scholarship will furnish the data for fashioning better systems. One can throw a log over a stream to cross it, or swim across a river, or build a bridge. But the science of Cro-Magnon man did not furnish data or theory for the magnificent bridges of modern man. Still he had to cross rivers.

Gordon S. Brown reports that Professor Elting Elmore Morison appropriately noted that, "Doing engineering is practicing the art of the organized forcing of technological change."[1] In a similar way, doing educational engineering is practicing the art of the organized forcing of educational change. For the *origins* of public policy and practice (social policy, if you will) is in the education children get — and in the contributions they will make.

We are at this stage in the art of educational engineering: We need to cross rivers, but we do not have the science to fashion the truly magnificent structures we need. And while it is good scholarship to question, good sport to disagree, and amateurish to conclude, we need, nevertheless, to fashion curricular structures and to design modes and manners of instruction. The environment must be fit for teaching and fit for learning. The children keep coming.

The environment we shall construct comes, then, out of the rudimentary art of the educational engineer. This paper speaks to the art of educational engineering.



[1] Brown, Gordon S. "New Horizons in Engineering Education." *Daedalus*. Spring 1962. p. 341.

The Meaningful World

The problem – in broad strokes

ALL OF US try to construct a meaningful world; this is required of us as teachers. All of us have commerce with reality however we sense or interpret it; as teachers of science we are often called upon to be expert witnesses to our traffic with the objects and events of the material universe. All of us, one way or another, disseminate our understanding of the world; as teachers of science, it is our business to disseminate the idea of a world raised upon the arts of investigation, a world whose foundations are trustworthy, orderly, explanations of objects and events: orderly because conceptual, and trustworthy because they are subject to unceasing testing and self-cor. ction.

True, teachers construct and disseminate the concept of a meaningful world for children, but, tenuous as the world seems to be, its continuance as a world with meaning is assured when children become adult and join with others to keep it so. In turn, we assume that life in a meaningful world will give intellectual and moral force to children to assure the continuance of it. For all young people, in all times, a meaningful, productive world has been the environment in which life could have meaning and fulfillment.

Perhaps Gardner Murphy, whose studies in psychoanalysis are germinal, uses terms which are more productive. He tells us in his evocative little book, *Freeing Intelligence Through Teaching*,[2] that the "organism is equipped with devices for making eager contact with reality." . . . Speaking of children, he considers that there is "an innate capacity for effective reality seeking and testing, exactly as a rationalist would seem to demand." There is, in short, a "love of the structured rational order."

[2] Murphy, Gardner. *Freeing Intelligence Through Teaching*. Harper & Brothers, New York. 1961.

Is not our central aim — too often unspoken — to free intelligence for seeking and testing effective reality? We refer to intelligence at whatever level, and with it the freeing of the personality for useful growth and work. Percy Bridgman, Nobel Laureate in physics, suggests that what we have called "scientific methods" (or "processes of the scientist") are, after all, "methods of intelligence." [3]

The Intelligence-Freeing Environment

We need to wed these two concepts; one, the way of the scientist (he uses "methods of intelligence") and the other, the way of the teacher (he frees intelligence through teaching). Indeed, wherever we have observed fruitful teaching of science, we have observed teachers creating an environment in which a child's intelligence is freed to use methods of intelligence to seek a world of meaning, a rational world, a world that does not offend sense and sensitivity. At first the statement seems simplistic, but it bears analysis.

How do we create such an intelligence-freeing environment in the junior high school? This is in the face of obstacles which at times appear enormous; and in the face of problems which seem without solution. When we strip obstacles and problems to fundamental considerations, there seem always to be two which encompass all others. Stated simply and starkly, these considerations seem always to be:

What to teach
and
How to teach

Any teacher in any school faces these problems perennially, regularly, urgently, and — happily or not — dutifully *every single day*. A teacher must engineer the bridge to cross the school year — and take with him the great and vast variety of children. Somehow, at the end of the year, the children must be better for the crossing.

We first seek, then, a curricular structure. For a curricular structure is indeed a bridge which unites teaching and learning. A curricular structure *braces*, and *supports*, what is to be taught. It furnishes a kind of stability within the considerable diversity, the enormous variety, of the boys and girls who make up the junior high school population. For curricular structure not only *braces* what is to be taught; it *embraces*, as well, those who are to be taught.

[3] Bridgman, P. W. "Prospect for Intelligence." *Yale Review* 34: 450; 1945.

Diversity within Constancy

The junior high school child and the time-binding nature of the school

CHANGE is characteristic of the scientific enterprise; change is characteristic of society; change is the very fundament of the growth of children. A curricular structure must then show a kind of stability, a kind of constancy, otherwise teachers, supervisors, administrators, and parents cannot communicate with each other. They cannot plan for the children coming to them from teachers who have worked with them in the years past. We must examine the nature of the changes in us, in science, and in children, in order to reemphasize the significance and utility of a curricular structure that can be both stable and flexible.

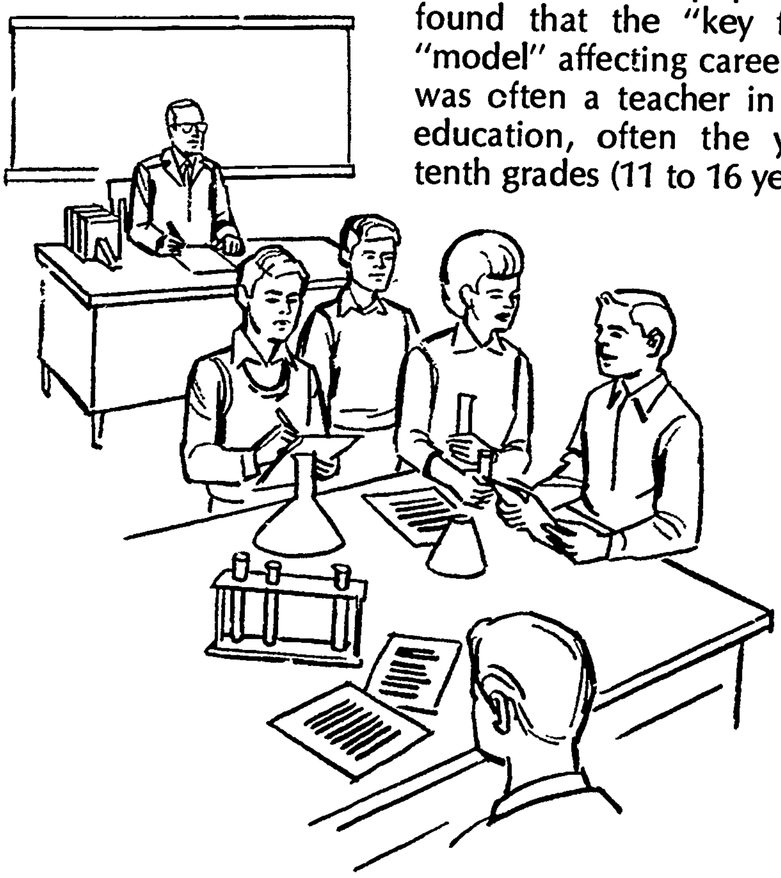
But we are getting ahead of our story. Before we deal with structure, with the edifice, we need to know for whom the edifice is built. A home is after all built for people; a curriculum is an intellectual home. We build a curriculum for children and teachers; we build in this time-binding moment of history, yet always preparing for an eventful future.

We know — and we know it well — that children in the junior high school years change; they change before our eyes. In fact, in terms of a critical period of development and maturation, the junior high school years are anxious years for the boy and girl. The increase in the level of the sex hormones produces physical and psychological changes varying in intensity; parents and surrogate parents (teachers) are called upon to be supportive. They must be at once compassionate, friendly but not slushy, firm but not coercive, demanding but not overreaching. It is the time when boys and girls — within the wide dimensions of the throes of puberty — search for models among the adults. They begin new tests of their personality in face of the dogmas, hypotheses, theories, and myths

of the world; they begin new additions to self-image and self-ideal. Each boy and girl is in a state of rapid maturational change.

The boy or girl at 12, 13, 14, 15 years is in turbulence. Must not the junior high school years offer some vision of stability — within the turbulence of the change?

The change in person is too often accompanied by direction: During these years boys and girls often (too often) make surprisingly firm decisions concerning career and commitment. The writer found that, for the populations he studied, youngsters who found their future in science often made their decisions before they were fifteen. The specific area, e.g., chemistry, biology, physics, may not have been fixed — but the general disposition toward science seemed fixed. Further, for the populations he studied, Brandwein found that the "key figure" (a person used as a "model" affecting career and other personal decisions) was often a teacher in the early years of the child's education, often the years between the sixth and tenth grades (11 to 16 years).[4]



Consider then the possibility that the junior high school years are not only years of turbulence in the development and maturation of the pre-adolescent; consider also the possibility that these are years in search of a "model"; consider, too, the fact that the children in the junior high school also embrace the entire spectrum of human variability. This variability is in gift, opportunity, and destiny.

[4] Branwein, P. F. *The Gifted Student as Future Scientist.* Harcourt, Brace & World, Inc., New York. 1955.

In the seventh grade, all the children, of whatever gift — intellectual, physical — of whatever aptitude or temperament, who are still educable, are in school. The range is enormously wide — for example, children with the ability to read at the third grade level are often in the same class as those who read at the college level. The home and social environment may be rich or barren; the destinies of the children may be hampered by intellectual, physical, social, or personal barriers. *All these children come to the junior high school.*

There are also the parents with all the determination of those who, themselves having failed in their own expectations, and not yet wise or fully competent, still expect the school to take on the task of perfecting the child. All these parents come, one way or another, to the junior high school. These parents have also been the teachers of their children. Indeed, in the first six years, parents have the main responsibility. Further, during his school years, the child spends six hours in school and eighteen hours at home and in the environment of the home. Parents have not always known how to turn the random play of the child gently into purposeful play, and then at last to retrieve purpose from the play. In other words, they do not always know how to turn experience into meaning. *To turn experience into meaning is,* after all, *the art of teaching.*

Curricular Structure:
corrective and adaptive

The Variety and Richness of Science

If one wished to read the reports of research of scientists, communicating fact, hypothesis, theory, technique, technology, in 1964 alone, for example (we are told by those who like to calculate these things), we would have been required to read to the year 3363, eight hours a day, presumably in eight languages. Add to this the richness of the work in 1965, 1966, and 1967 — not to mention the years prior and centuries past, and we are forced to say that covering of the facts is not feasible, practical, desirable, possible, or probable. As teachers of science we must look elsewhere than to the simplistic purpose: Cover the facts.

Add to this problem of coverage, the magnificent variety and richness of the scientific enterprise, the variety of personalities, the vast variability in gifts, opportunities, and destiny, the variety in parental aim and ambition, the seemingly inexorable, inflexible time-binding nature of the school.

After all, children advance in a school; teachers expect that a junior high school student will have knowledges, skills, aptitudes which, for example, a student in the fifth grade does not have. Even if the school is nongraded, it builds on a sequence of educational events: Curriculum, method, administrative devices of all sorts must help children grow and advance. Yet not all schools have similar curriculums, nor similar methods, noı similar administrative devices. Young people come to the junior high school with all manner of developed aptitudes, knowledges, and skills.

The junior high school has, then, the enormously difficult task of developing a curriculum which embraces a *full spectrum of ability and experience*. This is to say that the populations of boys and girls entering the junior high school encompass the widest ranges of ability (for example, verbal, numerical, spatial), experience (poor to rich science programs, poor to rich personal experience).

Therefore, the junior high school program needs be, at once, *corrective* of impoverished experience and *adaptive* to a variety of abilities. Modes of instruction must also have these qualities. At the same time, the

posture of the junior high school requires that it reflect the nature of science as an enterprise of intelligence using the methods of intelligence. How can this be done?

Science Teaching

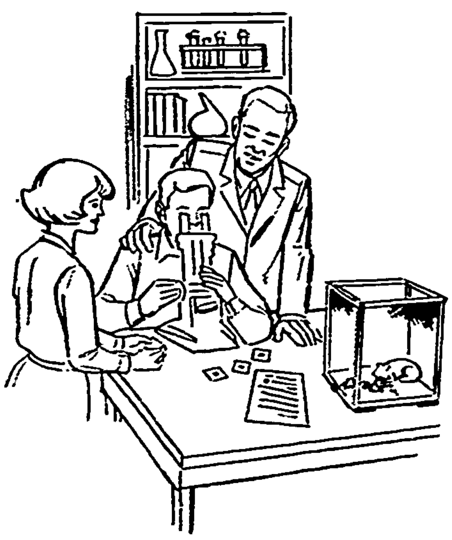
Surely the purposes of the science teacher need to be in harmony with the purposes of the scientist. Stated as simply as definition will permit, we may say:

Science is the investigation of the material universe, to seek orderly explanations of objects and events, but these explanations must be testable.

And in turn we may say:

Science teaching consists of the acts in which teachers create situations through which children engage in the investigation of the material universe, to seek orderly explanations of phenomena, and their persistent testing.

We would insist that a definition of the acts of teaching flow naturally into the acts which characterize science: **investigation, the seeking of orderly explanations** (that is, concepts), and **the testing of these explanations.**



These are the ingredient processes of science, and they are, in turn, the ingredient processes in the teaching of science, and the learning which takes place in it.

We are concerned with the curricular structure which supports these corrective and adaptive, indeed creative, aspects of science teaching. This structure should not be at the mercy of whim or fad. It should, in short, be responsive to the stable aspects of science: its structure of orderly explanation, that is, its conceptual structure. Just as the orderly explanation is the central product of science, so is concept attainment central to understanding of the way the world works. Concept attainment is central to seeking the correspondence of thought with the "real" world (the testable world).

A curriculum based on concepts has a stability which contravenes whim and fad. The Machine Age yielded to the Atomic Age, which in turn yielded to the Space Age, and soon to the Age of Inner Space. Each age finds the curriculum changing, not in changes responsible to the ways of the scientist, but to the ways of technology. However, concepts are more stable than inventions — or even facts. Concepts spawn inventions, and in turn, invention catalyzes concept-seeking — but rationally, in our investigation into the world, we begin our thinking with ideas, not tools. A brief journey into the nature of a conceptual ordering of the curriculum would be fruitful. If science is indeed process-centered, that process uses the tools of *concept and analysis* particular to the discrepant event under investigation.

When we observe a familiar object or event, we rarely catalogue its special, or idiosyncratic, characteristics. Quickly we catalogue what we perceive; we have habitual tracks of association, a thought-system, or, if you will, a ready-made set of concepts. We make, in short, a *consistent response* to a *consistent* (or particular) *set of stimuli*. The basis of a concept is a consistent response coming out of prior experience. That is, we engage in classification to interpret a host of experience. A concept categorizes; it is a mental filing system for quickly sorting experience. There are possibly 7,000,000 permutations in color to which we may respond, but we limit the number of concepts of color in order to identify objects and place them quickly and precisely into relatively few categories. We economize in the energies (the activities) required for learning, by reducing the amount of learning required to develop a concept.

A concept is mental content apart from sensation and image.

In still other words, a concept is a mental construct, isolating from experience the common attributes which are idiosyncratic of a given object or event. Thus, the concept "bird" exists only in the "mind"; robins, gulls, ducks, hummingbirds exist in particular "experience." A concept retrieves the common attributes of gulls, ducks, robins, and the like, and melds them into "bird." Any new object never seen before (which is a new bird) is easily classified as "bird"—not a rock, nor electron, nor snake. Possession of a concept eases learning. The possessor of a concept rigorously developed out of valid experience automatically applies past experience to present contingencies, whether a "new" object, a "new" event, or a "new" problem.

For human beings, words or other symbols (hieroglyphics, mathematical formulae) link items of experience in statements that are conceptual in nature, that is, are statements of concepts. Thus *matter* is a concept, *mass* is a concept, but always we deal with *levels of understanding* or *levels of conceptual statement*. Thus, two concept *levels* describing matter might be:

A. Matter undergoes physical and chemical changes.
B. In a chemical reaction the totality of matter remains constant.

But, it is clear that the formulation of *B* requires more experience than does the statement in *A*. We may then, for purposes of developing a curriculum, place *B* in a sequence which follows *A*. Similarly, the development of the concept level $F=ma$, depends on the development of prior concepts in which the concept m is apprehended through experience. A curricular struc-

ture based on concept levels requiring ever-expanding levels of experience can then be developed. It is to be emphasized that a concept level is synonymous with the experiences which gave it birth.

A meter stick measures length, we may say, not intelligence. The concept of length is synonymous with the experience of using the meter stick. If one uses a meter stick to measure intelligence, one comes out with a useless concept.

Bridgman,[5] puts it this way: "In general, we mean by any concept nothing more than a set of operations; the concept is synonymous with the corresponding set of operations."

Granted that conceptual thinking (concept-seeking through reformulation of orderly explanation) is not easy to come by. Granted that the work of cognitive psychologists leans strongly to the propositions that very young children learn mainly through discrete experience. But it is also true that the work of cognitive psychologists and investigators (Piaget and Vygotsky, by way of example) into the learning process, did not investigate children whose educational experience was based on curriculums engineered in the conceptual mold. Children whose experiences are continuous because they are engaged in concept-seeking, have the opportunity to develop the "habitual tracks of association" which are the products of concept-seeking. Our hypothesis is: Given curriculums engineered in the conceptual mold, children will gain in ability and speed in conceptual thinking. Indeed, our preliminary observation of children approaching mathematics in the SMSG — and science in conceptually organized curriculums — lends support to this hypothesis.

Examples of two types of conceptual structure for the junior high school are given in the following charts. One of the sets illustrating a *vertical* development in conceptual structure was developed by a group of teachers in several communities in California. The structure is based on a conceptual structure for the elementary school developed by the writer and modified in trial in schools by the staff of St. Mary's County, Maryland. This conceptual structure has recently been embodied in a program for elementary science instruction.[6]

[5] Bridgman, P. W. *The Logic of Modern Physics*. Paperback. The Macmillan Company, New York. 1946.

[6] Brandwein, Paul F.; Cooper, Elizabeth K.; Hone, Elizabeth B.; and Blackwood, Paul E., *Concepts In Science*. Harcourt, Brace & World, New York, and San Francisco, California. 1966.

Grid A: A VERTICAL Development

	A*	B	C
Level VII	The behavior (motion and direction) of objects is a result of forces acting upon them.	The behavior of the outer electrons of the atom affects the manner of combination of atoms.	The behavior of atmospheric masses effects change in the environment.
Level VIII	The motion and direction of particles is a result of forces acting upon them.	Changes in the nucleus of the atom result in changes in the properties of the atom.	The supply of renewable, nonrenewable, and inexhaustible resources of an area are affected by change in movement of land, sea, and air masses.
Level IX	The motion and direction of electromagnetic waves is a result of forces acting upon them.	Changes in the atomic nucleus are basic to the development of energy resources.	Man as organism affects the resources of the planet.

* Letters A, B, C, D, E, F refer to Conceptual Schemes as initiated in *Substance, Structure and Style* (see footnote 9, on page 16).

Grid B: A HORIZONTAL or LATERAL

Level VII Life	Organisms are adapted to a variety of environments.	Organisms are adapted by structure and function to their environments.	Organisms interchange matter and energy with each other and with their environments.
Level VIII Matter	The present planet is the result of continuing change.	Constructive and destructive forces affect the movement (change) of land masses.	The behavior of atmospheric masses effects change in the environment.
Level IX Energy	The behavior (motion and direction) of objects is the result of forces acting upon them.	The motion and direction of particles is the result of forces acting upon them.	The motion and direction of electromagnetic waves is a result of forces acting upon them.

in CONCEPTUAL STRUCTURE

Note that the development in any track of association (conceptual scheme) proceeds from the seventh grade through the ninth grade.

D	E	F
ombinations and recombinations in the genetic code affect the characteristics of organisms.	Changes in the environment affect the movement and distribution of the organisms.	Constructive and destructive forces affect the movement of land masses.
Combinations and recombinations within the genetic code produce new varieties of organisms.	Organisms fitted by adaptation to the environment survive.	Geologic periods coincide with constructive and destructive changes in land masses.
Mutation is the result of heritable changes in the characteristics of organisms.	Modern species are the result of speciation through the ages.	The present earth planet is the result of continuing change.

This Grid of Concepts basic to a Curricular Structure for the Junior High School was developed by teachers and supervisors in Redondo Beach and Manhattan Beach, California.

Development in CONCEPTUAL STRUCTURE

Note: The development in any track of association (conceptual scheme) proceeds laterally in any given year. Nevertheless, conceptual schemes developed in the vertical development (see Grid A) ramify the development in the three years of work.

Organisms in great variety are distributed in a variety of environments.	The characteristics of organisms are affected by combinations and recombinations in the genetic code.	Modern species of organisms are the result of speciation (change) through the ages.
Matter — whatever forms it takes — is particulate in nature.	Combinations and recombinations of atoms are the results of the behavior of outer electrons of the atoms. (In chemical change, matter is neither created nor destroyed.)	Changes in the nucleus of the atoms result in changes in the properties of the atoms. (In nuclear charge, the sum total of matter and energy is constant.)
Mass-energy is conserved.		

Note: A given concept is not synonymous with the number of units in the instructional material devoted to it (units in a course of study, or text, or laboratory materials). For example, Concept 3 in Energy deals with machines, laws of motion and the like. Conceptual structures illuminate *relatively stable interrelationships;* instructional materials per se are rooted in these conceptual schemes, but the *topics* and *experiences* may change as technologies change.

A second type of structure which can be developed is a lateral or *horizontal* development in conceptual structure. In this structure, the conceptual development proceeds within a course of study — or within a given year or semester. Particularly, it lends itself to development within a given discipline. Such a structure is useful when it is considered desirable to stress the structure within a discipline — and thus to develop the *concept* of a *discipline* per se. Perhaps the junior high school years — now that strong conceptually structured programs are being developed for the elementary years — is a place for the introduction of curriculums structured not only on the basis of conceptual schemes (habitual tracks of association) but also in the concept of a discipline (concentration on special views of the universes of life, matter, energy).

The conceptual structure (a track of association) is a guide to instruction; it is a guide to the teacher. Admittedly, the idea of a curricular structure based on a conceptual structure is not new — if the term "concept" is interpreted broadly.

The 31st Yearbook of the National Society for the Study of Education (1932) emphasized principles as basic to curricular structure. Conant [7] has defined science as a "series of concepts or conceptual schemes arising out of experiment or observation and leading to new experiments and observations." Psychologists such as Cronbach, Pressey, Hilgard, Skinner, and Bruner have emphasized concepts as cognitive elements; Bruner, in *The Process of Education* (1960) emphasized "concept" as structure and emphasized its utility in structure. In 1958, Brandwein, Watson, and Blackwood [8] proposed that concepts formed a useful base in curricular structure. Brandwein (1962) [9] continued to explore the utility of conceptual schemes in the organization of the curriculum of the elementary school. With the publication of *Theory Into Action*,[10] the curriculum committee of the National Science Teachers Association

[7] Conant, James Bryant. *On Understanding Science*. Yale University Press, New Haven, Connecticut. 1947.

[8] Brandwein, P. F.; Watson, F. G.; and Blackwood, P. E. *Teaching High School Science: A Book of Methods*. Harcourt, Brace & World, New York. 1958.

[9] Brandwein, P. F. *Elements in a Strategy for Teaching Science in the Elementary School*. Harcourt, Brace & World, New York. 1962. (The Burton Lecture, reprinted from *The Teaching of Science*. Harvard University Press, Cambridge, Massachusetts. 1962.) (Also, *Substance, Structure and Style*, Harcourt, Brace & World, New York. 1965.)

[10] *Theory Into Action in Science Curriculum Development*. National Science Teachers Association, Washington, D. C. 1964.

made a fundamental statement which has given scope and direction to the development of a conceptual base for the science curriculum.

A Flexible Network

A conceptual base yields stability even as it promotes the *flexibility* and the *inventiveness* so essential to instruction in science. A conceptual framework, far from being the unyielding structure characteristic of a topical sequence, accommodates a variety of approaches in the teaching of science, and the great variability in experience, gift, and opportunity characteristic of children. A curricular structure, after all, is only a matrix for the varied, innovative, supportive, and creative styles of the teacher as he or she fashions instructional method.

If teachers had no responsibility to other teachers, a curricular plan for a school *might* not be necessary. But as we have repeatedly stressed, the central fact of *current* educational life is this: Teachers meet children in schools; the school is an educational environment in which teachers are interdependent. Hence the need for a network of lesson plans serving purposes, served, in turn, by a master curricular plan.

Learning Through Inquiry

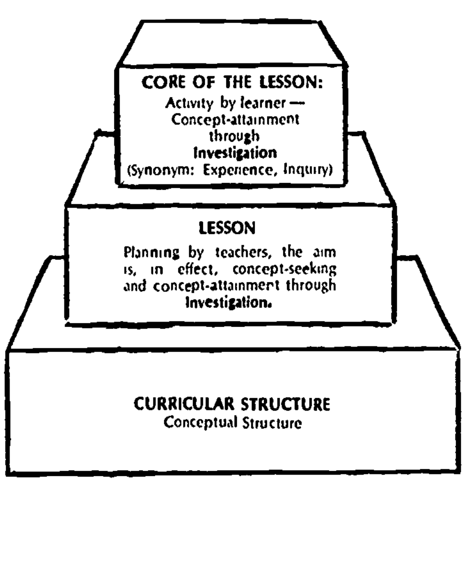
Whereas concepts in a curricular plan furnish compass, as well as comfort, concept-attainment by the student involves other strategies and tactics. Concepts are attained by the learner; they are not transmitted by the teacher. Nevertheless, the teacher can, by planning apprentice experiences in search of concept, pave the way for concept-attainment through individual experience. For the moment, let us define an apprentice experience as one planned and directed by the teacher through the use of instructional materials sequentially ordered by the teacher. These experiences are *problem-doing,* where the solution of the problem can be planned within a given time schedule (say a laboratory period). Individual experiences are, on the other hand, within the realm of *problem-solving,* where the solution of the problem, if it is attainable, is within the artifice of the learner. Inquiry, if it means anything at all as a strategy in learning, suggests that the energy for learning originates in the cognitive, conative, psychomotor apparatus of the child — even if the "problem" seems to come from the environment or the teacher. A further word about "problem-solving" and "inquiry."

First, inquiry as strategy or tactic in learning is but a new word for an old tactic. Even Socrates talked only half the time. From time immemorial, effective teaching has been equated with *learning by doing.* But problem-solving is still another matter. For it is an open question whether mental activity is primarily di-

rected by problems. Rather, increasing analysis indicates that mental activity is directed by objects and events. *If the object or event is not recognized, a problem is not identified.* And further, if a concept — however vaguely, or incompletely apprehended — is not brought to bear on the problem, the problem is usually not clarified. One must *know* something to recognize a problem. Aristotle, after all, did not ask: Is poliomyelitis virogenic? or What is the origin of quasars?

Gagne, one of the architects of what has come to be known as the "process approach," puts it this way: "Obviously, strategies are important for problem solving, regardless of the content of the problem. The suggestion from some writings is that they are of overriding importance as a goal of education. After all, should not formal instruction in the school have the aim of teaching the student "how to think"? If strategies were deliberately taught, would not this produce people who could then bring to bear superior problem-solving capabilities to any new situation? Although no one would disagree with the aims expressed, it is exceedingly doubtful that they can be brought about by teaching students "strategies" or "styles" of thinking. Even if these could be taught (and it is possible that they could), they would not provide the individual with the basic firmament of thought, which is subject-matter knowledge. Knowing a set of strategies is not all that is required for thinking; it is not even a substantial part of what is needed. To be an effective problem solver, the individual must somehow have acquired masses of structurally organized knowledge. Such knowledge is made up of content principles, not heuristic ones." [11]

That is to say, a certain amount of *comprehension* precedes a *confrontation* (a recognition of a discrepant event). Further, in science, a new comprehension is based on the strategies of investigation. The ingredient process in the teaching of science is the investigation by the student; through investigation the student learns how to learn.



A schema of a lesson plan for teaching of science might then be as shown in the diagram.

The core of the lesson then depends on the teacher's art in confronting a variety of children with interesting and problem-begetting objects and events.

An act of teaching requires the creation of new situations; in responding to these situations the learner should gain capacities not achieved through prior ex-

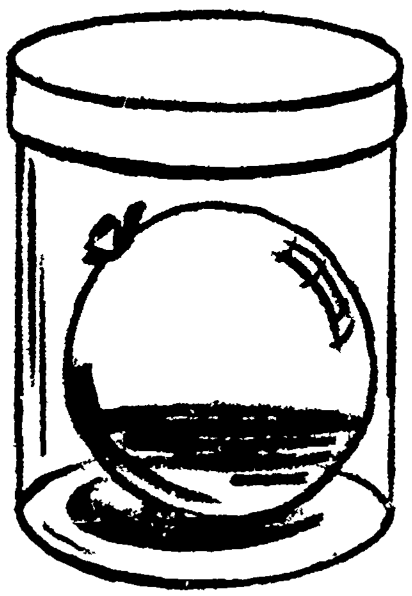
[11] Gagne, Robert M. *The Conditions of Learning*. Holt, Rhinehart & Winston, New York. 1965. p. 170.

perience. The creation of the new situation is what we mean by a confrontation, but the confrontation should engage energies in learning of the wide varieties of youngsters.

For example:

Apprentice Investigation

A class has been studying the general properties of certain molecules. The teacher confronts the class with the device at left. She asks, "How could you determine whether molecules of perfume could go through the walls of the balloon?" The suggestions come swiftly. Put perfume in the balloon (or jar). If the perfume goes through the walls of the balloon, it will be detected in the jar (or balloon). Each student proceeds to investigate. After some time, the teacher asks: "What do you infer, now that you smell the perfume in the jar?"



The students suggest that since the molecules must have penetrated the walls of the balloon, the molecules of perfume must be very tiny.

In this *apprentice investigation* (as we will use the term), the class was guided to the inference by the skills of the teacher. We prefer the term *apprentice investigation* to *experiment*, since the results were, in effect, plotted in advance by the teacher — and an experimental design was, in effect, obviated. The apprentice investigation might even have been suggested by the text in hand, and, to be sure, the suggestion of an apprentice investigation is well within the function of the text. An experiment is another matter, requiring the design of a fresh investigation, and above all the time, patience, and industry to carry it out.

Now perhaps the apprentice investigation having been done, and the techniques apprehended, the teacher confronts the class with the following: "Do molecules in air go through a balloon? Who will design an investigation to find out whether or not they do?" (Students can indeed use the apprentice investigation for clues — but actually the investigation is difficult, depending on a number of variables — kind of balloon, technique, and the like. The "conclusion," if any, is not easy to come by. Besides, it is not to be found in any readily available source — if at all. Hence, it is as near an experiment as can be developed in the school. In the 7th grade — in our observation — it has taken as long as two weeks to develop data for tentative analysis. In the 5th grade, almost a month, or more.)

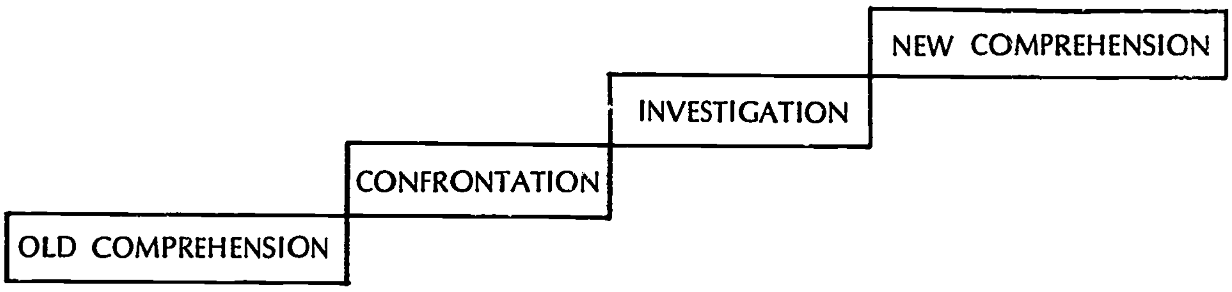
Developing Concepts

In later lessons, the students investigate the particulate nature of various molecules, with confrontations getting ever more complex. As the students investigate and design their own investigations, they

form "tracks of association" which later become "habitual tracks of association," adding further to development of the concept: *matter is particulate*.

Concepts, in effect, become habitual tracks of association. But the "habitual track" is not a fixed one. For it is constantly open to the self-correcting elements of science: testing of orderly explanation. Indeed, there is a constant attempt to defeat the "known."

A concept develops over a long period of activity and thought; that is, out of discriminating experience. The lecture is not then the select mode of instruction in concept formation. Another way of pressing this important strategy in science teaching is to plot a lesson as follows:



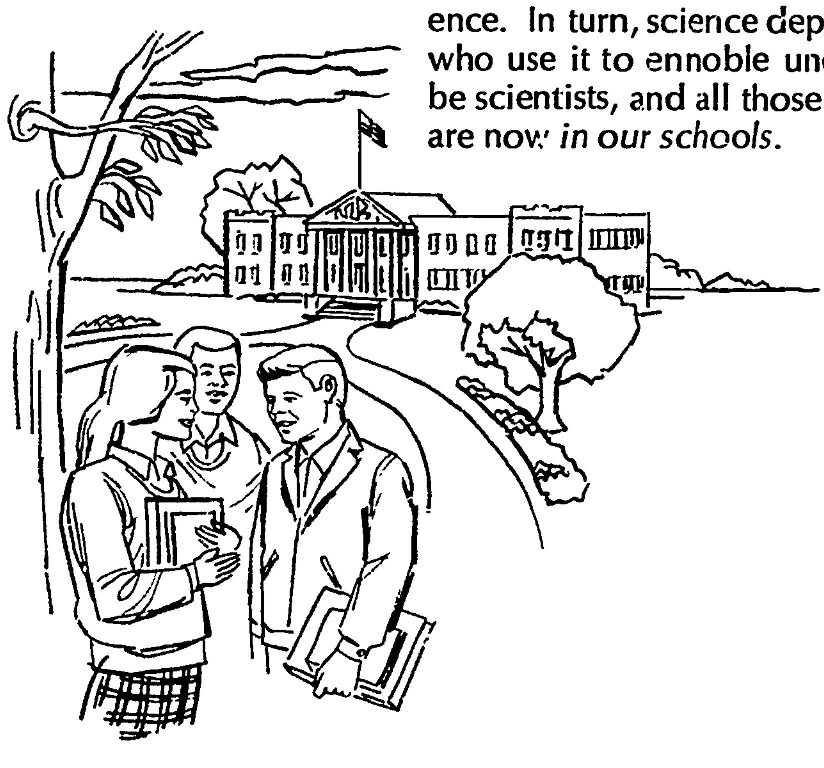
Then it would seem that (speaking very broadly) the lecture, the film, the text are effective mainly in the area of bringing to the student what is known. This is in the area of what we have called the *old comprehension*. But the past is prologue. Without a prior comprehension there is no base for concept-attainment. Further, the school is a time-binding institution, it builds on the concepts developed up to the point of its origin. Science, being conceptual, is cumulative and we discard the knowledge accumulated at our peril. Through the processes allied in the art of investigation, students come to a new concept (new to them) or to a concept developed on a higher level of understanding.

Consider, too, that a confrontation can lead to investigation in which experimental design and technique are involved. In one school, I observed students designing an investigation to determine whether canned peas were a source of auxins. They had hypothesized the possibility. Variables were being isolated — but above all, *time* was being taken, because an experiment takes time. The "new comprehension" might be in decent hypothesis — but certainly the outcome was in doubt. After all, science is an enterprise of the intelligence, and science is in one sense the art of failing intelligently, that is, building on one's failures.

Science as Democracy

Science is clearly an attempt of man to understand his world, to achieve that precious correspondence of "thought" with "reality," to feed one's love of the rational order. And if the case for democracy is that it has humane and rational ends, then the case for the manner of achieving these ends lies in a minimum of coercion and a maximum of voluntary assent. Science, in this view, is precisely a pure capsule of democracy. Its concepts are achieved through confirmation and collaboration of individuals in the common bond of a search for understanding of the world and its work. All young people, being born into this world, need to understand the world insofar as their gifts permit. Some of these young — now in school — will add to the fund of knowledge and tools; others (whatever they become) will support the scientist.

For now we know that a scientist cannot pursue meaning unless the citizens living in the same period of history support him in his search — that is, citizens literate in its concepts, its arts, and its tools. Science survives and flourishes in a free world. A free world, in this age, depends, in turn, on the newest ingredient in the search for humane and rational ends — science. In turn, science depends on the men and women who use it to ennoble understanding. Those who will be scientists, and all those who will use it to enrich life, are now *in our schools*.



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